

Mozambican Tomato Markets: Structural Breaks and Their Impact on Price Transmission and Integration

Mercado de Tomate em Moçambique: Quebras Estruturais e Seus Impactos Sobre a Transmissão e Integração de Preços

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Abstract

This study analyzed the influence of structural breaks on the integration and transmission of tomato prices in the Maputo, Moamba, and Chókwè markets in southern Mozambique (2015-2019), using ANOVA, Tukey-HSD, ADF, DF-GLS, Franses-Haldrup for outliers, and Gregory-Hansen tests for cointegration with structural breaks. The results showed significant differences in average prices, as well as a strong interaction between the Chókwè, Moamba, and Maputo markets. The cointegration of the tomato price series across the analyzed markets and the identification of a break in February 2019 indicate a structural change in tomato prices in Chókwè and Moamba, highlighting their significant influence on price stability in Maputo. The ARDL-ECM (1,0,2,0,0,0) and ARDL-ECM (1,0,2) models suggest that long-term fluctuations in tomato prices in Maputo result from exogenous shocks from Chókwè and Moamba. Therefore, it is necessary to improve early-warning systems for extreme weather events and information sharing, as well as reduce barriers that inhibit efficient price transmission between markets.

Keywords: Adverse Shocks, Structural Break, ARDL-ECM Analysis, Maputo, Moamba and Chókwè Markets.

JEL Codes: Q11, R32, D40

Resumo

Este estudo analisou a influência de quebras estruturais na integração e transmissão dos preços do tomate nos mercados de Maputo, Moamba e Chókwè no sul de Moçambique (2015-2019), usando ANOVA, Tukey-HSD, ADF, DF-GLS, Franses-Haldrup para outliers e testes de Gregory-Hansen para cointegração com quebras estruturais. Os resultados mostraram diferenças significativas nos preços médios, bem como uma forte interação entre os mercados de Chókwè, Moamba e Maputo. A cointegração da série de preços do tomate nos mercados analisados e a identificação de uma quebra em fevereiro de 2019 indicam uma mudança estrutural nos preços do tomate em Chókwè e

Moamba, destacando sua influência significativa na estabilidade de preços em Maputo. Os modelos ARDL-ECM (1,0,2,0,0,0) e ARDL-ECM (1,0,2) sugerem que as flutuações de longo prazo nos preços do tomate em Maputo resultam de choques exógenos de Chókwè e Moamba. Portanto, é necessário melhorar os sistemas de alerta precoce para eventos climáticos extremos e o compartilhamento de informações, bem como reduzir as barreiras que inibem a transmissão eficiente de preços entre os mercados.

Keywords: Choques adversos, ruptura estrutural, análise ARDL-ECM, mercados de Maputo, Moamba e Chókwè.

JEL Codes: Q11, R32, D40

1. INTRODUCTION

Mozambique's geographical location and topography render the country particularly vulnerable to global climate change, increasing its exposure to more frequent and intense tropical cyclones, floods, and droughts (USAID, 2018). These weather events impact agricultural production, disrupt local markets, and jeopardize household livelihoods and food security of rural communities (FAO *et al.*, 2023). Climate shocks also affect logistics, infrastructure and agricultural markets, foster market fragmentation and widen price disparities (Dercon, 1995). Consequently, producers with limited access to price information and risk management mechanisms (Van Campenhout, 2012) become more susceptible to manipulation by intermediaries, who often impose non-competitive prices (Zidora *et al.*, 2022).

This scenario establishes barriers to the effective integration of agricultural markets, undermining the efficient transmission of prices between production and consumer regions. Within this framework, the present study aims to examine how exogenous shocks influence market integration and price transmission in local markets. In this way, the guiding question of this study is: How do structural breaks caused by exogenous shocks, such as extreme climate events, influence the integration and asymmetric price transmission dynamics among the tomato markets of Maputo, Moamba, and Chókwè in southern Mozambique? In other words, we intend to examine the integration of tomato markets in southern Mozambique and the transmission of price signals among these areas.

Notwithstanding advances in the literature on agricultural price integration and transmission (Baulch, 1997) and its empirical application in Africa (Yacob, Zeray, 2025; Bekoe, 2023; Onubogu, Dipeolu, 2021), a gap remains in the analysis of African horticultural markets vulnerable to recurrent climate shocks — Mozambique being a representative case. In this context, Venkat and Master (2023) already highlighted the need for price analysis of food groups, such as fruits, vegetables, and animal-based foods. Furthermore, most studies have centered on cereals or export commodities and have overlooked the structural disruptions triggered by extreme climatic events. This research contributes to the understanding of spatial price integration in Mozambique's tomato markets by incorporating the effects of structural breaks and exogenous shocks.

In integrated markets, food commodities typically flow from surplus to deficit regions (Abay *et al.*, 2023). In this setting, the southern region of Mozambique serves an essential role in sustaining the diet, income and livelihoods of local communities through the vegetable cultivation (Zidora *et al.*, 2022). The region accounts for more than 90% of the area cultivated with food crops has tomatoes, cabbage and onions as the main crops produced by small and medium-sized producers (Quilambo; Zavale; Cribb; Cachomba, 2015). However, Mozambique's high exposure to adverse climate events has increase dependence on food imports, driving up food prices and revealing the structural weaknesses of its agricultural sector (Marassiro; Oliveira; Perreira, 2021).

Regarding the spatial scope of analysis, the selection of study regions is justified by their relevance in the national marketing network. According to the Famine Early Warning Systems Network (FEWSNET), Maputo is considered the main consumer market for agricultural products in the region. The Moamba district, through the Zimpeto and Fajardo markets, is considered the largest commercial hub for agricultural products supplying the province and the city of Maputo. In tum, Chókwè is recognized as the reference market for the southern region (FEWSNET, 2021). Price

fluctuations caused by adverse shocks in these regions are conveyed to other markets, impacting the purchasing power of Mozambican households, particularly those with limited income.

In turn, the temporal scope of the analysis is defined by the occurrence of extreme events – cyclones, floods, and droughts. The most significant cyclones included Dineo (2017), Desmond (January 2019), Idai (March 2019), Kenneth (2019), Belna (December 2019), Chalane (December 2020), Eloise (January 2021), Guambe (March 2021), Gombe (March 2022), and Freddy (January and February 2023). In turn, the major floods occurred in 2000, 2013, and 2023, and the main drought occurred in the South and Center of Mozambique.

Accordingly, an analysis of the average annual growth rates of harvested area, production, and yield of tomatoes in Mozambique, from 2014 to 2020, reveals an annual growth of 20.8% in area, 25% in production, and 2.9% in average yield (FAOSTAT, 2025). The vegetable market in Mozambique is relatively informal and underdeveloped. Notwithstanding its deficiencies and lack of formality, national vegetable production sustains 20 million Mozambicans, with tomatoes comprising 77% of the designated area and the vegetable market (Ecole and Malia, 2015; Zavale, Cribb, Quilambo, and Cachamba, 2015).

The domestic vegetable supply market in Mozambique is characterized by "informal" activities predominantly located in extensive irrigated regions in the south, including Moamba and Chókwè, as well as the Green Zones adjacent to major consumer hubs such as Maputo, Beira, Chimoio, and Nampula, mainly in urban and peri-urban areas, particularly in the southern region. The domestic market is supplied with both local and imported vegetables, predominantly from South Africa.

The main vegetables include tomatoes, onions, cabbage, green beans, peppers, beets, garlic, lettuce, kale, and carrots. Gradually, the assortment of products is broadening to encompass processed or value-added items, including pre-washed vegetables. Finally, the majority of transactions involving agricultural products are centered on relationships. Transactions persist in direct exchanges inside physical markets, and economies of scale in marketing are not entirely exploited.

Finally, this article is organized into six sections, including this introduction. Section 2 presents the theoretical fundamentals on price transmission, market integration and structural breaks. Section 3 discusses empirical studies on price transmission and market integration in Mozambique; Section 4 details the methodological procedures, including descriptive, correlation, ANOVA, and cointegration analyses; Section 5 synthesizes and discusses the main findings; and Section 6 offers the conclusions and policy recommendations.

2. THEORETICAL FUNDAMENTS

This section outlines the main theoretical foundation of the transmission and integration of agricultural markets and their association with structural breaks in time series analysis. Regarding the integration of agricultural markets, it is usually categorized as either spatial (horizontal) or vertical. In the case of horizontal integration, which is the scope of this article, two product markets within a single currency area are said to be integrated if, when trade takes place between them, price in the importing market equals price in the exporting market plus the transfer costs of moving the product between the two markets. Transfer costs encompass transportation, storage and processing expenses plus a nominal margin for the merchant's standard profit (Baulch, 1997).

In this way, integrated food markets are characterized by the simultaneous determination of prices. This simultaneity allows for the analysis of market interconnection and the efficiency of price transmission. The price transmission refers the process through which price changes in one market, region, or chain segment are transmitted to another (Balcombe; Marrison, 2002) which may be symmetric or asymmetric (Minot, 2001). In this context, asymmetries in price transmission are detected when the intensity or speed of adjustment differs between positive and negative shocks within a price series (Presotto; Freitas & Oliveira, 2023).

In integrated markets, even in the absence of trade flows, the flow of information allows the transmission of price signals between these markets (Facker & Tastan, 2008). On the other hand, the lack of integration means that price signals do not flow adequately from regions with supply shortages to those with surpluses (Akhter, 2007). The absence of integration may lead to price

distortions and inefficient resource allocation, compromising the efficiency and equity of food distribution (Sicsú; Castelar, 2009).

Price series correlation is regarded as a convenient indicator of market integration, but this approach has been strongly criticised despite its simplicity in the literature on market performance in rural areas (Ravallion, 1986). Nonetheless, the literature on time series has supported the advancement of econometric methods for assessing markets integration. This progression underlines the concepts of causality (Granger, 1969) and cointegration (Engle and Granger, 1987; Johansen, 1988), and the popularization of models like the ARDL (Ravallion, 1986; Blank and Schmiesing, 1988; Alexander and Wyeth, 1994). Despite analytical advances, many models still employ the assumption of linear model stability over time, an assumption that has been frequently criticized.

Consequently, structural break testing frameworks emerged as a methodological response to the challenge of capturing changes in time series dynamics. The analysis of structural breaks encompassed tests to identify their existence, estimate the date of the break, and conduct tests incorporating unit roots and structural breaks (Andrews, 1993). Early methodologies from the 1960s relied on exogenous assumptions about break dates, while later approaches — especially from the 1990s — introduced endogenous estimation of multiple breaks in the presence of unit roots (Bai & Perron, 1998; Zivot & Andres, 2002; Perron, 2006).

Other approaches have prominently emerged in literature applied to test market integration in underdeveloped countries, as noted by Mafimisebi (2012) and Van Campenhout (2007, 2012), which include: correlation analysis, the Law of One Price (LOP), Granger causality tests, the Ravallion model, and cointegration. However, recent studies — particularly those focusing on Mozambique's economy and the Southern African Development Community (SADC) region — demonstrate the use of advanced multivariate econometric techniques, such as: vector autoregression (VAR), Granger causality tests, Cointegration Test, Threshold Autoregressive (TAR) Model, Multivariate Asymmetric Price Transmission Framework Model, and Multivariate Vector Error Correction Model (VECM) integration and asymmetry in price transmission (Mandizvidza, 2013; Amikuzuno, 2009; Ihle & Amikuzuno, 2010).

Building upon this theoretical and empirical background, the present study applies the Nonlinear Autoregressive Distributed Lag (NARDL) model to investigate asymmetric price transmission and market integration in Mozambique's tomato markets. The NARDL methodology, formulated by Shin et al. (2014), enhances the linear ARDL framework by allowing potential asymmetries in both short- and long-term interactions, rendering it especially applicable in scenarios where structural breaks and nonlinear adjustments are anticipated.

3. METHODOLOGY

The study initially evaluates the behavioral patterns of tomato prices in the southern Mozambican markets. In the exploratory analysis, Spearman's rank correlation is used to assess price movements between markets, while ANOVA evaluates whether average prices differ significantly between Maputo, Moamba and Chókwè. Furthermore, Tukey's Honestly Significant Difference (HSD) test is used to identify which market pairs exhibit statistically significant differences in mean prices. For this purpose, joint ranges are calculated with a $1 - \alpha\%$ confidence level for all possible pairwise comparisons between means, expressed as $\mu_I - \mu_{I'} \in (\tilde{y}_I - y_{I'}) \pm HSD$. The null hypothesis (H_0) is accepted if $|\tilde{y}_I - y_{I'}| \leq HSD$; otherwise, it is rejected, indicating a significant difference between the two-market means.

Thereafter the evaluation of price variability, the process investigates the existence of unit roots to confirm the stochastic properties of the series. The study conducts ADF and DF-GLS unit root, in conjunction, to enhance robustness and reliability of results. As a complementary procedure, the methodology of Franses and Haldrup (1994) was utilized to detect outliers and mitigate the erroneous effects induced by anomalous observations in the identification of unit roots.

The optimal lag length is selected based on the minimum AIC, AICc, and BIC criteria (Fabozzi et al., 2014). Subsequently, The Gregory-Hansen cointegration test (1996) with structural break was also applied, an extension of the traditional cointegration test designed to account for potential structural changes in long-term relationships between I (0) and I (1) or I (1) series.

The Gregory and Hansen approach estimates a cointegrating regression with a possible regime change and, for each candidate breakpoint (τ), calculates ADF-type statistics. This test presents three test statistics resulting from the residuals of the cointegrating regression featuring a breakpoint:

$$Z_a(\tau) = n(\hat{\rho}_\tau^* - 1); \quad Z_\tau(\tau) = \frac{(\hat{\rho}_\tau^* - 1)}{\xi_\tau}, e \quad \hat{s}_\tau^2 = \frac{\hat{\sigma}_\tau^2}{\sum_1^{n-1} e_{t\tau}^2} \quad [1]$$

Where, $\hat{\rho}_\tau^*$ is the estimated autoregressive coefficient with ξ_τ as its default error, $\hat{\sigma}_\tau^2$ is the variance of the regression error of the residuals.

The test determines the minimal value of each statistic as the pertinent test statistic. If these values are lower the critical thresholds, the null hypothesis of no cointegration is rejected, signifying the presence of a cointegrating relationship with a structural break. Based on the results of the cointegration analysis, the long-run relationship is estimated using the ARDL bounds testing approach, while short-run adjustments are captured through the corresponding Error Correction Model (ECM).

$$\Delta \ln P_{map_t} = \alpha_1 + \alpha_2 D_{TB} + \sum_{i=1}^p a_{1i} \Delta \ln P_{map_{t-1}} + \sum_{i=1}^q a_{2i} \Delta \ln P_{ch_{t-1}} + \sum_{i=1}^q a_{3i} \Delta \ln P_{moa_{t-1}} + \gamma t + \delta t D_{TB} + \lambda ECT_{t-1} + u_t, \quad [2]$$

Where, Δ represents the variables in first difference, α_1 is the intercept before the break and α_2 the change in the intercept due to the break. a_{ni} are coefficients of the independent variable; y_t (P_{map_t}) is dependent variable, x_t are independent variables ($P_{ch_{t-1}}$, $P_{moa_{t-1}}$) in the time dimension t ; t is trend, γ is coefficient of the trend before the structural break, and δ is change in the coefficient of the trend due to the structural break. TB =point of rupture or structural break, D_{TB} =dummy variable that takes on a value of 0 before the structural break and 1 after the structural break, i.e. $D_{TB} = 0$ if $TB \leq t$ and $D_{TB} = 1$ if $TB > t$; u_t is the error term. p_{map} is price of tomatoes in Maputo expressed in mzn/kg, p_{tch} is price of tomatoes in Chókwe expressed in mzn/kg, p_{moa} is price of tomatoes in Moamba expressed in mzn/kg. \ln =logarithm

The diagnosis of the model was based on the White Test for heteroscedasticity, the Breusch-Godfrey LM test for autocorrelation, the Jarque-Bera test for normality of the residuals, and the Cusum test and Cusumsquare Test for analyzing the stability of the model parameters.

This investigation extends the linear ARDL to a nonlinear form (Shin, Yu, and Greenwood-Nimmo, 2014) – also called ARDL Asymmetric Effects (NARDL), to investigate potential nonlinearities in price transmission. With certain adaptations, framed in an ARDL configuration along the lines of Pesaran and Shin (1998) and Pesaran et al. (2001), it can be rewritten as:

$$\Delta y_t = \rho \Delta y_{t-1} + \begin{pmatrix} \theta^+ x_{t-1}^+ \\ + \\ \theta^- x_{t-1}^- \end{pmatrix} + \sum_{j=1}^{p-1} \varphi_j \Delta y_{t-j} + \sum_{j=0}^{q-1} \begin{pmatrix} \pi_j^+ \Delta x_{t-j}^+ \\ + \\ \pi_j^- \Delta x_{t-j}^- \end{pmatrix} + \varepsilon_t \rho \zeta_{t-1} + \varepsilon_t \quad [3]$$

$$\text{With: } \rho = \sum_{j=1}^p \theta_{j-1}; \quad \varphi_i = -\sum_{j=i+1}^p \theta_j; \quad \theta^+ = \sum_{j=0}^q \theta_j^+; \quad \theta^- = \sum_{j=0}^q \theta_j^-; \quad \pi_0^+ = \theta_0^+, \quad \pi_0^- = \theta_0^-, \\ \pi_j^+ = -\sum_{j=j+1}^q \theta_j^+ \quad \text{e} \quad \pi_j^- = -\sum_{j=j+1}^q \theta_j^-.$$

In addition, $\zeta_{t-1} = \Delta y_t - \beta^+ x_t^+ - \beta^- x_t^-$ is the non-linear ECM, with $\beta^+ = -\theta^+/\rho$ and $\beta^- = -\theta^-/\rho$ being long-term asymmetric parameters that represent the impacts of increasing and decreasing x_t on y_t . $\sum \pi_j^+$ measures the short-term influences of increasing x_t on y_t , while $\sum \pi_j^-$ measures the short-term influences of decreasing x_t on y_t . The hypothesis to be tested in the model is $H_0: \theta_0 = \theta_1^+ = \theta_1^- = \theta_2^+ = \theta_2^- = 0$.

Based on the study variables, the NARDL model for each price series can be rewritten as follows:

$$\Delta Y_t = \rho Y_{t-1} + \begin{pmatrix} \theta^+ X_{t-1}^+ \\ + \\ \theta^- X_{t-1}^- \end{pmatrix} + \begin{pmatrix} \theta^+ W_{t-1}^+ \\ + \\ \theta^- W_{t-1}^- \end{pmatrix} + \sum_{j=0}^{q-1} \begin{pmatrix} \pi_j^+ \Delta X_{t-j}^+ \\ + \\ \pi_j^- \Delta X_{t-j}^- \end{pmatrix} + \sum_{j=0}^{q-1} \begin{pmatrix} \pi_j^+ \Delta W_{t-j}^+ \\ + \\ \pi_j^- \Delta W_{t-j}^- \end{pmatrix} + \sum \varphi_i \Delta Y_{t-i} + \varepsilon_t \quad [4]$$

The average prices of tomatoes, denoted as $Y_t = \ln P_{map_t}$ in Maputo, $X_t = \ln P_{chok_t}$ in Chókwè, and $W_t = \ln P_{moa_t}$ in Moamba, are stated in mts/kg across several markets. The long-term coefficients of each lagged variable are determined by dividing the negative of the corresponding coefficient, θ^+ and θ^- , by the coefficient ρ . The $\sum \pi_j^+$ and $\sum \pi_j^-$ quantifies the short-term effects of tomato price.

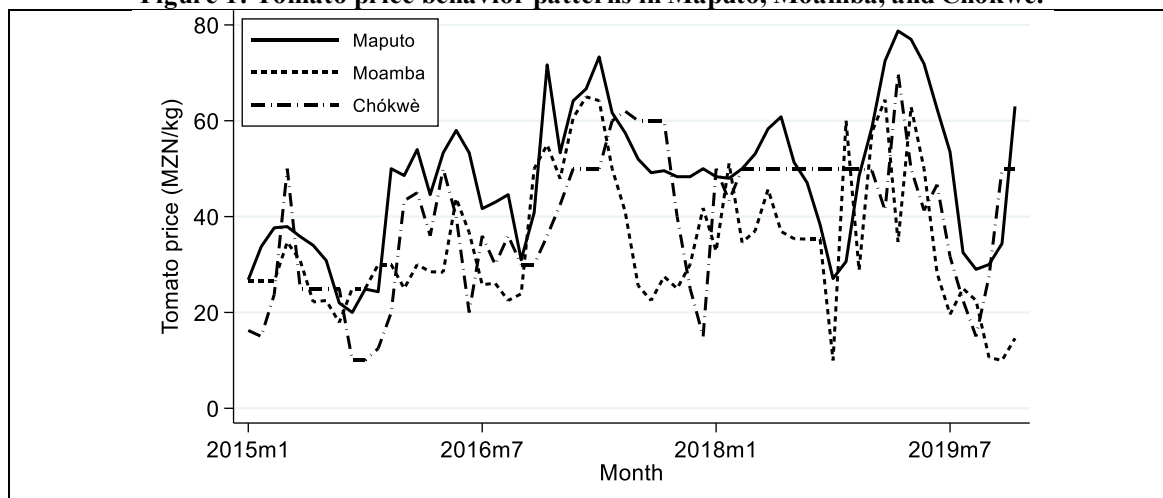
The diagnosis will be conducted utilizing the subsequent tests: i) The Portmanteau Test facilitates a comprehensive assessment of the potential inclusion of various non-linear transformations of combinations of explanatory variables alongside a chosen model structure. ii) Breusch/Pagan Heteroskedasticity Test, which evaluates heteroscedasticity in a regression model; iii) Ramsey RESET Test, which identifies specification errors in the regression equation; and iv) Jarque-Bera Test on Normality, which assesses normality based on the skewness and kurtosis of the data.

4. RESULTS AND DISCUSSION

4.1 Descriptive and variability analysis

The graphical analysis of tomato prices revealed high-frequency fluctuations originating from multiple factors. As noted by Adhikari & Agrawal (2013), these fluctuations behave erratically, without any clear pattern. While USAID (2018) and Ndapassoa (2023) have indicated that Mozambique has been experiencing an increase in the frequency of cyclones, floods and droughts, which have disrupted local markets and negatively impacted farmers' incomes (USAID, 2018; Matias, 2016; Mazive, 2017).

Figure 1: Tomato price behavior patterns in Maputo, Moamba, and Chókwè.



Source: SIMA Mozambique (2024)

In turn, the correlation matrix showed an average positive correlation between the market pairs of Chókwè and Maputo, as well as Moamba and Maputo, with correlation values of 0.66 and 0.58, respectively. The correlation between the prices of tomatoes in Moamba and Chókwè was also positive, but weak (Table 1).

Table 1: Correlation matrix of tomato prices in the Maputo, Chókwè, and Moamba markets

Matrix (obs=60)	$\ln P_{map}$	$\ln P_{ch}$	$\ln P_{moa}$
$\ln P_{map}$	1.000		
$\ln P_{ch}$	0.655***	1.000	
$\ln P_{moa}$	0.576***	0.239*	1.000

Source: prepared by the author

Note: Tomato price in Maputo ($\ln P_{map_t}$), Chókwè ($\ln P_{ch_t}$) and Moamba ($\ln P_{moa_t}$) expressed in MZN/kg. ln=logarithm. Significance level: (***)=1%, (**)=5%, (*)=10%.

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The positive average correlation between the Maputo and Moamba tomato markets is substantiated by Zavale *et al.* (2015) due to the Zimpeto wholesale market in Maputo being the predominant marketing hub for tomatoes cultivated in the Moamba district. In this context, over 70% of tomato producers in the Moamba district sell their produce primarily in Maputo city, with 3.3% directed to the Fajardo market and the remaining 64.1% designated for the Zimpeto wholesale market, which serves as the predominant outlet for tomatoes from Moamba producers.

The commercial relationship between the markets of Chókwè and Moamba is small, and all of them have a strong dependence on the large consumption center of Maputo city. In addition, they help local markets with supplies more efficiently than more distant markets, which tend to face greater challenges linked to logistical barriers, packaging, according to Chambo (2013), access to transportation and regulations (toll costs, weight and speed limitations), resulting in less intense and frequent interactions, as is the case between the Moamba and Chókwè markets.

As part of the exploratory analysis phase, the analysis of variance showed some differences in the average prices of tomatoes in the markets of Maputo, Chókwè, and Moamba, as pointed out in Table 5. Given the non-normal distribution of prices in the Chókwè markets, as evidenced by Skewness/Kurtosis, the conditions for applying a parametric ANOVA test were not met. Therefore, the Kruskal-Wallis test was used as a non-parametric alternative to ANOVA for independent sample.

Table 2: ANOVA, Levene, Skewness/Kurtosis test and Krustal-Wallis test of Tomato Prices in the Maputo, Moamba, and Chókwè Markets.

Panel a) ANOVA					
Prices	Sum of Squares	df	Average Square	F	Sig.
Between groups	5.518,005	2	2.759,003	12,953	0,000
In the groups	37.700,253	177	212,996		
Total	43.218,259	179			
Panel b) Levene's Test of Homogeneity of Variance					
Levene Statistic	df1	df2	Sig.		
0,476	2	177	0,622		
Panel c) Skewness/Kurtosis tests for Normality					
Markets	Pr (Skewness)	Pr (Kurtosis)	adj chi2(2)	Prob>chi2	
P_{map}	0.0864	0.5847	3.40	0.1828	
P_{ch}	0.0017	0.4454	8.96	0.0113	
P_{moa}	0.1220	0.2820	3.73	0.1552	
Panel d) Statistics of the Krustal-Wallis test					
Tests	Statistics				
Qui-square	21,163				
Df	2				
Asymptotic Significance	0,000				
b. Grouping Variables: Market					

Source: prepared by the author.

Note: Tomato price in Maputo (P_{map_t}), Chókwè (P_{ch_t}) and Moamba (P_{moa_t}) expressed in MZN/kg.

According to Martinez and Ferreira (2010), the Krustal Wallis test allows detection of meaningful differences between central values of three or more situations, when it is considered different subjects. As for the Krustal-Wallis test shown in Table 6, it validates the ANOVA results, making it evident that, on average, the prices of tomatoes on the analyzed markets presented some meaningful differences.

In this regard, Tukey's multiple comparisons revealed that the tomato prices in Maputo were on average 8.48 MZN/kg higher than the price in the Chókwè market, and 13.41 MZN/kg higher than the price in Moamba, standing out from the other markets. Junior, Bazo, and Romão (2022) indicate that this phenomenon is frequently observable from January to March, when tomato prices in the markets of Maputo City peak. During April and June, tomato prices exceed the average in the marketplaces of Maputo province, Maputo city, and Gaza. From July to November, prices in Gaza province exceed the average until September, subsequently declining from October through the remainder of the year, whilst other provinces experience a resurgence in prices in December.

Table 3: Tukey’s Multiple Comparison Results for Tomato Prices Across Markets

Panel a) Tukey’s Simultaneous Multiple Comparison Tests for Mean Differences

	(I) Markets	(J) Markets	Mean Difference (I-J)	Standard model	Sig.	Confidence interval 95%	
						Inferior limit	Superior limit
Tukey HSD	P_{map}	P_{ch}	8,481*	2,664	0,005	2,183	14,778
		P_{moa}	13,406*	2,664	0,000	7,108	19,704
	P_{ch}	P_{map}	-8,481*	2,664	0,005	-14,778	-2,183
		P_{moa}	4,926	2,664	0,157	-1,372	11,223
	P_{moa}	P_{map}	-13,406*	2,664	0,000	-19,704	-7,108
		P_{ch}	-4,926	2,664	0,157	-11,223	1,372

Panel b) Information from Homogeneous Subsets using Tukey's Method and 95% Confidence

	Markets	Alpha subsets = 0.05	
		1	2
Tukey HSD ^a	P_{map}	34,2933	
	P_{ch}	39,2188	
	P_{moa}		47,6993
	Sig.	0,157	1,0

Source: prepared by the author.

Note: Tomato price in Maputo ($\ln P_{map_t}$), Chókwè ($\ln P_{ch_t}$) and Moamba ($\ln P_{moa_t}$) expressed in MZN/kg.

The tomato prices in Chókwè and Moamba have homogeneous subsets, in contrast to prices in Maputo, which have inhomogeneous subsets. This differential makes Maputo City's markets the preferred markets for tomatoes, as it is a major consumption center in the southern region (Campenhout, 2012). This result highlights a scenario that reflects a certain instability in the supply of tomatoes, resulting from large deficits or low supplies of tomatoes in the Maputo city markets, which affect the price dynamics in these markets. However, whether the markets are integrated and whether the price signals derived from shocks are transmitted between the markets analyzed, and the magnitudes of these signals, is a subject to be addressed in later topics.

4.2 Stationarity tests and structural break analysis

Based on the ADF and DF-GLS tests, the series proved to be integrated in different orders. In other words, they were stationary in level and in first difference, with a combination of the I(0) and I(1) series. In this case, VAR or VECM models should not be applied directly. Therefore, ARDL (AutoRegressive Distributed Lag) models are used, as they allow for variables with mixed integration orders.

And the Engle-Granger or Johansen cointegration tests are not applicable, as they require all variables to be I(1). In this situation, the Bound Test associated with the ARDL model (AutoRegressive Distributed Lag Model), proposed by Pesaran et al. (2001), is used. After detecting cointegration, the ARDL model with an error correction term (ECM) is estimated to analyze the short- and long-term dynamics of the series.

Table 4: Augmented Dickey-Fuller Test and DF-GLS for Unit Roots

Series	Variables	Test statistics	Order Integration	Test statistics	Order Integration
In level	$\ln P_{map}$	-3.478**	I(0)	-3.957	I(0)
	$\ln P_{ch}$	-3.124**	I(0)	-3.315**	I(0)
	$\ln P_{moa}$	-2.039	-	-2.113	-
1st dif.	$d. \ln P_{map}$	-3.934	I(0)	-3.438**	I(0)
	$d. \ln P_{ch}$	-5.506	I(0)	-5.559	I(0)
	$d. \ln P_{moa}$	-4.455**	I(1)	-4.336**	I(1)

Source: prepared by the author

Note: Tomato price in Maputo ($\ln P_{map_t}$), Chókwè ($\ln P_{ch_t}$) and Moamba ($\ln P_{moa_t}$) expressed in MZN/kg. ln=logarithm. Significance level: (***)=1%, (**)=5%, (*)=10%. (-) =presence of unit root

Regarding Zivot-Andrews and Bai-Perron tests for structural breakage $Z_{\tau}(\tau)$, statistics from the Zivot-Andrews test indicate that structural breakage is present in the model. These results reinforce the supW(tau) statistics of the Bai and Perron test, which provide analytical and numerical evidence that there are multiple break points in the structure of the series analyzed, which show the presence of multiple exogenous shocks that affected the dynamics of the series on the dates highlighted in notes (a), (b) and (c) of Table 10, suggesting the possibility of structural changes in the short and long-term relationships between the variables analyzed.

Table 5: Zivot & Andrews and Bai & Perron structural break test for tomato prices in the Maputo, Moamba and Chókwe markets

Test	Coef.	$\Delta \ln P_{tmap}$	$\Delta \ln P_{tmoa}$	$\Delta \ln P_{tch}$
Zivot Andrews test	Z_stats	-5.035 **	-3.319	-4.343 **
	Break	2015m12	2016m11	2016m1
Bai & Perron test	supW(tau)	2.99**(a)	1.91 (b)	3.68***(c)

Source: prepared by the authors based on the results of the tests described above.

Note: Significance level: (***)=1%, (**)=5%, (*)=10%, number of lags (2) included based on the AIC in the unit root tests, : ptmap=tomato price in Maputo expressed in mzn/kg, ptch=tomato price in Chókwe expressed in mzn/kg, ptmoa=tomato price in Moamba expressed in mzn/kg. D=first difference, ln=natural logarithm. Estimated structural break points under hypothesis H0: no break(s) vs. H1: 5 break(s): (a) 2015m11 2016m11 2017m8 2018m5 2019m2; (b) 2015m11 2016m11 2017m8 2018m5 2019m3; (c) 2015m12 2016m12 2017m9 2018m6 2019m3; at 2016m1

If there is a structural break in the time series, the traditional unit root and cointegration tests such as ADF, Engle-Granger, Johansen and Bound Test can generate invalid or misleading results. This is because these tests assume constancy of the parameters over time. Traditional tests may not correctly detect unit roots or cointegration if they do not take structural breaks into account.

In this context, unit root and cointegration tests that accommodate explicit structural breaks should be used. To this end, we used the Gregory-Hansen Test for cointegration with structural break (1996), which allows for a structural break in the cointegration vector (level, trend, level and trend, regime change).

Regarding Results of the ADF with additive outliers and Gregory-Hansen tests for Cointegration with Regime Change, the Gregory-Hansen (1996) cointegration test applied to the analysis of long-term dynamics and carried out considering changes in level and tendency indicates cointegration presence. This result suggests that the linear combinations of the analyzed variables display stable properties in the long term, but with structural breaks.

The Gregory-Hansen $Z_{\tau}(\tau)$ and $Z_{\alpha}(\tau)$ statistics test shows cointegration and the structural change that occurred in February 2019, thus suggesting that there is a structural change in the data at that point. USAID (2018) and Ndapassoa (2023) corroborate this by showing that in 2019 alone, cyclones Idai (March 14 and 15, 2019) and Kenneth (2019) disrupted local markets and farmers' incomes. The results of Franses and Haldrup (1994) provided analytical and numerical evidence of the non-existence of additive outlying observations or additive outliers in the series analyzed.

Table 06: Gregory-Hansen and Franses & Haldrup Tests for Cointegration with Regime Changes

Panel a) Asumptotic critical Values						
	Stat test	Breakpoint	Data	1%	5%	10%
ADF	-6.20	50	2019m2	-5.80	-5.29	-5.03
Z_t	-6.26	50	2019m2	-5.80	-5.29	-5.03
Z_{α}	-49.09	50	2019m2	-64.77	-53.92	-48.94

Panel b) Test for Cointegration with Regime Changes					
Tested variables	Maxlag	Period of Time	Deterministic terms	obs	outliers
$\ln P_{map}$	10 chosen by the Schwart criteria	2015m3 to 2019m12	Constant + trend	58	0
$\ln P_{ch}$				59	0
$\ln P_{moa}$				59	0

Source: prepared by the author

There is analytical and numerical evidence that there are multiple break points in the structure of the series analyzed, raising the possibility of structural changes in the short- and long-term relationships between the variables analyzed. Once we know that the markets are integrated, the next step is to assess which price signals, derived from shocks, are transmitted between the markets analyzed and the magnitudes of these signals, and whether there is symmetry or asymmetry in this transmission.

To this end, the ARDL-ECM model will be estimated using the Gregory-Hansen approach, analyzed in two contexts, i.e. in the presence of a structural break and without a structural break, with the aim of this approach serving as a reference for comparing results with the model with a break, and verifying the robustness of cointegration. Models without structural breaks assume that the long-term relationship between the variables is constant and can fail if there is a shock or structural change in the period analyzed.

4.3 ARDL and NARDL models: specification and analysis

The adjustment coefficients or error correction mechanism, $\ln p_{map}$ (L1), associated with tomato prices in the ARDL-ECM (1,0,2,0,0,0) and ARDL-ECM (1,0,2) models, with values of -0.4764 and -0.4393, respectively, were highly significant at 1% and also negative, which strengthens the evidence of a long-term relationship between the variables analyzed. The significance of the error correction mechanism suggests Granger causality in the long term among the tomato prices in the markets studied. The error correction terms of ARDL-ECM (1,0,2,0,0,0) and ARDL-ECM (1,0,2) suggest that approximately 47.64% and 43.93% of any movements towards disequilibrium are corrected within a month, respectively.

In the ARDL-ECM (1,0,2,0,0,0) model with a structural break, a percentage increase of one unit in the variables $\ln p_{ch}$ and $\ln p_{moa}$, *ceteris paribus*, is associated with an increase of approximately 0.3080% and 0.5424% in $\ln p_{map}$ in the same period. However, the exogenous shocks associated with $z_{\ln p_{ch}}$ and $z_{\ln p_{moa}}$ indicate a significant impact on $\ln p_{map}$, at 5% and 10% significance levels. In this regard, unit percentage increases in exogenous shocks in Moamba and Chókwe reduce or increase tomato prices in Maputo by 0.5418% and 0.7862%, respectively. This result suggests that, in the long term, exogenous shocks to tomato prices in Chókwe and Moamba affect the dynamics of tomato prices in Maputo.

In the ARDL-ECM (1,0,2) model without a structural break, a percentage increase of one unit in $\ln p_{ch}$, *ceteris paribus*, is associated with an increase of approximately 0.5041% in $\ln p_{map}$ in the same period.

However, despite the limited or nonexistent studies on this topic in the local context of the study, the evidence from USAID (2018) and Ndapassoa (2023) suggests the influence of exogenous shocks on price dynamics, with results supported by the Gregory-Hansen test.

Table 07: Results of the ARDL-ECM (1,0,2,0,0,0) and ARDL-ECM (1,0,2) Models

Panel a) Adjustment of Error Correction Term		
Method	ARDL-ECM Regression (1,0,2,0,0,0)	ARDL-ECM Regression (1,0,2)
L1. $\ln p_{map}$	-0.4764***	-0.4393***
Panel b) Long-Term relationship		
Method	ARDL-ECM Regression (1,0,2,0,0,0)	ARDL-ECM Regression (1,0,2)
L. $\ln p_{ch}$	0.3080**	0.5041***
L. $\ln p_{moa}$	0.5424***	0.2095
Z	-0.7605	
Z $\ln p_{ch}$	0.7862**	
Z $\ln p_{moa}$	-0.5418*	
Panel c) Short-Term relationship		
Method	ARDL-ECM Regression (1,0,2,0,0,0)	ARDL-ECM Regression (1,0,2)
D1. $\ln p_{moa}$	0.0848	0.1439
LD. $\ln p_{moa}$	0.2243*	0.2227***
_cons	0.3836	0.5774**
Panel d) Model Fit Diagnostics		
Method	ARDL-ECM Regression (1,0,2,0,0,0)	ARDL-ECM Regression (1,0,2)
R-squared	0.6152	0.4619
Adj R-squared	0.5524	0.4101

Source: prepared by the author.

Note: Tomato price in Maputo ($\ln p_{map_t}$), Chókwe ($\ln p_{ch_t}$) and Moamba ($\ln p_{moa_t}$) expressed in MZN/kg. Dependent Variable: $\ln p_{map}$. Significance level: (***)=1%, (**)=5%, (*)=10%. (-) =presence of unit root z = exogenous shock, $z_{\ln p_{ch}}$ = exogenous shock to the tomato price in Chókwe, $z_{\ln p_{moa}}$ = tomato price shock in Moamba. L1 = first lag. D1 = first difference, LD = first lag of the first difference, \ln =logarithm

In the ARDL-ECM (1,0,2,0,0,0) model with a structural break, the results showed no autocorrelation. However, the residuals were not homoscedastic at the 10% level, which is a normal distribution, but with parameter stability. For the ARDL-ECM (1,0,2) model without a structural break, the results revealed no autocorrelation, homoscedastic residuals, and a normal distribution, though with some parameter instability, indicating a certain robustness in the data under analysis.

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Table 08: Diagnostic Tests of the Analytical Models

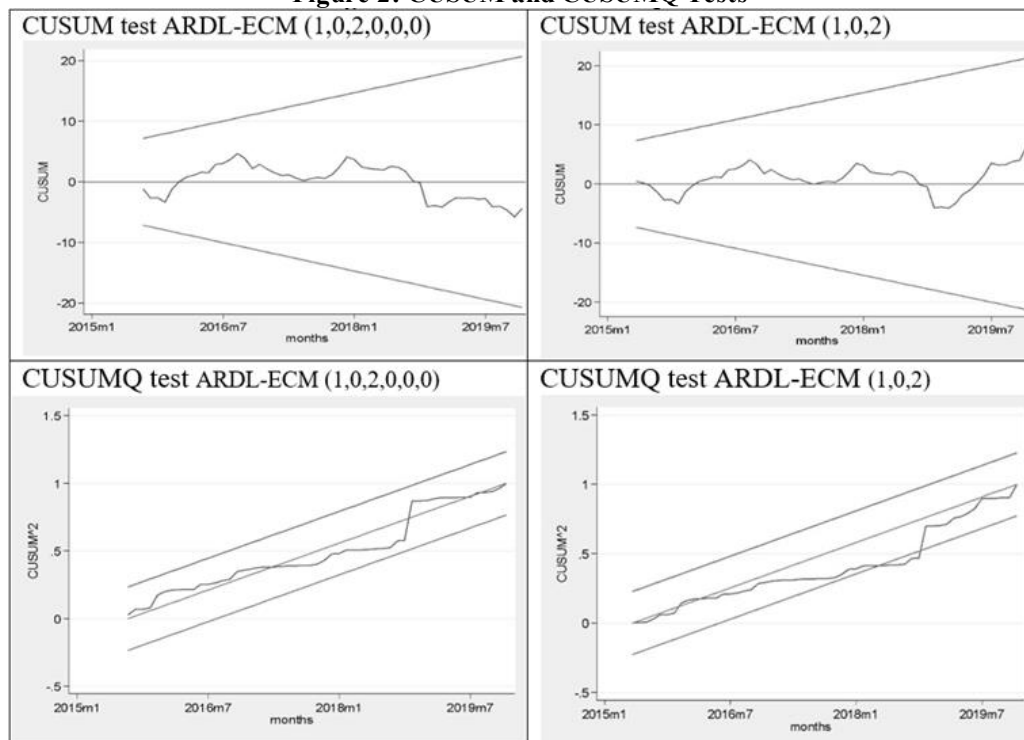
Panel a) Tests for Autocorrelation and Heteroscedasticity		
	ARDL-ECM (1,0,2,0,0,0)	ARDL-ECM (1,0,2)
Breusch-Godfrey LM Test for Autocorrelation	0.4525	0.3394
White Test for Heteroscedasticity	0.0815	0.1007
Panel b) Jarque-Bera Test for Normality (H_0)		
P_{map}	P_{ch}	P_{moa}
0.5491	0.2325	0.1051

Source: prepared by the authors.

Note: the calculation procedure for the Jarque-Bera asymptotic test for normality is based on the specified variable in level form ¹.

In the ARDL-ECM (1,0,2,0,0,0) model with a structural break, its plotted points are within the two 5% critical limits, while in the ARDL-ECM (1,0,2) model without a structural break, there is some parameter instability based on CUSUMSQ, as shown in Figure 2. This result is derived from the control or adjustment that the Gregory test applies to the structural break in the regime-shift model.

Figure 2: CUSUM and CUSUMQ Tests



Source: prepared by the authors

Concerning the outcomes of the ARDL non-linear model, the cointegration test presented in Table 9 panel a), utilizing the t_{BDM} and F_{PSS} statistics, indicates the absence of cointegration in the series examined within the NARDL model. The F value falls between the critical values at the 5% significance level, with the upper limit at $I(1)=3.34^{**}$ and the lower limit at $I(0)=2.14^{**}$. These thresholds denote the essential reference values established by Pesaran et al. (2001).

¹ For more, see: C.M. Jarque and A.K. Bera. 1987. "A Test for Normality of Observations and Regression Residuals. International Statistical Review 55:163-172; In Damodar Gujarati. Basic Econometrics. p. 143, 1995.

Table 09: Cointegration test, short- and long-term symmetry and asymmetry statistics, positive (increases) and negative (decreases) long-term effects

Cointegration test statistics		Critical Values of Pesaran, Shin e Smith (2001) k=3					
	lnptmap	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
t_BDM	-3.0639	-2.58	-4.44	-1.95	-3.83	-1.62	-3.49
F_PSS	2.3910	2.82	4.21	2.14	3.34	1.81	2.93
Cointegração	Indecisão	1%		5%		10%	

Assymetry statistics		
Exog. var.	Long-term effect [+]	Short-term effect [-]
	Nardl	Nardl
lnptch	0,461**	-0,545**
lnptmoa	0,653***	-0,561***
Exog. var.	Long-term assymetry	Short-term assymetry
	Nardl	Nardl
lnptch	0,5857	0,7246
lnptmoa	1,365	0,4237

Source: prepared by the authors

Note: the asterisks ***, ** and * are respectively the 1%, 5% and 10% significance level, NARDL=Non-Linear, Autoregressive Distributed Lags, $p>|t|$ =probability value. A series is said to be integrated of order d, denoted as I(d), if it becomes stationary after being differentiated d times. Thus, in the table I(0) the series is stationary at level, on the other hand I(1) is integrated at order 1. The t_BDM(Banerjee-Dolado-Mestre) and F_PSS(Pesaran-Shin-Smith) tests.

There are positive effects from the Chókwè tomato market and negative effects from the Moamba tomato market. The positive long-term effects of the Chókwè market explain the increase in the price of tomatoes in Maputo and the negative long-term effects of the Moamba market explain the reduction in the price of tomatoes in Maputo. However, there was no evidence of asymmetry or skewness in the relationships between the variables analyzed, based on the evidence from the asymmetry statistics highlighted in Table 9 panel b).

However, despite the ARDL-ECM and NARDL approaches focusing on the Maputo market, they showed a better adjustment to price imbalances following asymmetric shocks in long-term relationships. However, the NARDL approach was unable to draw conclusions about long-term dynamics given the indecisiveness of the cointegration evidence. Both approaches converge despite having linear and non-linear relationships between the variables analyzed and performing well in the diagnostic tests.

Table 10: Results of the Nonlinear Autoregressive Distributed Lag model, Cointegration and Asymmetry Statistics of tomato prices in the Maputo market of Mozambique

lnptmap_dy	Nardl
Prob > F	0.0004
R-squared	0.5486
Adj R-squared	0.4016
Portmanteau test	0.9890
Breusch/Pagan heteroskedasticity test (chi2)	0.0545
Ramsey RESET test (F)	0.5142
Jarque-Bera test on normality (chi2)	0.3642

Source: Prepared by the authors

The Nardl model demonstrates global significance, indicating that 40.16% of the variability in the dependent variables are accounted for by the explanatory variables in the models. The Portmanteau, Jarque-Bera (JB), Breusch/Pagan heteroscedasticity, and Ramsey RESET tests indicate that the NARDL model for asymmetric tomato pricing correlations in the Maputo market was a good fit.

5. FINAL CONSIDERATIONS AND POLICY RECOMMENDATIONS

This study examined how tomato prices are integrated and transmitted across southern Mozambique's markets. The results suggest that structural disruptions caused by exogenous shocks—especially extreme weather events—significantly influence the integration and price

transmission dynamics between the tomato markets of Maputo, Moamba, and Chókwe. Climate shocks cause disruptions in the production and distribution of goods, rearranging physical and informational flows and briefly impairing the process of price arbitrage. We observe an increase in asymmetry in price transmission as a result. Whenever an extreme climate event occurs, structural breaks are observed, with the dynamics of price integration and transmission occurring with elasticities and speeds distinct from those observed before the shocks.

Fluctuations in tomato prices in Chókwe and Moamba, as well as exogenous shocks (such as cyclones, cyclical floods, drought) affect the dynamics and stability of tomato prices in the Maputo market in the long term. However, although there are few or no studies on this subject in the local context, the evidence supported by the Gregory-Hansen test suggests a strong influence of exogenous shocks on price dynamics in the markets analyzed. The NARDL model showed no evidence of an asymmetrical long-term relationship between the variables analyzed.

In light of the aforementioned, the following policy ideas warrant consideration: Enhance monitoring and early warning systems for extreme weather occurrences that may affect the assessed markets to increase their efficacy. Enhance the effective communication of information among the Moamba, Chókwe, and Maputo marketplaces. Mitigate logistical obstacles that may impede the effective transfer of prices across marketplaces. Ultimately, to enhance the analytical models, it is essential to integrate fresh data and methodologies to guarantee that policies remain aligned with the constantly evolving market dynamics.

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