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Price Dynamics and Extent of Integration in Indian Retail Milk Markets

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Abstract

Market integration plays a vital role in determining how spatially related markets respond to price changes and shocks. This study examines the cointegration and price transmission dynamics across four major Indian retail milk markets Andhra Pradesh, Karnataka, Haryana, and Punjab using monthly data from April 2014 to April 2025. The analysis reveals a consistent upward trend in retail milk prices, with Haryana recording the highest and Karnataka the lowest prices, largely due to Karnataka's strong cooperative pricing system. Granger causality tests indicate asymmetric interstate price transmission, with Andhra Pradesh and Punjab acting as significant unidirectional influencers. Johansen cointegration analysis confirms a stable long-run equilibrium among these markets, highlighting stronger integration within southern states and contrasting long-term effects from northern dairy hubs on Andhra Pradesh. Vector Error Correction Model results identify Karnataka and Punjab as key transmitters of short-term price shocks, underscoring their critical roles in national dairy price dynamics. The findings suggest that while long-term price adjustments vary regionally, short-term shocks propagate rapidly, emphasizing the need to strengthen cooperative networks, supply chains, and market intelligence to enhance price stability and market integration.

Keywords: Cointegration, Granger Causality, Price Transmission, Retail Milk Markets, India

1 Introduction

Market integration holds critical importance in the Indian dairy sector due to the country's position as the world's largest milk producer and the reliance of two-thirds of rural households on dairying for livelihood (Acharya and Malhotra, 2020). The dairy market's fragmented nature, characterized by numerous smallholder producers and a mix of formal cooperatives and informal marketing channels, creates complex spatial and institutional linkages that influence price transmission and market efficiency. Effective integration ensures timely and accurate price signals across geographically dispersed markets, reducing arbitrage opportunities, minimizing inefficiencies, and stabilizing consumer prices. This is especially relevant in India, where milk is highly perishable and supply chains are vulnerable to disruptions, as highlighted by the COVID-19 pandemic's impact on northern states' prices (Cariappa et al., 2022). Furthermore, regional disparities in cooperative strength, infrastructure, and demand patterns necessitate a nuanced understanding of integration dynamics to inform targeted policy interventions.

Despite prior studies on milk market integration in India (Jha et al., 2012; Sharma, 2015), there remain significant gaps in comprehensively analyzing the extent and asymmetry of price transmission across major retail milk markets, particularly combining both southern and northern states in a unified framework. Existing literature often focuses on wholesale markets or isolated regions, lacking longitudinal analysis with recent data that captures evolving market structures and shocks. Moreover, the differential roles of cooperative networks and urban demand centers in shaping integration patterns have not been fully explored. This study addresses these gaps by employing advanced econometric techniques cointegration, Granger causality, and Vector Error Correction Models on monthly retail milk price data from April 2014 to April 2025 across four key states (Andhra Pradesh, Karnataka, Haryana, Punjab). It provides fresh insights into the asymmetric and region-specific dynamics of price transmission, long-run equilibrium relationships, and short-term shock propagation, thereby contributing to a more comprehensive understanding of Indian dairy market integration and informing policy measures for improved market stability and efficiency.

2 Literature Review

Market integration is a critical factor influencing the efficiency and stability of agricultural markets, including the dairy sector. It determines how spatially or vertically related markets respond to price changes and shocks, facilitating the transmission of price signals that reduce arbitrage opportunities and improve market performance (Von Cramon-Taubadel & Goodwin, 2021; Sendhil et al., 2019). In the context of India, the dairy sector holds particular importance due to the country's status as the world's largest milk producer and the livelihood dependence of a significant portion of rural households on dairying (Acharya & Malhotra, 2020).

The Indian dairy market is characterized by its fragmented structure, with numerous smallholder producers and a mix of formal cooperative and informal marketing channels (Sharma, 2015; Birthal et al., 2017). This fragmentation creates complex spatial and institutional linkages that influence price transmission and market efficiency. Cooperative networks, particularly in southern states like Karnataka, have demonstrated the capacity to stabilize prices and enhance market integration through assured procurement and coordinated pricing strategies (Birthal et al., 2017).

Previous studies on Indian milk market integration have largely focused on wholesale markets or isolated regions, often lacking comprehensive analyses that combine both northern and southern states or utilize recent longitudinal data (Jha, Singh, & Singh, 2012; Sharma, 2015). These studies highlight regional disparities in market integration and the asymmetric nature of price transmission but do not fully explore the differential roles of cooperative strength, urban demand centers, and supply chain disruptions.

The COVID-19 pandemic further underscored vulnerabilities in dairy supply chains, particularly in northern states where price surges reflected disruptions in transportation and increased input costs (Cariappa et al., 2022). This highlights the need for updated empirical research incorporating recent data to capture evolving market dynamics and shocks.

Econometric approaches such as Johansen cointegration, Granger causality tests, and Vector Error Correction Models (VECM) have been employed to analyze price transmission and market integration in agricultural commodities (Johansen, 1988; Granger, 1969; Sendhil et al., 2019). However, their application to retail milk markets across diverse Indian states remains limited, presenting an opportunity to advance understanding of both long-run equilibrium relationships and short-term price shock propagation within the dairy sector.

This study addresses these gaps by analyzing monthly retail milk price data from April 2014 to April 2025 across four major Indian states Andhra Pradesh, Karnataka, Haryana, and Punjab using advanced econometric techniques to uncover asymmetric and region-specific integration dynamics. The findings aim to inform policy interventions focused on strengthening cooperative networks, improving supply chains, and enhancing market intelligence for greater price stability and efficiency in India's dairy markets.

3 Research Methodology

This study employs a quantitative econometric approach to analyze the integration and price transmission dynamics across four major Indian retail milk markets: Andhra Pradesh, Karnataka, Haryana, and Punjab. Monthly retail milk price data spanning from April 2014 to April 2025 were sourced from the Food Price Monitoring and Analysis (FPMA) tool of the Food and Agriculture Organization (FAO).

3.1 Unit Root Test

The stationarity of the retail milk price series was examined using the Augmented Dickey Fuller (ADF) unit root test (Dickey & Fuller, 1979). This test evaluates whether a time series contains a unit root (i.e., is non-stationary) or is stationary. The null hypothesis assumes the presence of a unit root, while rejection of the null hypothesis indicates stationarity. The test was applied at both the level form and the first difference to determine the order of integration of the series.

The ADF test equation is specified as:

$$\Delta P_t = \alpha_0 + \delta_1 t + \beta_1 P_{t-1} + \sum_{j=1}^{q} \beta_1 \Delta P_{t-j} + \epsilon_t$$

Where

P represents price

α0 represents the constant

t represents time

q represents number of lag length

εt is the random error term

The null hypothesis of the test was there was a unit root and time series is non stationary and alternative was time series is stationary. It means rejection of the null hypothesis suggests particular hypothesis is stationary.

3.2 Granger Causality Test

To examine the direction and presence of causal relationships between the price series of different states, Granger causality tests (Granger, 1969) were conducted. This method tests whether past values of one price series help predict current values of another, indicating the direction of price transmission between markets.

$$P_t = \sum_{i=1}^{m} \propto_i P_{t-i} + \sum_{j=1}^{m} \beta_j R_{t-j} + \varepsilon_{1t}$$

$$R_t = \sum_{i=1}^{m} \propto_i R_{t-i} + \sum_{j=1}^{m} \beta_j P_{t-j} + \varepsilon_{2t}$$

Where
P and R are selected market price series
t is the time period
i and j represents number of lags to the respective price series

The null hypothesis of the test states that Pt does not Granger cause in Rt which means a rejection implies Granger causality between the selected price series pair.

3.3 Johansen Cointegration Test

Johansen's cointegration technique (Johansen, 1988) was used to detect the existence of long-run equilibrium relationships among the retail milk prices of the four states. The test evaluates the number of cointegrating vectors using trace and maximum eigenvalue statistics, which indicate whether the price series move together in the long run despite short-term deviations.

$$J_{trace} = -T \sum_{i=r+1}^{N} (1 - \lambda_1)$$

$$\lambda_{max} = -T (1 - \lambda_{r+1})$$

Where
r is the number of cointegrated vector
λ1 is the eigenvalue

λr+1 is the (r+1) th largest squared eigenvalue obtained from the parameter matrix of the cointegrated system,
T is the effective number of observation

3.4 Vector Error Correction Model(VECM)

Given evidence of cointegration, a Vector Error Correction Model was estimated to capture both short-term price adjustments and long-term equilibrium relationships. The VECM specification includes:

$$\Delta P_t = \alpha\beta P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \varepsilon_t$$

Where
Pt is a vector of logarithmic milk prices in different markets,
Δ denotes first differences
β represents the long-run price linkage (cointegrating vectors),
α denotes the speed of adjustment coefficients,
Γi captures short-run price transmission effects,
εt is a vector of white-noise error terms.
The error correction term (ECT) reflects the extent to which short-run deviations in milk prices are corrected to restore long-run market equilibrium.

- The error correction term (ECT), which measures the speed at which prices revert to the long-run equilibrium after a shock.
- Short-run dynamics captured through lagged differences of price variables. This model helps distinguish between immediate price shock transmissions and gradual long-term adjustments across markets.

4 Data Analysis and Interpretation

The study examines the dynamics of retail milk prices and the extent of market integration across four major Indian states Andhra Pradesh, Karnataka, Haryana, and Punjab using monthly data from April 2014 to April 2025. A series of econometric tools including descriptive statistics, Augmented Dickey Fuller (ADF) unit root tests, Granger causality analysis, Johansen cointegration, and a Vector Error Correction Model (VECM) were employed to uncover both short-term adjustments and long-term equilibrium relationships in milk prices across these states.

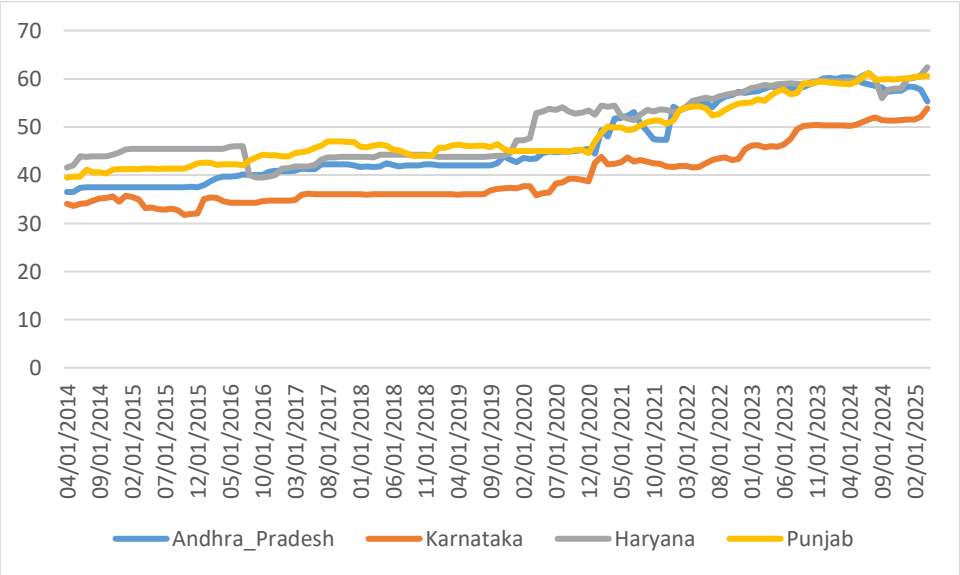

Figure 1: Trends in retail milk prices across major Indian states

4.1 Descriptive Statistics

- **Price Levels and Variability:**
    - Haryana records the highest average retail milk price (₹49.70), followed by Punjab (₹48.46) and Andhra Pradesh (₹46.62). Karnataka exhibits the lowest mean price (₹39.84), reflecting the stabilizing influence of its cooperative system (Nandini).
    - Andhra Pradesh shows the greatest price variability (SD = 7.92), indicating more pronounced month-to-month fluctuations, while Karnataka's prices are the most stable (SD = 6.07).
    - Positive skewness across all states suggests a tendency for prices to shift towards higher values over time, consistent with rising input costs and demand pressures.
    - Kurtosis values below 3 indicate relatively flat distributions without extreme price shocks.

Interpretation:
The higher prices and volatility in northern states (Punjab, Haryana) can be attributed to elevated input costs, strong urban demand (notably Delhi NCR for Haryana), and fragmented market structures. Karnataka's cooperative system effectively stabilizes prices, leading to lower levels and variability.

Statistics	Andhra Pradesh	Karnataka	Haryana	Punjab
Observations (N)	133	133	133	133
Mean	46.62	39.84	49.70	48.46
Std. Dev.	7.92	6.07	6.68	6.44
Variance	62.77	36.90	44.64	41.45
Skewness	0.50	0.80	0.31	0.63
Kurtosis	1.68	2.30	1.56	2.04

Table 1: Descriptive statistics of retail milk prices

4.2 Stationarity Tests (Augmented Dickey-Fuller Test)

- Retail milk price series for all four states are non-stationary at levels (fail to reject unit root null hypothesis), indicating persistent trends influenced by inflation, input cost increases, and structural market changes.
- After first differencing, the series become stationary (reject null hypothesis), confirming integration of order one, I(1).

Interpretation:
Non-stationarity at levels implies that price series contain trends, necessitating cointegration and error correction approaches to model long-run relationships and short-run dynamics appropriately.

State	ADF	P -Value	1st Diff ADF	P -Value
Andhra Pradesh	-1.53	0.77	-6.06	0.01
Karnataka	-1.62	0.73	-4.92	0.01
Punjab	-1.31	0.86	-4.87	0.01
Haryana	-1.99	0.57	-4.59	0.01

Lag Order 5

Table 2: Unit Root Test Results (ADF) for Retail Milk Prices

4.3 Granger Causality Analysis

- Andhra Pradesh and Punjab act as leading markets, exerting unidirectional causal influence on prices in other states.
- Karnataka and Haryana do not Granger-cause price changes in other markets, reflecting their relatively insulated or demand-driven pricing mechanisms.

Interpretation:
The asymmetric causality pattern indicates hierarchical price transmission, where Andhra Pradesh and Punjab serve as price leaders, likely due to their market size, production characteristics, or role in supply chains. Karnataka's cooperative-led market and Haryana's demand-driven pricing limit their influence on others.

pressures in the dairy sector.

Null Hypothesis	F-Statistic	Probability	Granger Causality (10% level)	Direction of Causality
Andhra Pradesh does not Granger-cause Karnataka, Punjab, Haryana	5.01	0.002	Reject H0 (Yes)	Unidirectional from Andhra Pradesh
Karnataka does not Granger-cause Andhra Pradesh, Punjab, Haryana	1.16	0.326	Fail to Reject H0 (No)	None
Punjab does not Granger-cause Andhra Pradesh, Karnataka, Haryana	2.47	0.061	Reject H0 (Yes)	Unidirectional from Punjab
Haryana does not Granger-cause Andhra Pradesh, Karnataka, Punjab	0.053	0.984	Fail to Reject H0 (No)	None

Table 2: Unit Root Test Results (ADF) for Retail Milk Prices

4.4. Johansen Cointegration Test

- Presence of one cointegrating vector among the four states' retail milk prices confirms a stable long-run equilibrium relationship.
- This implies that despite short-term fluctuations, prices tend to move together over the long term, reflecting moderate market integration.

Interpretation:
The cointegration result supports the hypothesis that Indian retail milk markets, though regionally heterogeneous, are linked by common structural factors such as national demand trends and input cost movements.

Null Hypothesis (H0)	Trace Statistic	10% Critical Value	Decision (10% level)
$r = 0$	51.11	49.65	Reject H0
$r \leq 1$	25.47	32.00	Fail to Reject H0
$r \leq 2$	7.95	17.85	Fail to Reject H0
$r \leq 3$	2.45	7.52	Fail to Reject H0

Table 4: Johansen Cointegration Test (Trace Statistic) for Inter-State Retail Milk Prices

4.5 Cointegrating Equation Coefficients

- Karnataka's positive coefficient (1.80) relative to Andhra Pradesh indicates strong positive long-term price co-movement between these southern states.
- Negative coefficients for Punjab (–1.98) and Haryana (–0.99) suggest an inverse long-run relationship with Andhra Pradesh prices.

Interpretation:
The positive linkage between Andhra Pradesh and Karnataka reflects integrated southern markets with cooperative-supported pricing. The negative coefficients for northern states indicate that price increases in surplus-producing Punjab and Haryana may exert downward pressure on Andhra Pradesh prices, possibly due to competitive substitution or differing demand-supply balances, revealing complex spatial market dynamics.

$$\text{Andhra Pradesh} + 1.80 \times \text{Karnataka} - 1.98 \times \text{Punjab} - 0.99 \times \text{Haryana} + 26.63 = 0$$

4.6 Vector Error Correction Model (VECM) Results

Variable	ECT Coefficient	Interpretation (direction)
Andhra Pradesh	-0.055	Negative, slow correction to equilibrium
Karnataka	-0.070	Negative, moderate correction to equilibrium
Punjab	+0.042	Positive, divergence or weak correction
Haryana	+0.053	Positive, divergence or weak correction

Table 5: VECM Error Correction Term Coefficients

- **Error Correction Terms (ECT):**
  - Andhra Pradesh and Karnataka have negative ECT coefficients (–0.055 and –0.07), indicating prices adjust towards long-run equilibrium after shocks, with Karnataka adjusting moderately faster.
  - Punjab and Haryana show positive ECT coefficients (0.042 and 0.053), implying divergence from equilibrium and weak or absent corrective adjustments.
- **Short-Run Dynamics:**
  - Karnataka and Punjab are key transmitters of short-term price shocks, with their lagged price changes significantly influencing other states.
  - Andhra Pradesh's lagged prices tend to dampen price shocks, stabilizing southern markets.
  - Haryana has weaker short-run spillover effects.

Explanatory Variable (Lagged Δ)	Andhra Pradesh Δ	Karnataka Δ	Punjab Δ	Haryana Δ
Andhra Pradesh.dl1	-0.154	-0.089	+0.196	-0.109
Karnataka.dl1	+0.096	+0.090	+0.182	+0.104
Punjab.dl1	+0.315	+0.094	+0.124	+0.302

Haryana.dl1	+0.036	+0.060	+0.017	+0.081

Table 6: VECM Short-Run Dynamics.

Interpretation:
Southern states (Andhra Pradesh, Karnataka) exhibit stronger integration and responsiveness to price signals, facilitating correction towards equilibrium. Northern states (Punjab, Haryana) operate more independently, with localized market conditions and demand pressures causing slower or divergent adjustments. The role of Karnataka and Punjab as shock transmitters highlights their importance in national dairy price dynamics.

4.7 COVID-19 Price Surge and Supply Chain Disruptions

- A pronounced price spike in Punjab and Haryana during 2020–2021 corresponds with COVID-19 induced disruptions such as transportation bottlenecks, labor shortages, and increased feed costs.
- These disruptions caused temporary supply-demand imbalances and elevated prices in northern markets.

Interpretation:
The pandemic underscored vulnerabilities in dairy supply chains, particularly in northern states with fragmented procurement systems. The episode emphasizes the necessity for resilient infrastructure, diversified marketing channels, and real-time market intelligence to mitigate future shocks.

Overall Interpretation

The data analysis reveals a moderately integrated Indian retail milk market with significant regional heterogeneity. Southern states benefit from stronger cooperative networks and more coordinated market structures, leading to stable prices and effective long-run adjustments. Northern states, characterized by surplus production and fragmented marketing, display more volatile prices and weaker integration signals. Asymmetric price transmission and differing adjustment speeds highlight the complexity of Indian dairy markets. Policy interventions aimed at strengthening cooperative frameworks, improving supply chain infrastructure, and enhancing market intelligence are essential to promote greater integration, reduce volatility, and ensure price stability across regions.

5 Findings

The study reveals several key insights into the price dynamics and market integration of retail milk markets across Andhra Pradesh, Karnataka, Haryana, and Punjab from April 2014 to April 2025:

- Retail milk prices exhibit a consistent upward trend in all four states, with Haryana recording the highest prices and Karnataka the lowest, largely due to Karnataka's robust cooperative pricing system.
- Descriptive statistics highlight greater price volatility in northern states (Punjab and Haryana) compared to more stable southern markets.
- Stationarity tests confirm that milk price series are integrated of order one, necessitating cointegration analysis.
- Granger causality tests indicate asymmetric interstate price transmission, with Andhra Pradesh and Punjab acting as significant unidirectional price leaders influencing other states.
- Johansen cointegration analysis confirms the existence of a stable long-run equilibrium relationship among the four states, indicating moderate market integration despite regional disparities.
- The cointegrating equation shows positive long-run price co-movement between Andhra Pradesh and Karnataka, while Punjab and Haryana exhibit negative coefficients relative to Andhra Pradesh, reflecting inverse long-term relationships likely driven by regional production surpluses and differing market structures.
- Vector Error Correction Model (VECM) results demonstrate that Andhra Pradesh and Karnataka adjust prices towards long-run equilibrium after shocks, whereas Punjab and Haryana diverge, indicating weaker corrective mechanisms in northern states.

- Karnataka and Punjab serve as key transmitters of short-term price shocks, underscoring their pivotal roles in shaping national dairy price dynamics.
- The COVID-19 pandemic caused significant price surges in northern states due to supply chain disruptions, highlighting vulnerabilities in dairy market infrastructure.

6 Conclusion and Policy Recommendations

The findings underscore the importance of tailored policy interventions to enhance market integration and price stability in Indian retail milk markets:

- **Strengthen Cooperative Networks in Northern States:** The weaker price adjustment and divergence from equilibrium in Punjab and Haryana suggest a need to bolster cooperative institutions, improve procurement coordination, and formalize marketing channels to enhance price responsiveness and reduce volatility.
- **Improve Market Linkages and Supply Chain Infrastructure:** Enhancing transportation, cold storage, and logistics infrastructure, especially in northern regions, will mitigate supply disruptions and facilitate smoother price transmission.
- **Enhance Market Intelligence Systems:** Real-time data monitoring and dissemination can improve market transparency and enable stakeholders to respond promptly to price shocks, reducing inefficiencies.
- **Promote Regional Integration Strategies:** Encourage policies that foster stronger linkages between northern and southern markets to harmonize price signals and reduce spatial disparities.
- **Support Resilience Against External Shocks:** Develop contingency plans and diversified marketing channels to safeguard dairy supply chains from disruptions akin to the COVID-19 pandemic.

Future Research Directions

- **Expand Geographic Scope:** Include additional states from diverse regions to capture broader market dynamics and integration patterns across India's dairy sector.
- **Examine Informal Market Impact:** Investigate the role and influence of informal milk marketing channels on price transmission and market efficiency.
- **Incorporate Quality and Product Differentiation:** Analyze how variations in milk quality and product forms affect price dynamics and market integration.
- **Longitudinal Impact Assessment:** Study the evolving effects of policy reforms, cooperative expansions, and infrastructure improvements over extended periods.
- **Integrate Socioeconomic Factors:** Explore how producer characteristics, consumer preferences, and rural-urban linkages influence market behavior and integration.

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