



**Dr. Ghulam Hussain Wagan¹, Dr. Jam Ghulam Murtaza Sahito¹, Dr. Aijaz Ali Khooharo²,
Dr. Hakimzadi Wagan¹, Dr. Sohail Ahmed Rajper³**

1. Departments of Agricultural Economics, Sindh Agriculture University Tando Ja, Pakistan.

2. Departments of Agricultural Education & Extension, Sindh Agriculture University Tando Jam, Pakistan.

3. Department of Biotechnology, Faculty of Crop Production, Sindh Agriculture University Tando jam, Pakistan

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Corresponding Author:

Dr. Ghulam Hussain Wagan

Email: ghwagan@sau.edu.pk

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Abstract: *Maize is one of the key cereal crops in Pakistan, which serves as a fundamental source of food for humans, and an important fodder and feed to cattle and poultry. This study has analyzed the degree of market integration in the Pakistani maize markets by applying the cointegration techniques, leaving out the use of sophisticated econometric analysis that takes into consideration the transaction costs. The current research uses the Threshold Vector Error Correction Model (TVECM), a more comprehensive method, to analyze important maize markets in the country with the data range of 1991-2023. The model incorporates the transaction costs by embracing non-linear, complicated dynamics of price adjustment and making it more accurate than traditional means. The major objective of the study is to determine the extent and size of market integration by collecting data on area, production, and growth indicators of maize in Pakistan. The results show that there is a strong long-term equilibrium between most of the market pairs, with the strong long-term integration between domestic markets, especially those grouped around the cities of Faisalabad, Gujranwala, and Lahore; however, the inefficiencies in the short-run are still present, attributed to infrastructural drawbacks and regulatory barriers. There were 18 statistically significant threshold effects out of 28 market pairs analyzed. The findings significantly advance the academic knowledge on the agricultural markets in Pakistan and support the need to question the integration of the maize market to protect food availability, affordability, and accessibility. The paper also emphasizes that to achieve a competitive, resilient, and sustainable maize sector in Pakistan, there is a need to have an integrated approach that would include the development of infrastructure, policy changes, digital transformation, and international cooperation. The investment in the market infrastructure by the private sector in storage and transportation infrastructure of maize would tend to enhance efficiency in the market and reduce the spending by the government. This kind of approach will not only be beneficial to the producers and consumers but also contribute to the economic security and food security of Pakistan.*

Introduction

Maize (*Zea mays* L.) or corn was domesticated in 7,000 to 10,000 years ago in Mexico and is currently emerging as one of the major cereals globally (along with wheat, *Triticum aestivum* L., and rice, *Oryza sativa* L.) contributes up to 30 percent of the world population to the global caloric intake (Maize, 2021). Maize as a C4 crop delivers food security, nutrition and livelihood of farmers, although it is resilient and sustainable (Karnatam et al., 2023). Maize grains are typically composed of 66-74.5 percent starch, 7.7-15.5 percent protein, and 2-7.7 percent fat where the energy of the food ranges between 360 and 470 kcal/100 grams. Maize can be converted into many different forms of its use, and depending on the variety and processing, it can be used in the feed industry, as well as in the industrial industry as starch, oil, ethanol, and sweeteners (Yang and Li, 2024).

In terms of production, maize is the leading crop globally, 1.23 billion metric tonnes produced in 2024, with the United States, China, Brazil, the EU, and Argentina as top producers (Statista, 2024; USDA, 2025). It is the third major cereal crop of Pakistan after wheat and rice and an important contributor to GDP and agricultural value addition (Mukhtar and Javed, 2007; Hussain et al., 2023; Govt. of Pakistan, 2024). Its cultivation increased from 1.08 million hectares in 1990–91 to 1.72 million hectares in 2022–23, with production increasing from 1.18 million tonnes to 10.18 million tonnes in the same period. Punjab accounts for 85 percent of the national production of maize, followed by Khyber Pakhtunkhwa, with limited contributions from Sindh and Baluchistan (Govt. of Pakistan, 2024).

Maize is used as a primary food source for human beings, as well as fodder for animals and feed for poultry (Shakoor et al., 2017). Currently, estimates suggest that approximately 40-50 percent of maize in Pakistan is used on farms, 15-20 percent is traded in local markets, and 40 percent is sold through the organized wholesale markets, highlighting its diverse role in food and industry (Butt, 2024). Direct human consumption of maize is on the decline, largely due to its increasing utilization in animal feed and industrial processing, however, its utilization in the feed and wet milling industries is growing far more quickly than anticipated. The poultry industry consumes more than 60 percent of Pakistan's maize, and the availability of high-quality feed will help the industry continue to flourish (Tariq & Iqbal, 2010). The last two decades recorded impressive growth in maize cultivation in Pakistan, as well as most Asian economies, showing a significant increase in maize, both in terms of area and production (GoP, 2024). Markets contribute significantly in meeting food security by ensuring food is available and accessible to the population. Integrated markets enable a coordinated price action, greater market performance, and supplier variety (Wagan et al., 2024). This is necessary to promote the global economic performance (Dominguez -Barreto et al., 2023; Jiang et al., 2023; Mechri et al., 2023). Market integration is where price transfers are made across geographically and vertically distanced marketplaces. In the case of staple crops like wheat, rice, and maize, integration researchers play a crucial role in influencing policy on prices and managing food insecurity and enhancing the rural livelihood (Sahito, 2017; Stepien et al., 2022).

Crop marketing and market mechanisms in Pakistan is the neglected area of research. The major objectives of this study was to determine the long and short-run relations and to examine the degree of integration among different domestic maize markets. Based on the objectives, this study was designed to test two hypotheses;

H1: Maize markets in Pakistan are integrated in the long run and,

H2: Short-run price transmission is weak and asymmetric due to transaction costs and market frictions. Unlike previous studies, this study has used advanced econometric models like the Threshold Vector Error Correction Model (TVECM) for analyzing market dynamics in Pakistani maize markets. It has focused on the maize market instead of the other cereal crops because of the limited research on maize,

and to ensure food security it is essential to examine maize market integration.

Methodology

For this study, eight regional maize markets i.e., Hyderabad, Quetta, Peshawar, Lahore, Multan, Faisalabad, Gujranwala, and Sargodha, were selected to capture spatial price dynamics across Pakistan. Five markets were selected from Punjab, as it is a major producer of maize in Pakistan among all provinces, and one market has been selected from each province, Sindh, Baluchistan, and Khyber Pakhtunkhwa (KPK). From 1991 to 2023, prices were recorded to be 100 PKR per kilogram by using data from 396 monthly observations taken from the Bureau of Statistics and AMIS Pakistan. This 33 year long dataset is sufficient for analyzing both short and long-run price fluctuations.

The paper uses quantitative time series data analysis to comprehend maize market integration trends and issues. The estimation was conducted with econometric tools based on EViews and RStudio where key packages were used; urca (Pfaff, 2008) and tsDyn (Antonio et al., 2008; Stigler, 2010) were used in RStudio. The prices were converted into natural logarithms to minimize the price changes, enhance the stationarity of the first differences, and view first differences as growth rates and elasticity coefficients (Keho, 2021).

Statistical methods are used to study intermarket interactions. The Augmented Dickey-Fuller (ADF) test was used to test the concept of stationarity the first time. The pair-wise and joint cointegration tests were used to test the long-run equilibria and a Vector Error Correction Model (VECM) was used to estimate the short-term adjustment parameters. Nevertheless, traditional linear models usually cannot explain the market friction seen in the real world such as transaction costs, transportation delays and policy barriers that cause nonlinear price changes. In a bid to deal with these complexities, this study has used the Threshold Vector Error Correction Model (TVECM) that provides realistic perspective of the market behavior that examines both long-term market relationship and short-term fluctuations. Since this strategy is especially effective when developing countries are to be analyzed in the market in terms of wheat and rice, as Sahito (2015) emphasized.

Unit root tests, developed by Dickey and Fuller (1979, 1981). The basic model for this test is an autoregressive model of order 1 AR (1):

$$Y_t = \varphi Y_{t-1} + u_t$$

The model is reformulated by subtracting Y_{t-1} from both sides to simplify testing.

$$Y_t - Y_{t-1} = \varphi Y_{t-1} + Y_{t-1} + u_t$$

$$\Delta Y_t = (\varphi - 1)Y_{t-1} + u_t$$

$$\Delta Y_t = \beta Y_{t-1} + u_t$$

The test statistic β , equal to $(\varphi - 1)$, is used to test for the time series stationarity. The null hypothesis is $H_0: \beta = 0$, indicating a non-stationary time series, while the alternative hypothesis is $H_1: \beta < 0$.

$$\Delta Y_t = \alpha_0 + \beta Y_{t-1} + u_t$$

$$\Delta Y_t = \alpha_0 + \alpha_1 t + \beta Y_{t-1} + u_t$$

The Dickey-Fuller (DF) test determines the stationarity of a time series using the lagged dependent variable coefficient $\beta = 0$, and rejects the null hypothesis if the DF statistic is less than the crucial value.

The modified Dickey-Fuller test equations are expanded upon below:

$$\Delta Y_t = \beta Y_{t-1} + \sum_{i=1}^k \gamma \Delta Y_{t-i} + u_t$$

$$\Delta Y_t = \alpha_0 + \beta Y_{t-1} + \sum_{i=1}^k \gamma \Delta Y_{t-i} + u_t$$

$$\Delta Y_t = \alpha_0 + \alpha_1 t + \beta Y_{t-1} + \sum_{i=1}^k \gamma \Delta Y_{t-1} + u_t$$

Cointegration identifies long-term equilibrium relationships between non-stationary time-series variables. which is used in open economy macroeconomics to test market efficiency, dominance, and segmentation. The trace test, a method used to assess the number of cointegrating relationship, is based on the stochastic matrix and defined as follows:

$$\lambda_{trace} = -2\ln Q = -T \sum_{i=r+1}^p 1n(1 - \lambda_i)$$

$$\lambda_{max} = -2\ln(Q : r|r + 1) = -T\ln(1 - \lambda_{r+1})$$

The Vector Error Correction Model (VECM) analyzes time series variables with cointegration, capturing both short-term dynamics and long-term equilibrium and useful in econometric analyses, particularly in economics and finance. The following is a description of a bivariate VECM model:

$$\begin{bmatrix} \Delta P_{1t} \\ \Delta P_{2t} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \sum_{i=1}^k \begin{bmatrix} \beta_i^{P_1, P_1} & \beta_i^{P_1, P_2} \\ \beta_i^{P_2, P_1} & \beta_i^{P_2, P_2} \end{bmatrix} \times \begin{bmatrix} \Delta P_{1t-1} \\ \Delta P_{2t-1} \end{bmatrix} + \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

Where: $\Delta P_t = P_t - P_{t-1}$, one market's price series is P1, and the other market's pricing series is P2. The SupLM test (Hansen & Seo, 2002) examines threshold cointegration and nonlinear shifts, enhancing VECM by capturing real-world asymmetries in economic variables. The SupLM test statistics can be expressed as follows:

$$SupLM = sup_{\gamma^L \leq \gamma \leq \gamma^U} LM(\beta, \gamma)$$

Here, β is the estimated cointegration coefficient, λ the threshold parameter, $\gamma^L = \pi_0$ (lower regime trimming) and $\gamma^U = 1 - \pi_0$ (upper regime trimming) ensure sufficient sample sizes in threshold-based regimes.

$$\pi_0 \leq P(ECT_{t-1} \leq \gamma) \leq 1 - \pi_0$$

Balke and Fomby (1997) introduced threshold cointegration, where error-correction mechanisms activate only when deviations from equilibrium exceed a critical threshold, typically influenced by transaction costs or policy constraints. The Threshold Vector Error-Correction Model (TVECM) generalizes linear VECMs by allowing distinct adjustment processes across regimes.

$$\begin{aligned} \begin{bmatrix} \Delta P_{1t} \\ \Delta P_{2t} \end{bmatrix} &= \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \sum_{i=1}^k \begin{bmatrix} \beta_i^{P_1, P_1} & \beta_i^{P_1, P_2} \\ \beta_i^{P_2, P_1} & \beta_i^{P_2, P_2} \end{bmatrix} X \begin{bmatrix} \Delta P_{1t-1} \\ \Delta P_{2t-1} \end{bmatrix} + \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}, \text{ if } ECT_{t-1} \\ &\leq \gamma_1 \\ \begin{bmatrix} \Delta P_{1t} \\ \Delta P_{2t} \end{bmatrix} &= \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \sum_{i=1}^k \begin{bmatrix} \beta_i^{P_1, P_1} & \beta_i^{P_1, P_2} \\ \beta_i^{P_2, P_1} & \beta_i^{P_2, P_2} \end{bmatrix} X \begin{bmatrix} \Delta P_{1t-1} \\ \Delta P_{2t-1} \end{bmatrix} + \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}, \text{ if } ECT_{t-1} \\ &\leq \gamma_2 \\ \begin{bmatrix} \Delta P_{1t} \\ \Delta P_{2t} \end{bmatrix} &= \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \sum_{i=1}^k \begin{bmatrix} \beta_i^{P_1, P_1} & \beta_i^{P_1, P_2} \\ \beta_i^{P_2, P_1} & \beta_i^{P_2, P_2} \end{bmatrix} X \begin{bmatrix} \Delta P_{1t-1} \\ \Delta P_{2t-1} \end{bmatrix} + \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}, \text{ if } ECT_{t-1} \\ &\geq \gamma_2 \end{aligned}$$

Data analysis

To analyze the relationship between Pakistan's maize markets, quantitative analysis was used. Advanced econometric models and software were used, such as EViews, for time series analysis. Whereas for more advanced estimation, different packages of R software, like urca and tsDyn, to seek

more robust findings were used. The *urca* package was developed by Pfaff (2008), and the *tsDyn* package was developed by Antonio *et al.* (2008) and Stigler (2010).

Results

The results of Pakistan's maize market integration were investigated in this section, with a special focus on regional factors using cointegration, VECM, and TVECM. Before discussing the trends of wholesale prices of maize in Pakistan, and different estimations of the growth of the maize crop in detail, the statistics of the maize area, production, and yield are given for a brief overview of the economy of maize.

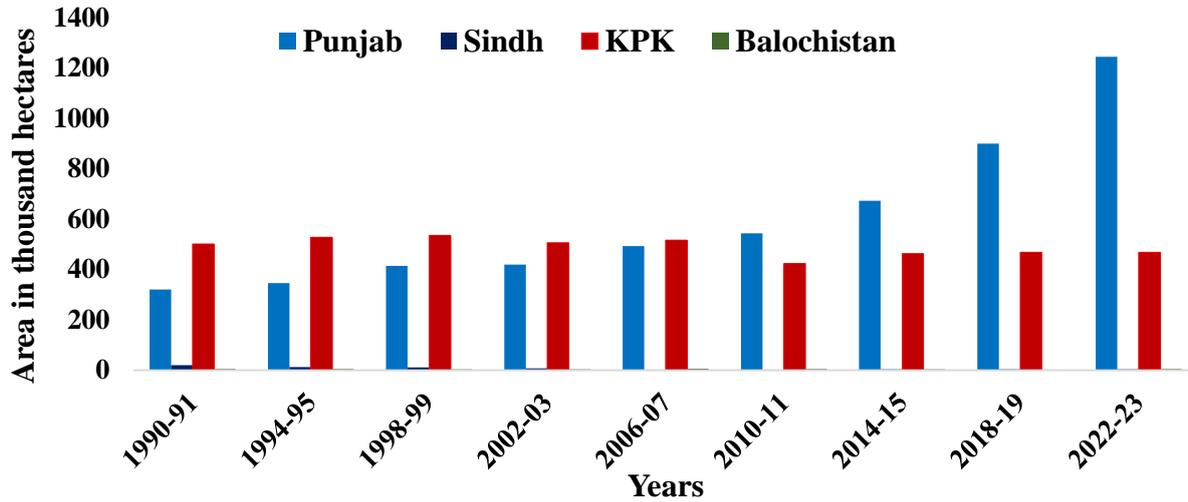


Figure 1. Province wise area sown under the maize crop in Pakistan
 Source: Agriculture Statistics of Pakistan, (Govt. of Pakistan, 2023).

Figure 1 illustrated that regional trends in maize cultivation area in Pakistan from 1990-91 to 2022-23. Punjab demonstrated substantial and accelerating growth, becoming the dominant producer by 2022-23, while KPK remains stable, and Sindh and Balochistan show minimal change. These numbers highlighted a pronounced regional disparity, with Punjab driving national expansion in maize cultivation.

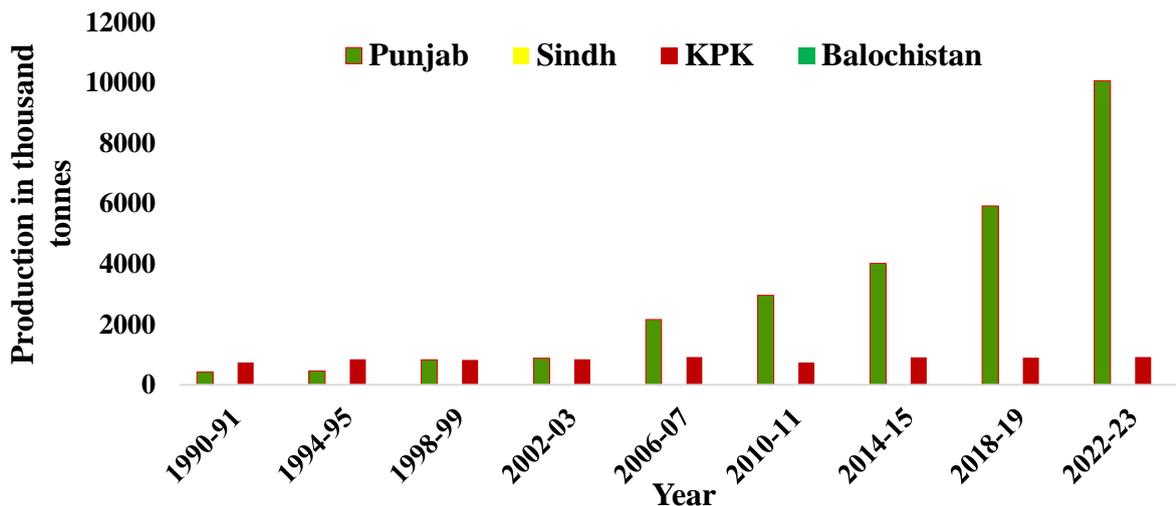


Figure 2. Province-wise production under the maize crop in Pakistan
 Source: Agriculture Statistics of Pakistan, (Govt. of Pakistan, 2023).

Figure 2 shows that maize production in Pakistan stood at about 10,985 thousand tonnes. The data showed that 91 percent (10055 thousand tonnes) of the national output of maize was produced by Punjab province and 8 percent (923.8 thousand tonnes) by Khyber Pakhtunkhwa (KPK). For instance,

maize production was less than 1 percent in Sindh (3.1 thousand tonnes) and Balochistan (3.2 thousand tonnes) provinces, as compared to production.

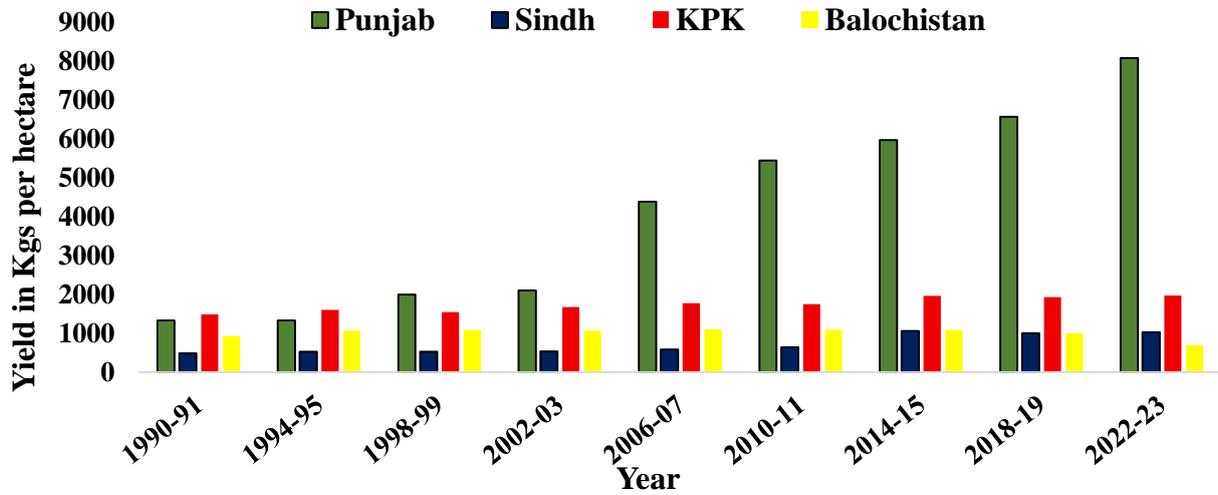


Figure 3. Province-wise yield under the maize crop in Pakistan
 Source: Agriculture Statistics of Pakistan, (Govt. of Pakistan, 2023).

Changes in maize yield (kgs per hectare) of the four provinces of Pakistan, namely Punjab, Sindh, Khyber Pakhtunkhwa (KPK), and Baluchistan, from 1990-91 to 2022-23 can be seen in Figure 3. Punjab witnessed a substantial growth in maize yields, accelerating significantly after 2005, becoming the leading province by 2022-23. KPK showed a more gradual trend, with marked and marginal variations only. Sindh and Baluchistan remained to a smaller extent, as yields have stayed basically unchanged over the duration of the investigation.

Figure 4 indicates the percentage growth rate for cultivated area, yield and total output of maize crops in Pakistan for 1991 through to 2023. The increase in the area of land cultivated was due in part to changes in agricultural policy and market ('the economy') forces, while improvements of yield were based on enhanced agricultural methods and the introduction of technology. The overall increase in production has resulted from both increased area cultivated and improved productivity to build a complete picture of the trends for maize output. The analysis of these patterns of growth can provide important insights into how changes in agricultural policy and advances in technology have affected maize production. The understanding of these trends is particularly important for addressing food security and economic challenges. Sindh and Balochistan's contribution to maize production has been relatively small.

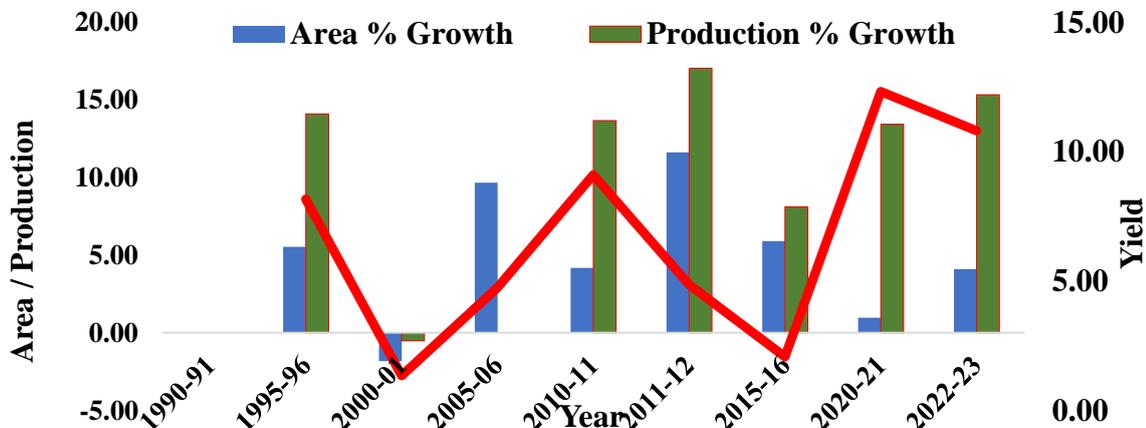


Figure 4. Present growth in area, yield and production of maize crop
 Source: (GoP, 2023).

The graph (Figure 5) showed that prices remained relatively stable in earlier years but gradually began to increase after 2007, with a sharp rise after 2019. By 2023, maize prices nearly doubled or tripled compared to a decade ago. Sharp increase suggested a substantial divergence; this could be because of inflation, higher production costs, and supply-demand imbalances.

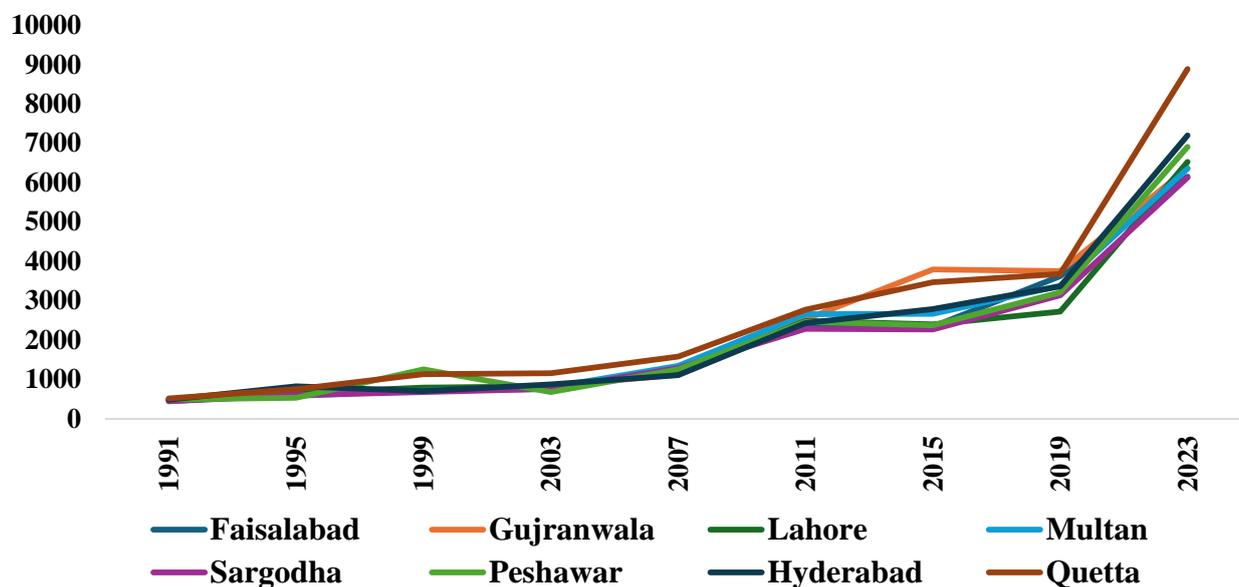


Figure 5. An analysis of wholesale prices of maize markets of Pakistan

Source: Agriculture Statistics of Pakistan, Govt. of Pakistan (2023)

The findings for the Augmented Dickey-Fuller (ADF) test (Table 1) for stationarity on time series data for maize markets in eight main markets in Pakistan showed that at levels, the test statistics were higher than the critical values, meaning the price series was non-stationary, indicating a unit root. However, after taking the first differences, the test statistics were much lower than the critical values, and the null hypothesis of a unit root was rejected. This confirms that the series becomes stationary after differencing. Result suggested that maize markets may have long-run equilibrium relationships, making them suitable for cointegration analysis.

Table 1: ADF test results for maize markets of Pakistan

Markets	Levels	1 st Differences
Faisalabad (LFSD)	- 1.426	- 21.505***
Gujranwala (LGWN)	-1.390	- 16.823***
Hyderabad (LHYD)	- 0.925	- 19.591***
Lahore (LLHR)	- 1.162	- 19.923***
Multan (LMLTN)	- 1.556	- 21.780***
Peshawar (LPSHWR)	- 1.004	- 15.939***
Quetta (LQUETTA)	- 1.366	- 16.012***
Sargodha (LSGD)	- 1.266	- 23.533***

Critical values at 1, 5 and 10 percent respectively are -3.454, -2.872, -2.572.

The Pairwise Cointegration Test for maize markets in Pakistan, given in the annexure section (Table 5), showed strong long-term equilibrium relationships among most market pairs. Most pairs exhibited significant cointegration at the 1 percent level for both Trace and Maximum eigenvalue statistics, indicating a 99 percent confidence level. However, Hyderabad-Quetta, Multan-Peshawar, and Peshawar-Quetta were cointegrated at 95 percent confidence level with certain exceptions being

caused by factors like market independence, geographical distance, and short-term shocks. The analysis has validated the close association of maize markets in Pakistan, which implies the coordinated movement in the long run, which is necessary in market efficiency and proper policymaking.

Table 2: Joint cointegration test results for maize markets of Pakistan

Equation Tested	H_0	H_1	The Trace Statistics	The Maximum Eigenvalue Statistics
LFSD	$r = 0$	$r \geq 1$	289.374 (159.529) ***	86.130 (52.362) ***
LGWN	$r \leq 1$	$r \geq 2$	212.244 (125.615) ***	74.408 (46.231) ***
LHYD	$r \leq 2$	$r \geq 3$	137.835 (95.753) ***	41.097 (40.077) ***
LLHR	$r \leq 3$	$r \geq 4$	96.738 (69.818) ***	40.352 (33.876) ***
LMLTN	$r \leq 4$	$r \geq 5$	56.386 (47.856) ***	26.170 (27.584) *
LPSHWR	$r \leq 5$	$r \geq 6$	30.215 (29.797) ***	22.029 (21.131) ***
LQUETTA	$r \leq 6$	$r \geq 7$	8.186 (15.494)	8.119 (14.264)
LSGD	$r \leq 7$	$r \geq 8$	0.067 (3.841)	0.067 (3.841)

Critical values at 95 percent confidence level are in parentheses.

The results of the Joint Cointegration test of the maize markets in Pakistan showed that there were strong long term equilibrium linkages with up to six cointegrating relationships being significant. The trace statistic and maximum eigenvalue statistics pass the critical value up to the 6th equation, and the additional cointegration of the remaining two (Quetta and Sargodha) markets does not add to the core group. There was also a single common stochastic trend indicated in the test which could have been caused by weather conditions, demand, and supply changes.

Analyses of the Pakistan maize markets were carried out using Vector Error Correction Model (VECM). The output from the linear VECM is presented in Table 3. The majority of pairs have statistically significant adjustment speeds, which provides evidence for strong evidence of adjustment in the short run to long-term disequilibrium. The negative adjustment values indicate a tendency to move back toward the long-term equilibrium; Faisalabad, Gujranwala, and Lahore have relatively rapid adjustments. Contrarily, the Hyderabad–Quetta and Peshawar–Sargodha markets tend to exhibit relatively slow adjusting rates.

Table 3: VECM Results for Maize Markets of Pakistan

Pairs of Market	Speed of Adjustment	Pairs of Market	Speed of Adjustment
LFSD-LGWN	-0.100*** 0.186***	LHYD-LMLTN	-0.068*** 0.123***
LFSD-LHYD	-0.135*** 0.076***	LHYD-LPSHWR	-0.025*** 0.028***
LFSD-LLHR	-0.153*** 0.148***	LHYD-LQUETTA	-0.020*** 0.072***
LFSD-LMLTN	-0.220*** 0.295***	LHYD-LSGD	-0.078*** 0.148***
LFSD-LPSHWR	-0.065*** 0.053***	LLHR-LMLTN	-0.129*** 0.146***
LFSD-LQUETTA	-0.081*** 0.091***	LLHR-LPSHWR	-0.052*** 0.054***
LFSD-LSGD	-0.140*** 0.281***	LLHR-LSGD	-0.080*** 0.179***
LGWN-LHYD	-0.137*** 0.047***	LMLTN-LPSHWR	-0.069*** 0.052***
LGWN-LLHR	-0.167*** 0.074***	LMLTN-LQUETTA	-0.066*** 0.098***
LGWN-LMLTN	-0.170*** 0.105***	LMLTN-LSGD	-0.025*** 0.026***
LGWN-LPSHWR	-0.066*** 0.038***	LPSHWR-LQUETTA	-0.025*** 0.056***
LGWN-LQUETTA	-0.072*** 0.087***	LPSHWR-LSGD	-0.025*** 0.076***

LGWN- LSGD	-0.120*** 0.096***	LQUETTA-LSGD	-0.093*** 0.122***
LHYD-LLHR	-0.075*** 0.098***		

Here: *, ** and *** show the significance at 10, 5 and 1 percent.

SupLM test was used on the price series of maize in Pakistan to test cointegration of thresholds at one lag and 5,000 bootstrap replications to determine critical values. The results of the analysis showed that there were significant threshold effects in 18 market pairs (e.g., Faisalabad-Lahore and Lahore- Multan), which means that the prices do not adjust linearly in response to the degree to which the system is not at equilibrium. This observation justifies the employment of a Threshold Vector Error Correction Model (TVECM) to model these dynamics. On the other hand, Table 4 indicated that pairs such as Faisalabad-Gujranwala and Sargodha-Hyderabad had no significant threshold effects, indicating smooth price transmission. The findings revealed the complicated price dynamics in the Pakistani maize markets, which were probably due to factors like market inefficiencies, transportation expenses, and policy interventions. Such nonlinear dynamics suggest that prices do not change gradually but change in regimes, which may not be identified in linear models.

Table 4: SupLM test estimates applied to the price series of maize markets of Pakistan

Market Pairs	Cointegration Vector	Threshold Parameter	SupLM Test Value	Critical Value	P-Value
LFSD-LGWN	-1.011	-0.274	8.759	18.298	0.956
LFSD-LLHR	-1.049	-0.374	24.566	20.933	0.021
LFSD-LMLTN	-0.986	0.070	20.219	18.127	0.041
LFSD-LSGD	-0.992	0.132	18.370	18.340	0.098
LFSD-LPSHWR	-1.002	-0.168	29.305	18.126	0.000
LFSD-LHYD	-1.005	-0.293	10.780	17.924	0.768
LFSD-LQUETTA	-1.080	-0.657	10.402	18.041	0.828
LGWN-LLHR	-1.044	-0.370	34.057	25.757	0.002
LGWN-LMLTN	-0.975	0.219	26.736	14.985	0.000
LGWN-LSGD	-0.982	0.163	20.539	17.805	0.028
LGWN-LPSHWR	-0.991	0.019	11.827	18.104	0.652
LGWN-LHYD	-0.993	0.087	29.460	29.989	0.063
LGWN-LQUETTA	-1.071	-0.691	26.309	22.698	0.023
LLHR-LMLTN	-0.940	0.473	33.967	14.824	0.000
LLHR-LSGD	-0.946	0.472	28.166	15.021	0.000
LLHR-LPSHWR	-0.958	0.241	36.286	28.207	0.003
LLHR-LHYD	-0.955	0.177	13.422	18.133	0.475
LLHR-LQUETTA	-1.028	-0.274	19.483	17.834	0.049
LMLTN-LSGD	-1.006	0.100	21.489	17.944	0.019
LMLTN-LPSHWR	-1.016	-0.218	24.041	17.934	0.005
LMLTN-LHYD	-1.016	-0.029	16.764	14.503	0.033
LMLTN-LQUETTA	-1.094	-1.041	8.809	17.603	0.932
LSGD-LPSHWR	-1.008	-0.125	24.660	17.935	0.005
LSGD-LHYD	-1.011	-0.322	14.998	14.318	0.074

LSGD-LQUETTA	-1.087	-0.709	10.289	17.718	0.850
LPSHWR-LHYD	-0.982	0.067	32.561	17.718	0.000
LPSHWR-LQUETTA	-1.077	-0.837	28.304	14.620	0.000
LHYD-LQUETTA	-1.086	-0.864	17.299	14.136	0.024

Table 5: Pairwise cointegration test results for maize markets of Pakistan

Market Pairs	H_0	H_1	The Trace Statistics	The Maximum Eigenvalue Statistics
LFSD-LGWN	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	31.00 (15.49)*** 0.41 (3.84)	30.59 (14.26)*** 0.41 (3.84)
LFSD-LHYD	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	35.95 (15.49)*** 0.41 (3.84)	35.88 (14.26)*** 0.07 (3.84)
LFSD-LLHR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	45.25 (15.49)*** 0.70 (3.84)	44.55 (14.26)*** 0.70 (3.84)
LFSD-LMLTN	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	63.70 (15.49)*** 0.44 (3.84)	63.25 (14.26)*** 0.44 (3.84)
LFSD-LPSHWR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	21.79 (15.49)*** 0.23 (3.84)	21.55 (14.26)*** 0.23 (3.84)
LFSD-LQUETTA	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	33.50 (15.49)*** 0.27 (3.84)	33.23 (14.26)*** 0.27 (3.84)
LFSD-LSGD	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	52.35 (15.49)*** 0.42 (3.84)	51.93 (14.26)*** 0.42 (3.84)
LGWN-LHYD	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	42.19 (15.49)*** 0.14 (3.84)	24.15 (14.26)*** 0.14 (3.84)
LGWN-LLHR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	29.24 (15.49)*** 0.46 (3.84)	28.78 (14.26)*** 0.46 (3.84)
LGWN-LMLTN	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	30.28 (15.49)*** 0.47 (3.84)	29.80 (14.26)*** 0.47 (3.84)
LGWN-LPSHWR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	19.13 (15.49)** 0.47 (3.84)	18.66 (14.26)*** 0.47 (3.84)
LGWN-LQUETTA	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	37.04 (15.49)*** 0.77 (3.84)	36.26 (14.26)*** 0.77 (3.84)
LGWN-LSGD	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	26.46 (15.49)*** 0.41 (3.84)	36.02 (14.26)*** 0.41 (3.84)
LHYD-LLHR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	28.93 (15.49)*** 0.09 (3.84)	28.83 (14.26)*** 0.09 (3.84)
LHYD-LMLTN	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	27.84 (15.49)*** 0.14 (3.84)	27.70 (14.26)*** 0.14 (3.84)
LHYD-LPSHWR	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	12.60 (15.49)** 0.53 (3.84)	12.06 (14.26)** 0.53 (3.84)
LHYD-LQUETTA	$r = 0$ $r \leq 1$	$r \geq 1$ $r \geq 2$	18.52 (15.49)** 0.19 (3.84)	18.32 (14.26)** 0.19 (3.84)
LHYD-LSGD	$r = 0$	$r \geq 1$	35.00 (15.49)***	34.94 (14.26)***

	$r \leq 1$	$r \geq 2$	0.05 (3.84)	0.05 (3.84)
LLHR-LMLTN	$r = 0$	$r \geq 1$	40.92 (15.49)***	40.51 (14.26)***
	$r \leq 1$	$r \geq 2$	0.40 (3.84)	0.40 (3.84)
LLHR-LPSHWR	$r = 0$	$r \geq 1$	23.01 (15.49)***	22.78 (14.26)***
	$r \leq 1$	$r \geq 2$	0.23 (3.84)	0.23 (3.84)
LLHR-LSGD	$r = 0$	$r \geq 1$	30.48 (15.49)***	30.01 (14.26)***
	$r \leq 1$	$r \geq 2$	0.46 (3.84)	0.46 (3.84)
LMLTN-LPSHWR	$r = 0$	$r \geq 1$	17.62 (15.49)**	17.28 (14.26)**
	$r \leq 1$	$r \geq 2$	0.33 (3.84)	0.33 (3.84)
LMLTN-LQUETTA	$r = 0$	$r \geq 1$	32.78 (15.49)***	32.34 (14.26)***
	$r \leq 1$	$r \geq 2$	0.44 (3.84)	0.44 (3.84)
LMLTN-LSGD	$r = 0$	$r \geq 1$	67.23 (15.49)***	66.78 (14.26)***
	$r \leq 1$	$r \geq 2$	0.45 (3.84)	0.45 (3.84)
LPSHWR-LQUETTA	$r = 0$	$r \geq 1$	17.71 (15.49)**	17.42 (14.26)**
	$r \leq 1$	$r \geq 2$	0.28 (3.84)	0.28 (3.84)
LPSHWR-LSGD	$r = 0$	$r \geq 1$	28.05 (15.49)***	27.08 (14.26)***
	$r \leq 1$	$r \geq 2$	0.971 (3.84)	0.97 (3.84)
LQUETTA-LSGD	$r = 0$	$r \geq 1$	36.43 (15.49)***	36.16 (14.26)***
	$r \leq 1$	$r \geq 2$	0.26 (3.84)	0.26 (3.84)

Critical values at 95 percent confidence level are in parentheses.

The Threshold Vector Error Correction Model (TVECM), given below in the Table 6 provides a comprehensive analysis of the maize markets in Pakistan, and it differentiates between the integrated markets and the ones that experience adjustment challenges. Unlike the conventional models, TVECM embraces long transaction cost and divides the market into three regimes depending on the price levels: lower, middle and upper. Markets in the lower regime like Faisalabad-Lahore and Gujranwala-Lahore are highly integrated with a fast and substantial price correction, which implies that there is a high level of integration and the equilibrium is well reinstated. The middle regime is a band of non-adjustment, where small deviations in prices would not attract any market reaction because the transaction costs would equalize the gains of adjustment. Conversely, in the upper regime, the adjustment of prices was slow and less responsive, which was indicative of inefficiency and increased transaction costs in high-price periods. The analysis also indicates asymmetric adjustments, whereby certain markets respond more to price changes in a given direction. The findings indicate the need to reduce trade barriers and enhance infrastructure to enhance market integration and resilience, which eventually leads to food security and economic stability in Pakistan.

Table 6: TVECM results of maize markets of Pakistan

Market Pairs	Tiers	Speed of Adjustment	Constant	ΔP_{1t-1}	ΔP_{2t-1}
LFSD-LGWN	Lower Tier	-0.080	0.008	-0.031	0.025
		-0.024	-0.046	0.261	-0.333**
	Middle Tier	-0.240	0.003	-0.033	0.057
		0.149	0.016	-0.006	0.086
	Upper Tier	-0.401	0.071	-0.127	0.150
		-1.306	0.064		0.110
				0.096	

LFSD-LLHR	Lower Tier	-0.297** 0.223**	-0.017 0.019	0.087 0.078	0.034 0.056
	Middle Tier	1.565 1.390	0.039 0.059***	-0.217 -0.259	-0.412 -0.086
	Upper Tier	-0.069 0.143	-0.011 -0.000	-0.086 0.073	0.247 -0.074
LFSD- LMLTN	Lower Tier	0.007 0.426***	0.039*** 0.027	-0.041 -0.046	0.001 0.072
	Middle Tier	0.057 0.556	-0.006 -0.018	0.147 0.147	0.017 -0.103
	Upper Tier	-0.268 0.590**	-0.015 -0.059	0.033 0.271	-0.018 -0.105
LFSD-LLSD	Lower Tier	0.089 0.332***	0.036 -0.015	-0.207 -0.216	0.081 -0.151
	Middle Tier	-0.134 -1.693	-0.002 -0.049	0.428** 0.166	-0.075 0.162
	Upper Tier	-0.367*** 1.396	0.038*** 0.016	-0.080 -0.012	-0.026 -0.048
LFSD-LPSHWR	Lower Tier	0.022 -0.062	0.029 -0.047***	-0.238 -0.036	0.532** 0.392***
	Middle Tier	-0.064 0.079	0.011 0.009	0.142 0.102	0.046 0.121
	Upper Tier	0.118 0.282***	-0.053 -0.045	-0.142 0.097	-0.100 0.072
LFSD-LHYD	Lower Tier	0.034 0.366***	0.032 0.096***	-0.412** 0.018	-0.512 0.171
	Middle Tier	-0.146 0.104	0.003 0.006	0.072 -0.030	0.117 0.162
	Upper Tier	-0.059 0.046	-0.020 0.011	0.094 0.061	-0.346 -0.259**
LFSD-LQUETTA	Lower Tier	-0.119 0.075	-0.008 0.005	-0.146 0.088	0.046 0.149
	Middle Tier	-0.417** 0.066	0.032 0.006	0.104 -0.124	-0.218 0.253**
	Upper Tier	-0.182 0.009	0.053 0.021	-0.007 0.050	-0.103 0.385**
LGWN-LLHR	Lower Tier	-0.605** 0.316	-0.004 0.039	0.205 0.010	-0.025 -0.072x`
	Middle Tier	0.370 0.721	0.031 0.034**	-0.005 0.028	0.139 -0.024
	Upper Tier	-0.040 0.096	-0.015 -0.003	-0.085 -0.012	0.134 0.105
	Lower Tier	0.018 0.184	0.039*** 0.017	0.031 0.029	0.014 -0.023

LGWN-LMLTN	Middle Tier	0.068 0.832	-0.010 -0.036	0.081 -0.031	0.107 0.114
	Upper Tier	-0.088 0.174	-0.019 -0.024	-0.194 0.037	0.135 -0.182
LGWN-LSGD	Lower Tier	-0.014 0.125	0.045*** 0.006	-0.044 -0.141	-0.078 -0.215**
	Middle Tier	-0.405 0.037	0.016 0.001	0.159 0.232	0.266** 0.104
	Upper Tier	0.101 0.022	0.003 0.022	0.003** -0.160	0.062 -0.109
LGWN- LPSHWR	Lower Tier	0.0607 -0.001	0.051 -0.011	-0.183 0.073	0.077 0.390**
	Middle Tier	-0.143 0.026	0.012 0.002	0.128 -0.001	0.078 0.221***
	Upper Tier	-0.142 -0.010	0.032 0.029	-0.341 -0.109	0.209 0.043
LGWN- LHYD	Lower Tier	-0.144** 0.096**	-0.000 0.013**	0.040 -0.029	0.166 -0.029**
	Middle Tier	-0.764 -0.088	0.099 0.025	-0.377 0.008	-0.040 -0.215
	Upper Tier	-1.073*** -0.104	0.252*** 0.032	0.512 0.055	0.224 -0.467**
LGWN- LQUETTA	Lower Tier	-0.110 0.035	-0.002 -0.002	-0.014 -0.044	0.016 -0.044
	Middle Tier	-0.036 0.131**	-0.004 0.013**	-0.031 -0.032	-0.031*** 0.350***
	Upper Tier	-1.001*** 0.129	0.246*** -0.009	0.532*** -0.070	1.768*** 0.085
LLHR-LMLTN	Lower Tier	-0.161 -0.017	-0.017 -0.053	-0.113 -0.373	-0.113 0.244
	Middle Tier	-0.354 -0.286	0.030*** 0.006	0.039 -0.016	0.022 -0.012
	Upper Tier	-0.200 0.104	-0.200 0.006	0.069 0.195	0.063 -0.217
LLHR-LSGD	Lower Tier	-0.031 0.160	0.013 0.013	-0.157 -0.172	0.031 0.186
	Middle Tier	-0.158 0.419**	0.017 -0.028	0.144 0.222	0.105 0.052
	Upper Tier	-0.123 0.123	0.012 0.012	-0.077 0.021	0.024 -0.240
LLHR- LPSHWR	Lower Tier	-0.025 -0.030	0.006 -0.023	-0.155 -0.082	0.174 0.258
	Middle Tier	-2.202*** -0.475	-0.037 -0.033**	0.324 -0.242	-0.006 0.274

	Upper Tier	-0.128 0.054	0.021 0.006	0.051 0.123	0.115 0.191**
LLHR-LHYD	Lower Tier	-0.066 0.078***	0.006 0.006	0.041 0.014	0.128 0.064
	Middle Tier	-0.153 0.000***	0.058 0.030	0.023 0.498	0.027 0.575
	Upper Tier	-0.707 -0.181	0.075 0.100	0.732** 0.221	-1.346*** -0.913
LLHR-LQUEETA	Lower Tier	-0.145 0.091	-0.018 0.011	0.060 -0.063	0.156 0.114
	Middle Tier	-0.531** 0.076	0.017 0.014	0.267 -0.187	-0.403** 0.451***
	Upper Tier	-0.289*** 0.071	0.080*** 0.006	-0.150 0.001	0.345 0.347
LMLTN-LSGD	Lower Tier	0.185 0.665***	0.063 0.040	-0.295 -0.102	0.198 0.030
	Middle Tier	-0.304 0.429	-0.003 0.000	-0.296 -0.061	-0.029 -0.037
	Upper Tier	-0.422*** 0.023	0.037*** 0.025	0.091 0.054	-0.002 -0.078
LMLTN-LPSHWR	Lower Tier	0.004 -0.000	0.017 -0.012	-0.323** -0.013	0.443** 0.470***
	Middle Tier	-0.236* 0.121	0.005 0.006	0.077 0.003	-0.205 0.185**
	Upper Tier	-0.285 0.294**	0.033 0.294	0.159 -0.008	0.240 -0.026
LMLTN-LHYD	Lower Tier	-0.203 0.124	-0.045 0.014	-0.526*** 0.025	0.174 0.263
	Middle Tier	-0.253 0.072	0.025*** 0.007	0.171 0.073	-0.115 0.050
	Upper Tier	0.000 0.008	-0.037 0.002	0.096 -0.066	0.008 -0.115
LMLTN-LQUETTA	Lower Tier	-0.124 0.108	-0.015 0.020	-0.181 -0.031	0.015 0.162**
	Middle Tier	-0.477 0.472***	-0.022 0.023**	0.064 -0.080	-0.437** 0.039
	Upper Tier	-0.191 0.053	0.028 0.007	0.032 -0.046	0.248 0.791***
LSGD-LPSHWR	Lower Tier	0.039 -0.022	0.036 -0.025	-0.269 -0.012	0.233 0.356***
	Middle Tier	0.077 0.226	0.003 -0.007	0.118 0.022	0.391 0.282**
	Upper Tier	-0.304*** -0.001	0.057*** 0.020	-0.147 0.014	0.078 0.082

LSGD-LHYD	Lower Tier	-0.086 0.190	-0.012 0.035	-0.440*** 0.036	-0.028 0.356**
	Middle Tier	-0.191 0.081	0.003 0.009	0.084 0.004	-0.006 0.008
	Upper Tier	-0.296*** -0.029	0.076** 0.040***	-0.271 0.040	-0.463 -0.218
LSGD-LQUEETA	Lower Tier	-0.182** 0.056	-0.022 0.005	-0.074 -0.068	-0.007 0.197***
	Middle Tier	-0.398 0.037	0.022 0.007	-0.178 -0.024	0.009 0.211
	Upper Tier	-0.550*** -0.012	0.167*** 0.045	0.055 -0.055	-0.163 0.316
LPSHWR-LHYD	Lower Tier	0.001 -0.009	0.011 -0.008	0.046 0.001	0.005 -0.053
	Middle Tier	0.746 0.612	-0.033 -0.016	0.490*** 0.158	0.067 0.233
	Upper Tier	0.014 -0.024	-0.019 0.026**	0.294*** 0.160	-0.087 -0.121
LPSHWR-LQUETTA	Lower Tier	-0.060 0.083	-0.012 0.014	0.003 0.104	-0.005 0.104
	Middle Tier	0.046 0.121	0.021** 0.015	0.347*** 0.209*	0.018 0.042
	Upper Tier	0.010 0.066	-0.015 0.001	0.358*** 0.034	0.183 0.519***
LHYD-LQUETTA	Lower Tier	0.010 0.074	0.018 0.015	-0.598*** -0.197	-0.096 0.131
	Middle Tier	0.008 0.033	0.005 0.003	0.167** 0.050	-0.007 0.107
	Upper Tier	0.063 0.028	-0.018 0.0261	-0.062 0.048	0.272 0.869***

Here: **, and *** show the significance at 5 and 1 percent.

Discussion

The paper examined the integration of maize markets in Pakistan using a sophisticated econometric framework of the Threshold Vector Error Correction Model on the monthly wholesale prices of eight major markets using data from 1991 to 2023. The findings indicate a high level of long-run integration in regional maize markets, indicating that price information flows efficiently, and that the markets are responding to long-run shocks in a coordinated manner, but still inefficiencies persist in short-run mainly due to transaction costs, poor infrastructure, and policy constraints. The key markets like Lahore and Faisalabad have become the main centres of price convergence, but the peripheral markets like Quetta and Sargodha are responding slowly, reflecting structural weaknesses. Further, the findings of this study are consistent with the previous research findings of the same topic in India (Rani et al., 2017), Ethiopia (Kidane, 2022), and Bangladesh (Alam et al., 2022), where the speed of adjustment differed depending on the region and commodity. The findings are contrasted with the past Pakistani

research studies carried out on other cereal markets, which mainly used linear VECM models, but the current research used the Threshold VECM, which allowed the researchers to develop a more subtle model of nonlinear processes and threshold-driven changes. In line with the findings of the Sahito (2015) study that highlighted the use of advanced econometric tools, the findings highlighted the need to improve the transport networks, storage facilities and market connectivity as well as policy reforms to improve efficiency, resilience and national food security.

Conclusion & Suggestions

This paper concludes that according to the findings of VECM and TVECM, there is a high and long-term integration in the maize markets of Pakistan. Transaction costs, poor infrastructure, and often subject to regulatory hurdles were also observed to be the major causes of short-run inefficiencies. The convergence is slow in the peripheral regions, and central markets are the driving force, which makes it necessary to implement certain policies and better connections. The study proposes a number of policy reforms to help overcome these issues in order to realise the best potential of the maize sector in terms of food security and economic development. The most important of these is the investment in infrastructure (particularly in less developed areas like Sindh and Balochistan), the decrease in trade barriers, and the encouragement of the involvement of the private sector. Key measures include digital platform market access, market information systems, policy reforms and intra-regional trade. By enhancing food security through establishing regional reserves and building food security networks for shock resistance, they can also stabilize food supplies. The initiatives will benefit farmers and consumers in addition to enhancing the overall economic resilience and food security of Pakistan.

Author Contribution

All authors contributed equally from idea development to data collection, analysis, and manuscript writing.

Conflict Of Interest

There is no conflict of interest.

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