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Price dynamics and market integration of tomato markets in India

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Abstract The current study uses the Johansen co-integration, Vector Error Correction model, and Granger causality test to investigate the level of market integration and price transmission in the key tomato markets in India. From January 2010 to March 2020, the study examined weekly average tomato pricing data (Rs/quintal) collected from specific markets in Kolar, Srinivaspur, Bangalore (production markets), Chennai, Kolkata, Pimpalgaon, and Delhi (consumption markets). The findings provided substantial evidence for the co-integration and interdependence of these market places in India. However, the rate of price adjustment was found to be moderate across all markets, and as a result, prices only correct a tiny portion of the market's disequilibrium, with external and internal forces accounting for the majority of the correction. Since there is unidirectional causality from Kolkata to Kolar markets, it makes it necessary for future research to examine the influence of internal and external factors like market infrastructure. It also calls for improving information technology to allow for the regular flow of market information to assist farmers in increasing their income.

Keywords Market integration, Agriculture, Indian markets, Granger causality

JEL codes Q11, Q13

No Indian kitchen is complete without tomato. Market integration is especially important because it promotes the efficient operation of well-integrated markets, which pay producers a fair price and enable consumers to purchase a commodity at a fair price. Price stability promotes high level of economic activity while preventing extended inflation or deflation. One of the signs of the existence of effective market functioning is the high degree of market integration. Because co-integrated markets are always competitive and efficient, market efficiency and competitiveness are positively correlated with co-integration of markets. Integration has an impact on how businesses behave in market places and how effectively they sell. Market integration is a requirement for maintaining regional price stability in both domestic and international markets (Mukim et al. 2009).

Data and methodology

Study area and data source: The present study has used secondary weekly wholesale average prices data from January 2010 to March 2020 from Kolar, Bangalore, Srinivaspur, Chennai, Kolkata, Delhi and Pimpalgaon markets. Kolar was taken as the central/ reference market.

In this study, ADF, KPSS and Zivot Andrews tests were employed to examine the unit root properties of data generating process (DGP). Prices of many agricultural products exhibit definite seasonal patterns which reflect the various marketing practices of farmers and market intermediaries as well as the natural biological lag processes that govern production.

Johansen's Co-integration test: Johansen's co-integration method serves as the foundation for the co-integration study. The Johansen's maximum likelihood approach was utilised to tackle the estimation of the co-integration vectors. Any p-dimensional vector autoregression can be expressed in the following "error correction" form, according to Johansen and Juselius (1990):

$$\Delta X_t = \sum_{t-1}^{k} \Delta X_{t-1} + \prod X_{t-k} + \mu + \varepsilon \quad (1)$$

Where;

X_t = p-dimensional vector of I (1) processes, μ = A constant, ε_t = A p-dimensional vector with zero mean (Δ is the variance– covariance matrix).

The Π matrix has a rank that is limited in the interval (0, r) and can be decomposed into components as follows; $\Pi = \alpha\beta'$ where; α, β p×r matrices, r: distinct co-integrating vectors. Johansen and Juselius Co-integration test procedure uses two tests to determine the number of co-integration vectors: The Maximum Eigen value test and the Trace test. The Maximum Eigen value statistic tests the null hypothesis of "r" co-integrating relations against the alternative of "r+1" co-integrating relations for r = 0, 1, 2…n-1.

Threshold model: Threshold models have been widely applied. Following the notation in Enders and Siklos (2001), the approach was employed in our study. This model permits a different speed of adjustment depending on the value of the error correction term (ECT). Popular specifications include the threshold autoregressive (TAR) and the momentum-TAR (M-TAR) models. Enders and Siklos (2001) discussed use of the Heaviside indicator produces; the threshold autoregressive model which can be expressed as

$$\Delta\mu_t = I_t\rho_1\mu_t + (1 - I_t)\rho_2\mu_{t-1} + \sum_{i=1}^{p} \gamma\Delta\mu_{t-1} + \omega_t \quad (2)$$

Where I_t is the Heaviside indicator function such that

$$I_t = \begin{cases} 1 \; if \; \mu_{t-1} \geq \tau \\ 0 \; if \; \mu_{t-1} \leq \tau \end{cases} \quad (3)$$

and τ is the value of the threshold, ω_t is a sequence of zero-mean, constant variance iid random variables, such that ω_t is independent of μ_t, J < t. The adjustment is symmetric if the speed of adjustment coefficients $\rho_1 = \rho_2$, and hence become a special case of Engle-Granger approach in equation $\Delta\mu_t = \rho\mu_t + s_t$. The lagged dependent variable was included to ensure the residuals were white noise and the lag length was selected using AIC or BIC. If the system is convergent then the long-run equilibrium value of the sequence is given by $\mu_t = \tau$. In such cases, adjustment is ρ_1 if μ_{t-1} is above its long-run equilibrium value and ρ_2 if μ_{t-1} below long-run equilibrium. If for instance $-1 < \rho_1 < \rho_2 < 0$, then the negative phase of the μ_t series will tend to be more persistent than the positive phase.

If the Heaviside indicator function depends on μ_{t-1} as in equation (3), then equation (4) is termed Threshold Autoregressive model (TAR). However, when the Heaviside indicator depends on the previous period's change in μ_{t-1}, *i.e.* Momentum Heaviside Indicator: then equation (4) is called Momentum-threshold autoregressive (M-TAR) model in that the $\rho_{5ØaÜ}$ series exhibit more "momentum" in one direction than the other. For M-TAR, if $|\rho_1| < |\rho_2|$, then the model exhibits little adjustment for positive but substantial decay for negative, thus, increases tend to persist but decreases tend to revert quickly to the attractor irrespective of where disequilibrium is relative to the attractor.

According to Enders and Granger (1998), M-TAR representation may capture sharp movements in a sequence while TAR is used to capture a deep-cycle process if, e.g. positive deviations are more prolonged than negative deviations. There is generally no presumption as whether to use TAR or M-TAR model, the recommendation is to select the adjustment process by a model selection criterion such as AIC or BIC.

The null hypothesis tested in the threshold model was no co-integration which is based on a nonstandard joint F-test of $\rho_1 = \rho_2 = 0$. The test statistic i (i = *TAR*, *MT*) was compared to critical values provided by Enders and Siklos (2001) when the point estimates of ρ_1 and ρ_2 imply convergence ($\rho_1 < 0$, $\rho_2 < 0$), alternatively the maximum t-statistic $t - max_i$, where i = *TAR*, *M-TAR* can be used. When the null hypothesis of no co-integration is rejected, then a standard F-test of symmetric adjustment can be performed by testing if $\rho_1 = \rho_2$. Rejection of both null hypotheses $\rho_1 = \rho_2 = 0$ and $\rho_1 = \rho_2$ imply the existence of threshold co-integration and asymmetric adjustment (thus price pairs exhibit nonlinear adjustment). The distribution of the test of the null of no co-integration is nonstandard and depends on the number of regressors included in the equation and the deterministic components.

According to Enders and Siklos (2001), τ is set to zero in most economic applications so that the cointegrating vector coincides with the attractor. However, in many applications, there is no a priori reason to expect the threshold to coincide with the attractor and therefore it becomes necessary to estimate the value of r along with the values of $\rho_1 = \rho_2$. Omitting the presence of threshold effects in the long-run equilibrium relationships will lead to misleading interpretations of equilibrium relationships because the co-integrating vector will not be consistently estimated (Gonzalo and Pitarakis, 2006).

In both the models, however, Chan's (1993) methodology which allows a grid search over potential thresholds that minimize the sum of squared errors from the fitted model to yield a super consistent estimate of the threshold was adopted. Thus, the estimated residuals were sorted in ascending order $\mu_1<\mu_2<\mu_3<\mu_4<\ldots\mu_t$ for TAR and $\Delta\mu_1< \Delta\mu_2<\Delta\mu_3< \Delta\mu_4<\ldots\Delta\mu_t$ for MTAR where T denotes the number of usable observations. The largest and smallest 15 percent of the values were eliminated and each of the remaining 70 percent of the series μ_t was considered as potential threshold.

Error Correction Method (ECM): The specification of standard VECM is given below

$$\Delta Y_t = \boldsymbol{\alpha_1} + \boldsymbol{\rho_1 e_1} + \sum_{i=0}^{n} \boldsymbol{\beta_1}\,\Delta Y_{t-i} + \sum_{i=0}^{n} \boldsymbol{\delta_1}\,\Delta X_{t-i} + \sum_{i=0}^{n} \boldsymbol{\gamma_1}\,\Delta Z_{t-i} \tag{4}$$

$$\Delta X_t = \boldsymbol{\alpha_1} + \boldsymbol{\rho_2} e_{i-1} + \sum_{i=0}^{n} \beta_i\,\Delta Y_{t-i} + \sum_{i=0}^{n} \delta_i\,\Delta X_{t-i} + \sum_{i=0}^{n} \gamma_i\,\Delta Z_{t-i} \tag{5}$$

The error correction representation sheds more light on the adjustment process in both short-run and long-run responsiveness to price changes which generally reflects arbitrage and market efficiency (Abunyuwah, 2007). The use of co-integration and error correction models help to explore further notions such as completeness, speed and asymmetry of price relationships as well as the direction of causality between two markets. The number of lags to be incorporated in the model before estimating the ECM will be determined using Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC).

Granger Causality Test: The presence and causality direction of long-run market price relationship can be assessed by using the Granger causality test directed within vector auto regressive (VAR) model. An autoregressive distributed lag (ADL) model for the Granger-causality test had been specified as below:

$$X_0 = \sum_{i=1}^{n} \alpha_i\, Y_{0-i} + \sum_{i=1}^{n} \beta_i\, X_{0-j} + \mu_1 \tag{6}$$

$$Y_0 = \sum_{i=1}^{n} \lambda_i\, Y_{0-i} + \sum_{i=1}^{n} \delta_i\, X_{0-j} + \mu_2 \tag{7}$$

Where,

μ_1 & μ_2 are error terms

t = time period,

X_0 & Y_0 are the price series of two different markets

To test the pattern of causality between two markets, F test was used.

The null hypothesis H_0: The lagged X_0 does not granger cause Y_0

The Alternative hypothesis H_1: The lagged X_0 granger cause Y_0

Here F statistic must be used in combination with the p value when deciding about the significance of the results.

If p value is less than the alpha level, individual p values are studied to find out which of the individual variables are statistically significant.

Results and discussion

Price instability

Prices of the agricultural commodities are influenced by many factors. The role of market intermediaries, domestic supply-demand mismatch due to the cob-web phenomenon in the market as well as the biological lags in the production process, weather and climatic factors influence the dynamic behavior in the agricultural price fluctuation. The higher growth of production with less instability would help in achieving sustainable growth. Analysis of fluctuations of prices

Table 1 Results of Cuddy Della Valle Index

Market	CV	Cuddy Della Valle
Kolar	72.54	70.59
Srinivaspur	76.15	74.92
Bangalore	76.16	74.93
Kolkata	54.43	51.65
Delhi	56.52	55.9
Chennai	67.84	65.86
Pimpalgaon	63.48	63.29

of commodities helps in knowing the nature of supply and demand conditions.

As per the results of Cuddy Della Valle Index value presented in Table 1, all the markets are considered to be highly unstable. Among the selected markets for study, Bangalore, Srinivaspur and Kolar markets (production markets) have highest instability with 74.93, 74.93 and 70.59 per cent, respectively. These values represent existence of very high instability in the prices of tomatoes in the markets considered. This may also lead to wholesale price inflation in the domestic markets, which, in turn, would reduce the consumption behavior of households. Further, the instability associated with the consumption markets (Kolkata, Delhi, Chennai and Pimpalgaon) is relatively less compared to production markets thereby indicating the scope for moving tomatoes from the production markets to distant consumption markets.

Correlation matrix

The results of the correlation matrix in Table 2 reveal that Chennai and Pimpalgaon markets were weakly correlated in prices. However, Kolar, Srinivaspur, and Bangalore markets were highly correlated in prices, due to the fact that these markets are located near to each other. Pimpalgaon market was weakly correlated with the other markets except with Delhi market, which is moderately correlated. Correlation coefficients however, are not a proof of market integration but rather are rough indicators of integration and efficiency. There have been criticisms against this approach by several authors such as Barrett (1996) and Negassa *et al.* (2003) who argued that testing of market integration based on correlation coefficients of local prices mask presence of other synchronous factors such as general price inflation, seasonality and population growth among others.

Unit root tests

The test of co-integration begins with the test of stationarity at different levels. Table 3 presents results of the evaluation of the univariate time series properties of the price series of the markets under study. Three different tests were conducted to verify the presence of a unit root in individual price series; an Augmented Dickey- Fuller (ADF) test, KPSS test and Zivot-Andrews test.

The test statistic rejected the null hypothesis of a unit root at level data for all the markets in the ADF, while KPSS test accepted (These tests have contradictory null hypothesis). To confirm the existence of a unit root in each price series with trend as deterministic part, the Augmented Dickey- Fuller (ADF) test was carried out. For all markets, the test statistic was unable to disprove the null hypothesis of a unit root in level data. As a result, it may be inferred that the markets are integrated into one another and have a similar long-run dynamic system.

Table 2 Zero Order Correlation Matrix for tomato prices

Markets	Kolar	Srinivaspur	Bengaluru	Kolkata	Delhi	Chennai	Pimpalgaon
Kolar	1						
Srinivaspur	0.878	1					
Bengaluru	0.797	0.836	1				
Kolkata	0.711	0.729	0.649	1			
Delhi	0.599	0.582	0.549	0.788	1		
Chennai	0.870	0.904	0.828	0.712	0.579	1	
Pimpalgaon	0.335	0.274	0.257	0.404	0.503	0.266	1

Note The correlation coefficients are significant at 0.01 level of probability

Table 3 Unit root tests for tomato markets

Market	ADF level	KPSS level
Kolar	-5.91[a]	0.82
Srinivaspur	-5.88[a]	0.42
Bangalore	-6.64[a]	0.44
Kolkata	-5.78[a]	0.92
Delhi	-5.99[a]	0.33
Chennai	-5.77[a]	0.73
Pimpalgaon	-6.11[a]	0.23

Note [a] denotes significance at 0.01 level of probability. The critical value for ADF at 1 is -3.98 for constant and trend specification.

The Zivot-Andrews unit root test, which allows for a single break point, was used to examine the structural break issue. Where t-Min is the minimum ADF test statistic and the probable break date is obtained, the break in intercept, trend, and both were taken into consideration. The test statistic was successful in rejecting the null hypothesis of unit root process when compared with the critical values (Table 4). All the tests for stationary/ unit root tests rejected the null hypothesis at level. This implies that the markets are integrated of the same order and share common long-run dynamics stochastic process. This test was used mainly to overcome the disadvantages of ADF test.

Co-integration

The approach for testing the integration of spatially separated markets is based on the fact that deviations from equilibrium conditions of two non-stationary variables should be stationary. This implies that, while price series may ramble extensively, market pairs should not diverge from one another in the long run (Abdulai, 2007).

Table 4 Zivot Andrews Unit Root test under Single Break Point

Market	Level	Potential break position	Date
Kolar	-5.7584[b]	359	17-Nov-17
Srinivaspur	-5.2426[b]	360	24-Nov-17
Bangalore	-8.3913[b]	360	24-Nov-17
Kolkata	-4.9683[b]	362	8-Dec-17
Delhi	-5.2908[b]	361	1-Dec-17
Chennai	-6.2738[b]	285	17-Jun-16
Pimpalgaon	-5.8263[b]	292	5-Aug-16

Note [b]denotes significance at 0.05 level of probability. The critical value for the test statistic at 95 per cent confidence level was -4.80.

Johansen Test of Co-integration

On the basis of the ADF test, the Johansen co-integration test frame work was employed to examine the long run equilibrium relationship among the selected markets of tomato and depicted in Table 5. The results were successful in rejecting the null hypothesis and confirming that there exists a co-integration between the markets. The results were found in accordance with the research conducted by Chandraprabha (2012), in which the author analysed the market co-integration between Kolar and Vaddahalli markets and found these markets to be co-integrated. From the results of Johansen co-integration test, it can be concluded that the selected markets exhibit long run co-integration between the market pairs.

Threshold and asymmetric transmission modeling

Here, test for possibilities of asymmetric adjustments and threshold Co-integration (non-linearity) other than assuming symmetric and linear relations as in the Johansen tests, were tested. In this regard, the Threshold Auto Regression (TAR) and its extension model called

Table 5 Johansen's co-integration test for selected tomato markets

Market pair	Null hypotheses	Trace statistic
Kolar-Srinivaspur	$r = 0$	69.6[a]
	$r \leq 1$	33.21[a]
Kolar-Bengaluru	$r = 0$	132.1[a]
	$r \leq 1$	33.47[a]
Kolar-Kolkata	$r = 0$	70.18[a]
	$r \leq 1$	30.14[a]
Kolar-Delhi	$r = 0$	91.58[a]
	$r \leq 1$	38.26[b]
Kolar-Chennai	$r = 0$	94.72[a]
	$r \leq 1$	32.45[b]
Kolar-Pimpalgaon	$r = 0$	94.6[b]
	$r \leq 1$	31.19[b]

Note [a] and [b] denote significance at 1 per cent and 5 per cent level of probability.

a "momentum" Threshold Auto Regression (M-TAR) with asymmetric adjustment as developed by Ender and Siklos (2001) was estimated to examine whether the prices of markets under study exhibit threshold co-integration and asymmetric adjustment. The null hypotheses were no co-integration ($\rho_1 = \rho_2 = 0$) and symmetric adjustment ($\rho_1 = \rho_2$).

The results of M-TAR model with zero thresholds (Table 6) revealed that all the markets considered for analysis exhibit a pair wise co-integration with the Kolar market, since Kolar is the second largest tomato market in the Asia. It is evident by rejection of null hypothesis of no co-integration ($\rho_1 = \rho_2 = 0$) at 1 per cent level of probability. The null hypothesis of symmetric price transmission ($\rho_1 = \rho_2$) was rejected in all market pairs with the reference market except with Srinivaspur. The Kolar market exhibited asymmetric price transmission mechanism with all other markets considered, except the Srinivaspur market which exhibited symmetric effect toward long-run equilibrium, due to the fact that these two markets are in the same locality with less distance between the markets. Here, the lags were selected based on the BIC since those estimates were more than AIC. The model considers the threshold value to be zero, in economic sense zero threshold would not exist, hence the consistent M-TAR model was run.

The results of the consistent M-TAR Model (CM-TAR) are presented in Table 7. The CM-TAR models revealed that all the variable pairs were co-integrated and have asymmetric price transmission, except Srinivaspur market. The TAR assumes zero as the threshold value, which is economically not true. Hence, CMTAR model is analysed. The point estimates of Kolar-Bangalore markets relationship were found to be $\rho_1 = -0.168$, and $\rho_2 = -0.684$, which indicates that 16.8 per cent of positive deviations and 68.4 per cent of negative deviations from the equilibrium were eliminated in one month. Since $|\rho_1|<|\rho_2|$, indicates markets players respond quickly and swiftly to the positive deviations than negative deviations. This may also be due to the market power, market agents react quickly and/ or more completely to shocks that squeeze their marketing margin than to corresponding shocks that stretches them (Amonde *et al*., 2009). All other market pairs such as Kolar-Kolkata, Kolar-Delhi, Kolar-Chennai and Kolar-Pimpalgaon had point estimates for positive deviations greater than negative deviations ($|\rho_1|>|\rho_2|$). These markets respond more to the positive deviations than the negative deviations. From Table 6 the obtained threshold values indicate that, if the transaction cost per quintal falls below the respective price then there won't be any price adjustments.

Asymmetric TVECM (Threshold Vector Error Correction Model)

By using a two-regime TVEC model, the price

Table 6 Results of M-TAR Model specification (null with Zero Threshold)

Variable	KS	KB	KK	KC	KD	KP
ρ_1	-0.123	-0.145	-0.049	-0.301	-0.137	-0.193
	(0.041)	(0.063)	(0.03)	(0.047)	(0.03)	(0.033)
ρ_2	-0.221	-0.4	-0.206	-0.175	-0.144	-0.169
	(0.039)	(0.064)	(0.033)	(0.053)	(0.04)	(0.04)
$\rho_1 = \rho_2 = 0$	19.884[a]	20.072[a]	20.942[a]	23.878[a]	17.16[a]	21.719[a]
$\rho_1 = \rho_2$	3.131[NS]	11.186[a]	12.3[a]	3.672[a]	0.019[a]	0.254[a]
Lags	1	4	1	2	1	7
LB(4)	0.647	0.971	0.809	0.938	0.994	0.992
LB(8)	0.653	0.978	0.551	0.716	0.784	0.999
LB(12)	0.583	0.946	0.58	0.701	0.733	0.985
AIC	6251	6748.14	6502.2	6459.6	6589.02	6639.38
BIC	6267.52	6769.18	6514.6	6474.31	6601.42	6657.13

Note 1. Figures in the parenthesis indicate standard errors.

2. [a] indicate significance at 0.01 level of probability; NS: Non Significant

3. KS: Kolar-Srinivaspur, KB: Kolar-Bangalore, KK: Kolar-Kolkata, KC: Kolar-Chennai, KD: Kolar-Delhi, KP: Kolar-Pimpalgaon

4. AIC- Akaike's Information Criteria, BIC- Bayesian Information Criteria, LB- Ljung-Box Q- statistic for residual autocorrelation

Table 7 Results of Consistent M-TAR Model Specification

Variable	KS	KB	KK	KD	KC	KP
Threshold value	98	209	335	541	183	246
ρ_1	-0.187	-0.168	-0.205	-0.209	-0.255	-0.353
	(0.052)	(0.052)	(0.053)	(0.045)	(0.041)	(0.054)
ρ_2	-0.169	-0.684	-0.102	-0.112	-0.221	-0.142
	(0.034)	(0.083)	(0.025)	(0.028)	(0.071)	(0.03)
$\rho_1 = \rho_2 = 0$	18.242[a]	34.368[a]	16.036[a]	18.887[a]	21.979[a]	28.999[a]
$\rho_1 = \rho_2$	0.087[NS]	38.116[a]	3.061[a]	3.235[a]	3.202[b]	13.544[a]
Lags	1	4	1	2	1	7
LB(4)	0.591	0.952	0.753	0.992	0.945	0.989
LB(8)	0.668	0.966	0.731	0.803	0.615	0.998
LB(12)	0.581	0.897	0.532	0.665	0.619	0.978
AIC	6347.08	6777.9	6620.18	6691.81	6542.94	6639.42
BIC	6363.67	6805.97	6636.77	6708.4	6563.66	6680.76

Note 1. Figures in the parenthesis indicate standard errors.
2. [a] indicate significance at 0.01 level of probability, [b] indicate significance at 0.05 level of probability
3. AIC- Akaike's Information Criteria, BIC- Bayesian Information Criteria, LB- Ljung-Box Q- statistic for residual autocorrelation

transmission dynamics of the tomato market prices were investigated and presented in Table8. Two-regime when relative price discrepancies exceed a certain threshold of transaction costs, trade between the physically separated markets occurs. TVECM enables us to characterize this trading environment. When trade encourages market integration and causes price movements and responses between markets, it is known as atypical regime in this instance. Markets may co-integrate in this manner under this unusual regime. When transaction costs are lower than relative price disparities between market places, the usual regime prevails. In this scenario, there is no incentive to trade, therefore price changes within the transaction cost band and between markets will not be related.

Kolkata, Chennai and Delhi consumption markets were analyzed with respect to Kolar market. Kolkata and Delhi markets respond more to the negative price changes in Kolar market, whereas Chennai market is responsive to the positive price changes in the Kolar market. Kolkata market adjusts to eliminate 14.5 per cent of price changes from disequilibrium towards equilibrium as a result of perturbation of prices in the reference market. Distributed lag asymmetric effect was found for Kolar for its own price and asymmetric effect on Chennai and Delhi market. The cumulative asymmetric effect or in long run, the price change in Kolar market, not only affects Kolar, but also the other consumption markets. In the long run, the prices deviation in Kolar market are independent on price shocks from any of the distant consumption market, However, in short run there are adjustments for change in consumption market prices. The half-life time calculated for adjustments to equilibrium revealed that, Kolkata takes 3 days for adjustment towards equilibrium as a result of price shocks in the reference market whilst Chennai takes 5 days and Delhi takes approximately 3 days for complete adjustment towards equilibrium due to perturbation in the prices in the reference market (Table 8).

From Table 8, the results revealed that, Bangalore market responds to negative deviations of prices in Kolar market. In the short run, deviations in Kolar market were affected by its own prices and as well as the changes in prices of Bangalore market. The long run price dynamics of Kolar market is influenced by the price changes in the Bangalore market. The point estimates of the adjustment parameters imply that Bangalore prices adjusted to eliminate about 73.5 per cent of prices change above the threshold value for the negative deviations. The Bangalore market was likely to exhibit asymmetric path of adjustment to equilibrium in the long-run to price changes created by Kolar prices. The half-life time calculated proved that, Kolar takes two days to reach equilibrium by adjusting to the price changes of Bangalore, whereas Bangalore requires

Table 8 Results of Asymmetric Vector Correction model of tomato markets

Variables	Kolar	Kolkata	Kolar	Chennai	Kolar	Delhi	Kolar	Bangalore	Kolar	Pimpalgaon
Ect^+	-0.12	-0.079	-0.088[b]	0.268[a]	-0.11[a]	0.065[b]	-0.083	0.072	-0.356 [a]	0.048
Ect^-	-0.04	0.145[a]	-0.197[b]	0.128	0.033	0.11 [a]	-0.016	0.735[a]	-0.129[a]	0.076
$\alpha_1^+ = \alpha_1^-$	8.24[a]	2.837[b]	13.65[a]	10.77[a]	13.08[a]	3.02[b]	18.13[a]	2.722[b]	0.206	0.062
$\alpha_2^+ = \alpha_2^-$	0.28	0.651	0.553	0.455	0.701	1.039	0.22	1.056	0.88	3.393[b]
$\alpha_3^+ = \alpha_3^-$	-	-	-	-	-	-	0.001	0.202	0.008	1.575
$\alpha_4^+ = \alpha_4^-$	-	-	-	-	-	-	0.051	1.43	0.08	6.019[b]
$\alpha_5^+ = \alpha_5^-$	-	-	-	-	-	-	-	-	0.714	0.209
$\alpha_6^+ = \alpha_6^-$	-	-	-	-	-	-	-	-	0.001	6.973[a]
$\alpha_7^+ = \alpha_7^-$	-	-	-	-	-	-	-	-	0.234	10.859[a]
$\beta_1^+ = \beta_1^-$	0.56 [b]	4.993	1.509	2.123	0.02	0.18	8.687[a]	3.428[b]	0.532	9.861[a]
$\beta_2^+ = \beta_2^-$	1.5	1.39	1.6	1.46	2.23	7.82[a]	8.536[a]	1.389	0.075	2.832[b]
$\beta_3^+ = \beta_3^-$	-	-	-	-	-	-	1.495	0.019	0.713	2.02
$\beta_4^+ = \beta_4^-$	-	-	-	-	-	-	2.721	2.016	0.521	3.18[b]
$\beta_5^+ = \beta_5^-$	-	-	-	-	-	-	-	-	0.004	0.008
$\beta_6^+ = \beta_6^-$	-	-	-	-	-	-	-	-	0.007	6.057[a]
$\beta_7^+ = \beta_7^-$	-	-	-	-	-	-	-	-	1.187	2.37
$\sum_{i=1}^{7}\alpha_i^+ = \sum_{i=1}^{7}\alpha_i^-$	4.36[b]	4.14[b]	7.71[a]	11.11[a]	5.70[b]	0.38	0.579	5.68[b]	0.718	0.965[a]
$\sum_{i=1}^{7}\beta_i^+ = \sum_{i=1}^{7}\beta_i^-$	0.13	0.58	0.56	0.03	1.18	3.62[b]	11.93[a]	0.213	0.554	10.826
$\delta^+ = \delta^-$	0.845	5.081[b]	1.178	0.84	3.501[b]	0.47	0.363	10.008[a]	8.864[a]	0.095
Half Life time	0.39	0.46	0.55	0.74	0.36	0.4	0.299	0.415	0.957	0.332

Note [a] and [b] indicate significance at 0.01 level and 0.05 level of probability, respectively. Ect^+ & Ect^- error correction term for positive and negative deviations, $\alpha^+_i = \alpha^-_i$ lagged symmetry/ short run deviations of price in reference market (Kolar market), $\beta^+_i = \beta^-_i$ short run deviations of Price in Bangalore or Pimpalgaon market

$\Sigma\alpha^+_i = \Sigma\alpha^-_i$, $\Sigma\beta^+_i = \Sigma\beta^-_i$ represents cumulative/ long term deviations of price in reference and other markets.

almost three days to adjust to price change equilibrium. In the case of Kolar-Pimpalgaon market, Kolar market responds to both positive and negative discrepancies in the price, it responds quickly to the positive deviations in the price than the negative deviations of its own price, as . The lagged symmetry of Pimpalgaon market was significant in short run as it responds to the price change of Kolar market and also to its own prices. In the long run, the Pimpalgaon market responds to the price changes of Kolar.

Granger causality test

The causality in tomato markets considered in the study was examined through Granger Causality technique. The results are depicted in Table 9 and Fig. 1. It is evident from the results that there is an existence of both unidirectional and bidirectional causality between tomato markets. Unidirectional causality was found between Kolkata-Kolar and Srinivaspur-Kolar. It means that a price formation in the former market in each pair granger cause the price changes in the latter market, whereas the price change in the latter market is not providing feed back to the price change in the former market.

Bidirectional causality exists between Bangalore-Kolar markets, Kolar-Delhi markets, Kolar-Chennai and Kolar-Pimpalgaon markets. In these cases, the former market in each pair granger causes the wholesale price formation in the latter market, which, in turn, provides the feedback to the former market as well. Results matched the estimates of Nandini *et al.* (2019), wherein the Granger causality test was employed to investigate the kind and direction of price transmission between market pairs, and it indicated that most markets had

Table 9 Results of Granger Causality Test

Null Hypothesis	F cal	p value
BANGALORE (x) does not Granger cause KOLAR	3.051[a]	0.002
KOLAR (y) does not Granger cause BANGALORE	4.75[a]	0.02
KOLKATA (x) does not Granger cause KOLAR	1.855[NS]	0.117
KOLAR (y) does not Granger cause KOLKATA	4.796[a]	0.001
DELHI (x) does not Granger cause KOLAR	8.832[a]	0.001
KOLAR (y) does not Granger cause DELHI	4.345[a]	0.002
PIMPALGAON (x) does not Granger cause KOLAR	5.445[a]	0
KOLAR (y) does not Granger cause PIMPALGAON	2.859[a]	0
SRINIVASPUR (x) does not Granger cause KOLAR	0.155 [NS]	0.856
KOLAR (y) does not Granger cause SRINIVASPUR	5.119[a]	0.006
CHENNAI (x) does not Granger Cause KOLAR	11.967[a]	0
KOLAR (y) does not Granger Cause CHENNAI	4.363[b]	0.013

Note [a] and [b] indicate significance at 0.01 level and 0.05 level of probability, respectively; NS: Non Significant

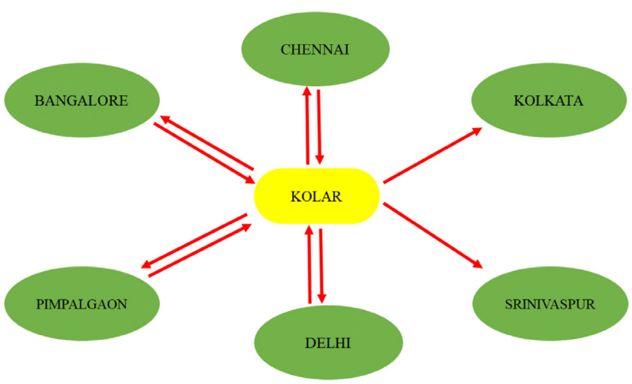

Figure 1 Granger causality directions between the tomato markets

bidirectional relationships whereas a small number of markets have unidirectional relationships in major vegetable markets in India. The discovered results show that the co-integration of the production and consumption markets hypothesis is accepted.

Conclusions

The study was conducted to assess the degree of the spatial market integration in distantly located three regional tomato markets in India, using co-integration and VECM model to the weekly wholesale prices from January, 2010 to March, 2020. According to the findings, the chosen markets—Kolar, Srinivaspur, Bangalore, Chennai, Kolkata, Pimpalgaon, and Delhi—are highly interconnected and have reached their long-term equilibrium. Between these market places, there are major differences in the rate of price transmission. The Granger Causality test findings showed that there is unidirectional causality from Kolkata to Kolar. This needs the attention of the policy makers to strengthen the use of information technology for flow of market information regularly and this will certainly help the farmers for increasing their income. On the whole, the study suggests that the regional markets for Tomato in India are strongly co-integrated and this encourages private traders' participation. Further, it was also observed that the distant consumption markets are less volatile in terms of prices compared to local production markets thereby suggesting that it is desirable to take advantage of the higher prices prevalent in the distant markets and increase the incomes.

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