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Market integration and price dynamics in major potato (*Solanum tuberosum*) markets of India

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a cash crop with nutritional value and wider consumer preference. Inadequate cold storage facilities, high price volatility and post-harvest losses are major challenges for the sector. The study examined the price linkages among spatially separated potato markets, viz. Azadpur, Ahmedabad, Bangaluru, Pune and Siliguri using daily price data obtained from AGMARKNET between 2015 and 2024. The Augmented Dickey-Fuller and Phillips Perron tests confirmed the stationarity of all price series at first difference. Trace statistics indicated long-run integration among the selected potato markets. The error correction model was estimated by the Vector Auto-Regression method. A slow adjustment rate was observed in Siliguri (0.64%) and Ahmedabad (3.09%), as they are producing markets, while Bengaluru with a high speed of adjustment (7.62%), emerged as a consuming market. Azadpur was the key price-determining market based on the Granger Causality test. The impulse response function indicated that with price shocks in any market, price fluctuations dissipated by the 10th–15th week in all the potato markets. The provision of infrastructure, market information (particularly for markets with unidirectional causality), price support and the promotion of value addition would enhance the income of growers and the sustainability of the potato sector.

Keywords: Causality, Impulse-response function, Market integration, VECM

Potato (*Solanum tuberosum* L.) is a cash crop cultivated widely across the globe, with India accounting for 15.5% of the world's potato production. The raw potato is rich in available carbohydrates (15.7 %), protein (1.8%), fat (0.1 %), dietary fibre (1.7%), vitamin C, Vitamin B6, potassium, phosphorus and magnesium (FAO 2024). Potato is extensively consumed globally and therefore it is a critical crop for food security in the present context of rising population and higher levels of hunger. The present per capita consumption of potato is 25 kg/year, which signifies its importance in the consumption basket of an average Indian. The export earnings of the country from frozen potato amounted to 4.89 million USD and major export destinations are Nepal, Bangladesh, United States, Japan, UAE, Maldives and Thailand (WITS 2023).

In India, potato is cultivated in an area of 2.23 mha, with a production of 57.05 mt and a productivity of 24.56 t/ha. It is sown from September-November and harvested from December-March, with an average crop duration of 90–120 days. Potato kept in cold storage of major states amounted to 214.25 lakh tonnes, which is 44.12% of all India production (485.62 lakh tonnes) during 2019–20 (MoA&FW 2020). Farmer’s share in consumer rupee is estimated at 37% for potato (RBI 2024). Due to high price volatility, potato contributes to food inflation in the economy. There exists higher inter-year and intra-year instability in potato prices in leading potato producing states (Sreepriya and Sidhu 2020, Ajmal *et al.* 2024). Therefore, marketing of potatoes is of great concern as there exists uncertainty in prices primarily due to a lack of market information.

Market integration reflects the extent to which prices in different markets move together (Saha *et al.* 2021). It enhances competitiveness and marketing efficiency and benefits both producers and consumers. The presence of market integration influences diversification to high value crops (Sidhu *et al.* 2010) and enables price stability and food security (Sonar *et al.* 2023). There may exist differences in prices in the short run but the price differentials should eventually converge in the long run. The strength and speed of price transmission is an indicator of the extent of integration among markets across regions (Goyal and Shivam 2025). The producing markets are the primary

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centres of production while major cities represent consuming markets. When markets are integrated, price shocks due to scarcity or frictions such as information asymmetry, market power, poor infrastructure, etc. in either producing or consuming markets gets transmitted across markets thereby aligning prices through demand-supply adjustments.

Against this background, the study aimed to examine the price behaviour of potato in the major markets of India; to analyze the spatial market integration among major potato markets; to assess the impact of price shocks in one market on the other markets; and to give suggestions for efficient marketing of potato to enhance the income of potato growers.

MATERIALS AND METHODS

Source of data: The study was constructed from secondary data. Based on the arrivals and consistent availability of data, five major potato markets in India, viz. Azadpur (Delhi), Ahmedabad (Gujarat), Bengaluru (Karnataka), Pune (Maharashtra), and Siliguri (West Bengal) were selected for the study. Time-series data on daily wholesale prices for 10 years from January 2015 to December 2024 were collected from AGMARKNET, Government of India. The prices were averaged over varieties for Fair Average Quality (FAQ) grade potato to arrive at a daily price, from which weekly prices were derived with linear interpolation of missing (weekly) data and outliers in STATA. Analysis was done in EVIEWS-12.

Analytical tools

Price behaviour of potato: The correlation of prices for selected markets were calculated using Pearson's correlation. A positive and significant correlation coefficient implies that prices in the selected markets are aligned. t-test was also used to test the significance of correlation coefficient.

$$R(X,Y) = \frac{Cov(X,Y)}{\sqrt{VAR(X).VAR(Y)}}$$

Where X and Y are the two-price series.

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \sim t(n-2)\,df$$

Test of stationarity: The first step for cointegration analysis is to perform unit root test to determine if the time-series data is stationary or not. Based on the assumptions, the formula for the unit root test is as follows:

No constant and trend ($\Delta Y_t = \delta\ Y_{t-1} + U_t$)

With constant ($\Delta Y_t = U\alpha + \delta\ Y_{t-1} + U_t$)

With constant and trend ($\Delta Y_t = \alpha + \beta\ T + \delta\ Y_{t-1} + U_t$)

To check for stationarity, the Augmented Dickey Fuller (ADF) test was employed. The specification of the model is as follows:

$$\Delta P_t = \alpha + \beta t + \gamma P_{t-1} + \sum_{i-1}^{q} \delta_i \Delta P_{t-1} + \varepsilon_t$$

Where P_t, Price in each market; α, Intercept; t, Time trend.

$\Delta P_t = P_t - P_{t-1}$, $\Delta P_{t1} = P_{t-1} - P_{t-2}$ and $\Delta P_{n-1} = P_{n-1} - P_{n-2}$

Where q, Optimal lag length was selected based on Akaike Information Criterion (AIC); ε_t, Pure white noise error term.

Null Hypothesis (Ho: $\beta_1 = 0$) was formulated based on that the time-series is non-stationary (unit root exists) while H^A: $\beta_1 < 0$). In addition, Phillip's Perron (PP), a non-parametric test was applied to conform the results of ADF test.

Johansen's cointegration test (JCT): When all the price series confirmed the presence of stationarity at the level or same order of differences, cointegration of markets can be tested. All the price-series had the same order of integration I(1), and hence, Johansen's cointegration technique was employed to analyze long-run price linkages among potato markets while Auto-Regressive Distributive Lag (ADRL) framework is relevant when the variables have different or mixed orders of integration (Rajeev *et al.* 2025). Specification of the model is as follows:

$$\Delta P_t = \sum \pi_i \Delta P_{t-i} + \pi P_{t-k} + \varepsilon_t$$

Where P_t, Vector of time series of prices; ΔP_t, First difference; Matrix π = α β', n x n order with rank r (0 ≤ r ≤ n); r, the number of independent cointegration relations; α, Speed of adjustment to the disequilibrium; β, Long term coefficients.

The model was estimated by regressing ΔP_t matrix against the lagged differences ('k' lags) of ΔP_t to determine the number of cointegrating vectors, the rank of π = α β' is found.

Vector error correction model (VECM): VECM accounts for both short term and long-term price fluctuations given by the equations:

$$\Delta \ln X_t = \alpha_0 + \sum \beta_{1i}\, \Delta \ln Y_{t-i} + \sum \beta_{2i}\, \Delta \ln X_{t-j} + \gamma\ ECT_{t-1}$$

$$\Delta \ln Y_t = \beta_0 + \sum \alpha_{1i}\, \Delta \ln X_{t-i} + \sum \alpha_{2i}\, \Delta \ln X_{t-j} + \gamma\ ECT_{t-1}$$

Where ECT_{t-1}, Lagged error correction term; X_t and Y_t, Variables under consideration; X_{t-i} and Y_{t-i}, Lagged values of variables X and Y; γ, Error correction coefficient that measures how the regressor reacts to changes in equilibrium in each period.

Granger causality test (GCT): This test was employed to investigate the existence and direction of long-run causality between selected potato markets and identify key markets. The test was conducted using the Vector Auto Regression (VAR) model given by the equation:

$$\ln X_t = \sum_{i-1}^{n} \alpha_i \ln X_{t-1} + \sum_{i-1}^{n} \beta_i \ln Y_{t-1} + \varepsilon_{1t}$$

$$\ln Y_t = \sum_{i-1}^{n} \alpha_i \ln Y_{t-1} + \sum_{i-1}^{n} \beta_i \ln X_{t-1} + \varepsilon_{2t}$$

Where X and Y, Two market price series; T, Time trend; n, No. of lags selected based on AIC; $H_0{:}\alpha_i = 0$ i.e. 'X' does not Granger cause a series 'Y'; $H_A{:}\alpha_i \neq 0$ i.e. 'X' Granger cause a series 'Y'; F-test gives significance of α_i.

Impulse Response Function (IRF): The Impulse Response Function demonstrated the market behaviour when a unit standard deviation shock or innovation takes place in a particular market. Generalised Impulse Response Function (GIRF) employs the VAR model, given by:

$$\text{GIRF } Y (h, \delta, w_{t-1}) = E [Y_t + h| \delta, w_{t-1}] - E (y_t + h|w_{t-1})$$

Where δ, Arbitrary current shock; W_{t-1}, Historical skcok given in equation for n = 0,1,2.

RESULTS AND DISCUSSION

Price behaviour of potato in major markets: There exist variations in prices across markets (Table 1). Average weekly price for potato was highest in Bengaluru (₹1,662/q) followed by Pune (₹1,483/q) and Ahmedabad (₹1,252/q). Instability in prices ranged from 33.60% in the Bengaluru market to 49.73% in Azadpur market. The correlation matrix of potato prices (Supplementary Table 1) showed a high positive correlation among markets, as price fluctuations are aligned in the markets.

Test of stationarity of time-series data: The ADF and PP test results showed that price series of all markets exhibited stationarity at the first difference and are statistically significant at 1% level (Table 2). Rajeev *et al.* (2020) and Saha *et al.* (2021) also observed stationarity of price series at first difference in their analysis of Indian potato markets. After ensuring stationarity of data, cointegration of markets was tested by Johansen's cointegration test.

Table 1 Market arrivals and weekly prices of potato in selected markets

Markets	Annual arrivals (Tonnes) TE 2023-'24	Weekly prices (₹/q) (2015–2024)			
		Minimum	Maximum	Mean	CV%
Azadpur	305152.40	362	2978	1083.20	49.73
Ahmedabad	177469.00	345	3100	1252.80	42.83
Bengaluru	276514.67	575	4090	1662.84	33.60
Pune	180904.43	633	4058	1483.04	39.22
Siliguri	63042.40	367	2600	1213.27	40.19

Table 2 ADF and PP tests to check for stationarity of data

Market	ADF test statistic	p-value	PP test statistic	*p*-value
At level				
Azadpur	-3.043**	0.031	-3.147**	0.023
Ahmedabad	-3.184	0.089	-3.674**	0.024
Bengaluru	-3.793*	0.003	-3.538*	0.007
Pune	-3.452**	0.046	-2.914**	0.044
Siliguri	-20.985*	0.000	-3.371*	0.000
At first difference				
Azadpur	-18.125*	0.000	-18.233*	0.000
Ahmedabad	-22.280*	0.000	-22.331*	0.000
Bengaluru	-24.831*	0.000	-26.209*	0.000
Pune	-27.190*	0.000	-27.235*	0.000
Siliguri	-20.985*	0.000	-21.106*	0.000

*, ** significance at 1% and 5% levels, respectively based on MacKinnon (1996) one-sided p-value. ADF, Augmented Dickey Fuller; PP, Phillip's Perron test.

Johansen's cointegration test: Cointegration means the existence of long-term relationship between price series of selected markets. There might be more than one cointegrating relationship among cointegrated variables. The JCT provided estimates of all such cointegrating equations and a test statistic called the maximum likelihood ratio or trace statistic; with H_0 of atmost 'r' cointegrating vectors against H_A of 'more that r' cointegrating vectors. The lag length in VAR model was chosen as two based on AIC to conduct the cointegration analysis (Supplementary Table 2). The LM test indicated absence of serial correlation in time-series data.

The calculated trace statistics > critical value denotes rejection of H_0. Johansen's test was estimated using a linear deterministic trend specification and VAR technique. Trace statistics indicated the existence of at least five cointegrating equations connecting the variables (Table 3). Majumder *et al.* (2022) and Katoch and Singh (2022) reported four cointegrating equations based on trace statistics (r = 0) at 5% level of significance in their study on cointegration of potato markets in the country. The higher number of cointegrating vectors indicates strong price linkages (Sharma *et al.* 2023). Therefore, we can conclude that the wholesale potato markets are cointegrated in the long run and appropriate policy interventions would help in reducing price volatility in the potato markets.

Vector error correction model (VECM): To know if there exists short-term and long-term equilibrium between markets, VECM was applied. VECM estimated using VAR method involved two non-stationary variables and it is, therefore, a simultaneous system of two equations, one for each variable describing short run adjustment of that variable towards long run equilibrium and the other is the lagged variables for each equation which denotes the number of time periods required for the adjustment process. The VECM in this study showed Siliguri and Ahmedabad, as producing markets, with a slower speed of adjustment, while Bengaluru, a consuming market, exhibited the highest speed. This is empirically comparable to Sharma *et al.* (2023), who reported faster equilibrium restoration in consumption centres than other markets and

Table 3 Unrestricted Cointegration rank test (trace) between potato markets

Hypothesized number of CE(s)	Eigen value	Trace statistic	0.05 Critical value	Prob**
None*	0.120	159.317	69.818	0.000
Atmost 1*	0.067	92.759	47.856	0.000
Atmost 2*	0.054	56.872	29.797	0.000
Atmost 3*	0.040	27.857	15.494	0.000
Atmost 4*	0.012	6.603	3.841	0.010

*denotes rejection of H_0 at 0.05 level; **MacKinnon-Haug-Michells (1999) *p*-values.

similar findings were found by Swaminathan *et al.* (2022) in potato consumption markets in Gujarat.

The Error correction term (ECT) indicates which markets exhibit long run causality. The coefficient of ECT gives the speed of adjustment. The data (Table 4) indicated that ECT was negative for Azadpur, Ahmedabad, Bengaluru and Siliguri, which meant that short term disturbances in these markets get corrected within one week and markets attained long term equilibrium. A positive coefficient of ECT for Pune implies divergence from equilibrium and was impacted by prices prevailing in other markets.

The speed of adjustment was 0.64% in Siliguri and 3.09% in Ahmedabad. Slow adjustment rate was primarily due to presence of more one-way transactions in these markets. They are producing markets that supply the produce to other markets. The speed of adjustment was 3.80% in Azadpur and 7.62% in Bengaluru. Among the markets, Bengaluru had a high adjustment rate and was discovered as a consuming market and similar findings were found by Saha *et al.* (2021). The demand supply adjustments quickly took place in Bengaluru market due to information network. But potato prices are high in Bengaluru market and therefore farmers may be encouraged to alter cropping patterns to meet the regional demand for potato and obtain higher income. Coefficients of lagged variables give short-term causality. Potato prices in Azadpur market were influenced by prices in Ahmedabad, Bengaluru and Siliguri with one week lag. Ahmedabad was affected by prices in Bengaluru with one-week lag. Azadpur and Ahmedabad influenced prices in Bengaluru market with two-week lag. Similarly, Azadpur and Ahmedabad influenced prices of Pune and Siliguri with one-week lag. Furthermore, previous period prices of potato in Azadpur and Pune markets also affected the current price of potato in these markets.

Azadpur, Ahmedabad and Bengaluru markets showed long term causality at 1% level of significance. Information flow was more in Pune market as reflected by positive coefficient of ECT but non-significant (0.0106). Short-term causality prevailed in all the markets with lag1 terms showing more significant results than lag 2. The findings highlight the need for providing information on prices prevailing in various markets to farmers to enable them to make decisions on time and place of sales. The short run coefficients for Ahmedabad are not significant except for Bengaluru, which implies no short run causality from the remaining markets to Ahmedabad market. The price discovery patterns observed in the selected markets highlight Azadpur (Delhi), a non-producing market as a lead price-setting market influencing price transmission nationwide which matches the dominant role of Delhi potato market (Majumder *et al.* 2022) and Delhi onion market (Areef *et al.* 2024) in transferring price signals in India.

Table 4 Results of vector error correction model

Error correlation	D (LN AZADPUR)	D (LN AHMEDABAD)	D (LN BENGALURU)	D (LN PUNE)	D (LN SILIGURI)
CointEq1	-0.0380*	-0.0309*	-0.0762*	0.0106NS	-0.0064NS
	[-3.2787]	[-2.9713]	[-6.7918]	[0.9381]	[-0.6529}
D (LN AZADPUR(-1))	0.1707*	0.0679NS	0.0576NS	0.1169*	0.0971*
	[3.7370]	[1.6576]	[1.3043]	[2.6075]	[2.5138]
D (LN AZADPUR(-2))	0.0020NS	0.0492NS	0.1126*	0.0648NS	0.0254NS
	[0.0453]	[1.2186]	[2.5851]	[1.4666]	[0.6686]
D (LN AHMEDABAD (-1))	0.1244**	-0.0339NS	0.0655NS	0.1589*	0.1290*
	[2.3873]	[-0.7269]	[1.3002]	[3.1084]	[2.9282]
D (LN AHMEDABAD (-2))	0.0017NS	-0.0762NS	0.1157**	0.0563NS	-0.0063NS
	[0.0334]	[-1.6203]	[2.2805]	[1.0949]	[-0.1428]
D (LN BENGALURU(-1))	0.1340*	0.1032*	-0.0625NS	0.0554NS	0.0198NS
	[2.8762]	[2.4678]	[-1.3863]	[1.2119]	[0.5036]
D (LN BENGALURU(-2))	0.0695NS	-0.0004NS	-0.0697NS	-0.0453NS	0.0065NS
	[1.5381]	[-0.0105]	[-1.5939]	[-1.2207]	[0.1700]
D (LN PUNE(-1))	-0.0090NS	0.0014NS	-0.0215NS	-0.2429*	0.0131NS
	[-0.1759]	[0.0324]	[-0.4341]	[-4.8357]	[0.3047]
D (LN PUNE(-2))	0.0394NS	0.0197NS	0.0241NS	-0.0755NS	0.0427NS
	[0.8128]	[0.4526]	[0.5141]	[-1.5874]	[1.0430]
D (LN SILIGURI(-1))	0.1428*	-0.0073NS	0.0592NS	0.0550NS	0.0435NS
	[2.6788]	[-0.1530]	[1.1487]	[1.0514]	[0.9655]
D (LN SILIGURI(-2))	-0.0299NS	0.0634NS	-0.0874NS	-0.0524NS	0.0273NS
	[-0.5684]	[1.3414]	[-1.7125]	[-1.0139]	[0.6131]
Intercept(C)	0.0010N(S	0.0011NS	0.0003NS	0.0004NS	0.0011NS
	[0.2476]	[0.3025]	[0.0827]	[0.0952]	[0.3143]

Figures in parenthesis denote 't' statistics. *, and ** denote significance at 1%, and 5% levels, respectively.

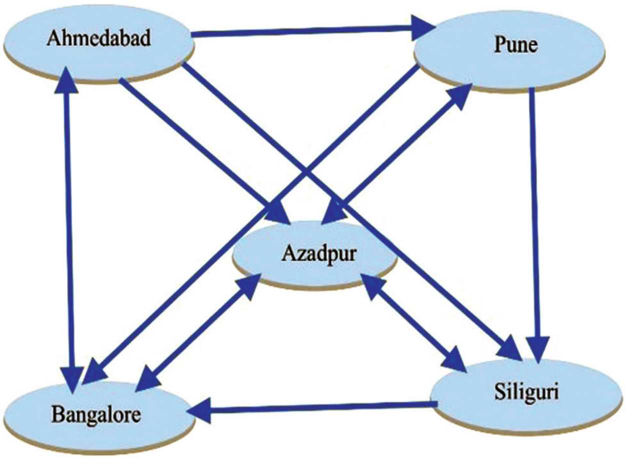

Fig. 1 Results of Granger cause directions between potato markets.
→Unidirectional ↔ Bidirectional causality.

Granger causality test: GCT gives the direction of long-run causality between the selected markets. An unidirectional causality between Ahmedabad → Azadpur, Ahmedabad → Pune, Ahmedabad → Siliguri, Pune → Bengaluru, Siliguri → Bengaluru and Pune → Siliguri was found (Fig. 1, Supplementary Table 3), which means prices of the former markets affected the later markets. There was bidirectional causality between Bengaluru ↔ Azadpur, Pune ↔ Azadpur, Siliguri ↔ Azadpur, and Bengaluru ↔ Ahmedabad, indicating that both markets influenced price transmission signals. Azadpur was the main market as it had bidirectional causality with Bengaluru, Pune and Siliguri potato markets which indicated that traders in Agricultural Produce Market Committee (APMC) at Azadpur market quickly reacted to changes in wholesale prices due to better communication facilities.

Out of the 20 market pairs, 12 market pairs were related in a unidirectional way and eight market pairs exhibited bidirectional causality. Azadpur was the lead market as it influence the wholesale prices in other markets, which is in agreement with evidence from Dey *et al.* (2021) and Sharma *et al.* (2023), suggesting robust information flows mostly taking place between central and peripheral markets. Information Communication and Technology (ICT) might be used for information flow to markets exhibiting unidirectional causality.

Impulse Response Function (IRF): The IRF showed the impact of a price shock in a market on price changes in that market as well as on other markets. The results of IRF (Fig. 2) indicated that the prices initially increased when a degree of unit shock was given to all markets except Bengaluru. There was an identical pattern of response in Pune and Siliguri to a positive shock in Azadpur, and from 15th week to positive shocks in Ahmedabad, and Bengaluru markets.

The impulse response for Azadpur market, estimated how the other markets would react to a unit standard deviation shock to the price of potatoes at Azadpur. Following the shock, all other markets reacted immediately with an increasing trend only up to 10th week and stabilised thereafter. The recording of market responses of Ahmedabad, Pune and Siliguri revealed that except for the Bengaluru market, prices in all other markets stabilised from 10th week. On the contrary, the impulse response of Bengaluru market revealed a declining trend initially and convergence towards equilibrium from 10th week onwards in all the markets. With a price shock in a particular market, prices in that market itself initially remained high but exhibited a declining trend and reached zero impulse by 50th week except in the Bengaluru market. Following the shock, prices in all markets tend to

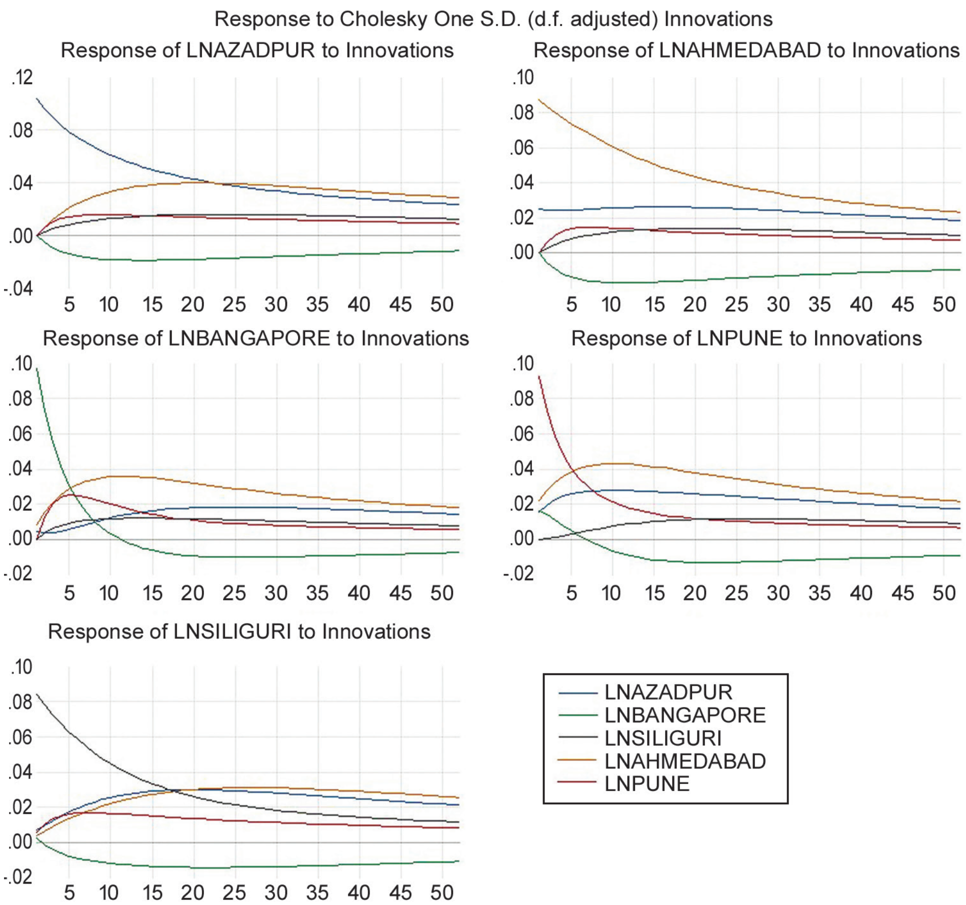

Fig. 2 Results of impulse response function.

remain stable from 10–15th week onwards. Impulse response analysis revealed that post price shock, most markets stabilize after 10–15 weeks, with Bengaluru showing a distinct quick adjustment pattern that closely mirrors the results of Kumar *et al.* (2022) on temporal market responses to shocks. This econometric framework has been applied to several perishable commodities such as rice, wheat, tomato, onion and pulses which signifies the validity of these methods for spatial price transmission and integration analysis in potato. Sendhil *et al.* (2019) observed price discovery in wholesale wheat markets initially with price shocks which were later transmitted to retail markets. A unit standard deviation shock in tomato markets led to stability in prices in all markets after five months period (Shubham *et al.* 2024). The transmission of price shocks were confirmed across onion markets (Ajay and Joginder 2025) and pulse markets (Singh *et al.* 2025) in India. An understanding of the impact of price shocks would help to devise strategies to provide market information and market intelligence to reduce price distortions and achieve price stability.

In conclusion, the study showed synchronized movement of prices in all markets. Instability in prices ranged from 33.60% in Bengaluru market to 49.73% in Azadpur market. Stationarity in price series was observed at first difference in all markets by ADF and PP Test. The unrestricted cointegration test indicated cointegration among the five markets. Bengaluru market had a high adjustment rate (7.62%) and Siliguri had the least (0.64%). The Siliguri is a producer market but with slow adjustment rate due to transport constraints and hence it has unidirectional causality with other markets except Azadpur. Bengaluru, as a major consumer market has a higher speed of adjustment, despite the distance which is due to the strong information network and has to be equipped with better cold chain infrastructure for efficient redistribution at lower prices. The Granger Causality test revealed dominance of unidirectional causality among potato markets. Impulse Response analysis implied that with a price shock in selected markets, prices remained stable in all markets from 10th week onwards except Bengaluru, which initially showed a declining trend and gradual convergence towards equilibrium. Azadpur emerged as the key potato market it impacted prices in all other chosen markets.

Non-integrated markets give misleading price information, distorting production and ultimately affecting the growth of the sector. Better market integration would help in the transfer of price signals from one market to another and benefit producers and consumers. The information flows through ICT platforms (web/mobile) would help in the dissemination of market information on price, demand and supply to enable farmers to make decisions, particularly in markets with unidirectional causality. Thus, policy focus should prioritise real-time price dissemination from Azadpur market to other markets.

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