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# Price Transmission Dynamics in the Indian Rice Market: Evidence from Wholesale and Retail Prices

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## Abstract

The present study was undertaken to study the integration and price transmission amongst the major rice centres of India in both its wholesale and retail markets, using monthly data for the period of 2014 to 2023. To achieve the objective various statistical tools like the unit root test, the Johansen cointegration test and Granger causality test is used. The results reveal the presence of long-run cointegration in both the wholesale and retail prices amongst the eight selected markets. The results of the causality test show presence of bidirectional causality among Kolkata & Mumbai in the wholesale market and Chennai & Visakhapatnam in both the wholesale and retail market segments. Furthermore, the analysis reveals Visakhapatnam, Kolkata, Chennai, and Ludhiana as pricing leaders, highlighting their importance in price discovery. On the other hand, markets like Lucknow and Patna demonstrate lagged responsiveness, underscoring potential weaknesses in transmission from surplus to deficit regions. The study provides evidence of multilateral integration across major rice markets of India.

***Key words*:** Granger causality, Integration, Rice centres, Price transmission, Wholesale and retail markets

Rice is one of the major staples of India. It is also the most produced food grain in India. A stable price of rice in the markets all around the country is very important for the welfare of the rice market participants. The present study aims to verify whether the national rice markets are integrated. A well-integrated rice markets indicates price efficiency and implies that the national rice markets are a reliable source to meet the demand for food security. In a well-integrated market, the effect of local disturbances in prices are mitigated by induced trading between surplus and deficit areas [1]. The importance of the analysis of cointegration between markets is due to the possibility that, as two markets are integrated, there is influence of one market in the formation of prices in the other. The question that arises: Is there dominance among producer markets? That is, in which market does price formation take place (dominant), and how are other markets (followers) affected by price variations in the dominant market (price transmission)? Aiming to provide a scientific basis for a better understanding of these relationships between rice producing markets, the objective of this study was to evaluate the dynamics of price formation in the national market, in order to define the dominant market (price maker) and its followers (price transmission). Knowledge of price relationships between markets is important for the government as well as various for the formulation public policies for the sector.

Several studies have been developed to analyze causal relationships for agricultural products. When there is influence (causality) of one market on the other, price transmission occurs between these two markets. In this case, prices in the dominant market influence prices in the follower market and establishing a sense of causality between prices in the two markets. Many of these studies were based on the causality tests proposed by Granger [2]. To mention a few, Zhou and Koemle [3] used the granger causality test to study the price transmission between the hog and feed price in China. Confoprti [4] also used the granger causality to test the price transmission of food commodities in agricultural markets of sixteen countries. Similarly, Wanjau *et al*. [5] used the test for egg markets in Kenya, while Alemu and Ogundeji [6] used it in the African food markets.

There are a number of studies that used the Granger causality test to analyze price transmission of agricultural products in India. Shivakumar and Uma [7] analyzed market integration, price transmission, and price volatility in major domestic markets for green gram in India from 2006 to 2018, using time series cointegration, Granger causality, and GARCH modelling. They found bidirectional causation between markets, suggesting measure for improving price discovery and market intelligence to manage price shocks. Similarly, Shilpa [8] examined market integration and price transmission across five major Indian apple markets from 2014 to 2019 using the same methodology. The results strongly supported cointegration and market interdependence. The authors found Shimla market as the price maker with causal relations to all selected markets. Horo [9] analyzed market integration and price transmission for lentil markets in major Indian producing states from 2009 to 2019 and found that the markets are highly integrated with most having unidirectional relationships while, Jaipur and Lucknow wholesale and retail markets exhibited little influence from other markets. Saha *et al*. [10] examined

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onion and potato market integration and price transmission across Indian wholesale markets from 2009 to 2019 using the same cointegration and Granger causality method. The results supported market cointegration and interdependence with bidirectional relationships found between most markets. Ahmed *et al.* [11] analyzed market integration and price transmission across wheat markets in India from 2006 to 2016. Employing cointegration tests and TVECM, the study found cointegration between markets and bidirectional causality. The determined that Delhi wheat prices remained higher than other regional markets. Pandey *et al.* [12] examined chickpea market integration and causality in India from 2003-2020 and confirmed market cointegration and interdependence, with some markets exhibiting stronger relationships than others.

For rice markets specifically, there are various studies conducted internationally studying the price transmission like Chen and Saghaian [13] studied the price transmission in the world rice markets of Thailand, Vietnam and the USA, and found that the export prices of their countries are cointegrated. Ghafoor and Aslam [14] explored the spatial market integration among major rice markets in Pakistan. The results shown causality between the markets. Alam *et al.* [15] conducted the study to determine the asymmetric price transmission of rice markets in Bangladesh. Korale Gadera *et al.* [16] conducted similar test for Sri Lanka. However, there are not many studies on the analysis of price transmission of the Indian rice markets. The study by Acharya *et al.* [17] is the only study found in our analysis which aims to study the market integration of Rice as well as Wheat markets in India. The study uses monthly rice price data from 2003 to 2011 for six domestic rice markets in India from the major rice producing states. The study found the presence of integration among the markets across the different levels of the Indian rice markets. Some of the markets exhibit bidirectional while some other show unidirectional causality. The determination of the degree of integration for the Indian rice market is important given its peculiar geographical characteristics. However, the analysis of rice market integration is largely neglected in literature especially for India. Our study aims to fill this paucity of research on integration and price transmission of Rice markets in India. This study contributes to the literature by identifying the long run equilibrium position of the eight major rice markets in India, and also analyses of causality between those markets.

## MATERIALS AND METHODS

*Unit root test*

To determine the order of integration of the variables of interest, this study used the Augmented Dickey-Fuller (ADF) unit root test. This test allows verifying the existence or not of unit roots in the time series, that is, if the variables are stationary or not [18].

A stochastic process is stationary when its mean and variance are constant over time and when the value of the covariance between two time periods depends only on the distance, interval or lag between the time periods, and not on the time itself over which the covariance is calculated. In terms of mathematical notation, the properties of the stationary stochastic process can be represented by:

$$\text{Mean } \mathrm{E}(Y_t) = \mu, \text{ Variance, } VAR(Y_t) = E(Y_t - \mu)^2 = \sigma^2 \text{and covariance } \gamma_k = \mathrm{E}[(Y_t - \mu)(T_{t+k} - \mu)]$$

A stochastic process with the properties described above is known, in the time series literature, as a weakly stationary process, or stationary in covariance, or second-order stationary, or stationary in the broad sense. The ADF test consists of estimating the following equation by Ordinary Least Squares and can be expressed, according to Enders [19] as follows:

$$\Delta y_t = \alpha_0 + \gamma\, y_{t-1} + \sum_{i=2}^{p} \beta_i\, \Delta y_{t-1+1} + \varepsilon_t$$

$$\text{With:} \qquad \gamma = -(1 - \textstyle\sum_{i=1}^{p} \alpha_i)\, e\beta_i = \sum_{j=1}^{p} a_i$$

where: $\alpha_0$ is the intercept; γ describes the behaviour of the time series; *y* represents the dependent variable; Δ is the representation of the difference operator and $\varepsilon_t$ denotes the error term, which is assumed to be identically and independently distributed.

The parameter of interest in the regressions is γ, and if γ = 0, the series contains a unit root. In this test, the result of the *t* statistic is compared with the appropriate values reported by Dickey-Fuller to determine whether to accept or reject the null hypothesis γ = 0. The null hypothesis will be rejected if the calculated value of the *t* statistic is greater than the Dickey-Fuller critical value, indicating that the series is stationary; otherwise, the series is non-stationary.

*Cointegration analysis*

In order to identify the possible long-term relationship between the variables, the cointegration test developed by Johansen [20] was used. Johansen's cointegration test provides a statistical conclusion about the long-term stability of time series. The cointegration methodology developed by Johansen [21] is described considering an Autoregressive Vector (VAR) of order *p*.

$$y_t = \alpha_1 y_{t-1} + \cdots + a_p y_{t-p} + \beta x_t + \epsilon_t$$

Where $y_t$ is a non-stationary k-vector *I(1)*, $x_t$ is a deterministic d-vector, and $\epsilon_t$ is an innovation vector. Transforming into a sum, the VAR equation can be rewritten as follows:

$$y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Pi_i \Delta y_{t-1} + \beta x_t + \epsilon_t$$

Where, $\Pi = \sum_{i=1}^{p} \Pi_i - 1,\ e_i = -\sum_{j=i+1}^{p} \alpha_j$,

Based on the representation of Granger's theorem, if the reduced coefficient matrix Π has ranking $r < k$, then there exists $k \times r$ matrices α and β, each with ranking r such that Π = αβ' and $\beta' y_t$ are *I (0)*. *r* is the number of cointegration relations and each column β is a cointegration vector.

With a priori information about the order of integration of the time series, it is recommended to use the deterministic trend specification test, to determine the number of cointegration vectors conditional on the assumptions made about the trend of the series with sequential procedures of $r = 0$ and $r = k - 1$ [21]. The result of the sequential procedure is reported through the Trace and Max statistics. Both the Trace and Max statistics test the null hypothesis of no cointegration against the alternative hypothesis of cointegration of the vectors *r*.

*Granger causality*

To verify in which direction the price transmissions occur, the causality test was used, following the methodology proposed by Granger [2]. The causality test seeks to verify whether the incorporation of lagged values of a variable x contributes to better predictions for another variable y. In this sense, the identification of a causality suggests the direction in which price transmission occurs. Thus, it is a test of temporal precedence and not of causality in the sense of a cause-and-effect relationship. In other words, this instrument is useful for evaluating whether price variations in one market precede price variations in another market [2].

The Granger causality test assumes that the best predictors of a set of predictive variables are the temporally lagged variables themselves. In these terms, be any two variables x and y, your best estimates of those variables are:

$$y_t = \sum_{i=1}^{n} \alpha_i\, x_{t-1} + \beta_j y_{t-j} + u_{1t}$$

$$x_t = \sum_{i=1}^{n} \lambda_i x_{t-1} + \delta_j y_{t-j} + u_{2t}$$

As this is an autoregressive model, it is possible to assume that the error terms are non-autocorrelated. These two regressions assume the assumption of two-sided causality in which *x* causes *y* and *y* causes *x*. However, if only *x* causes *y*, or if only *y* causes *x*, there is said to be unidirectional causality in the Granger sense. Ultimately, if the set of estimated coefficients of *x* and *y* is statistically different from zero, it is said that there is bilateral causality. The same exercise can be extended to a greater number of variables [22].

*Data source*

The study covers 8 major rice markets in India: Chennai, Kolkata, Lucknow, Ludhiana, Visakhapatnam, New Delhi, Mumbai and Patna along with the all-India average price of rice. The selection of the markets for our study is based on the production in and consumption of rice in India. The data of average monthly retail and wholesale price of rice (Rs. per quintal) for these centres for the period of January 2014 to June 2023, totalling 114 observations were obtained from the ministry of department of consumer affairs, GOI website. The wholesale price refers to the price at which the retailers purchase the Rice, while the retail price is the price at which the consumers purchase Rice.

## RESULTS AND DISCUSSION

*Descriptive statistics*

Summary statistics of the price data of different markets were computed and are reported in (Table 1).

Table 1 Descriptive statistics

| | Wholesale Price (Rs per Quintal) | | | | | Retail Price (Rs. Per Quintal) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Maximum | Minimum | Std. Dev. | Mean | Median | Maximum | Minimum | Std. Dev. |
| Chennai | 3526.219 | 3200.0 | 5093.33 | 2000.00 | 1001.93 | 4155.079 | 3600.0 | 6100 | 2700 | 1128.245 |
| Kolkata | 2451.656 | 2500.0 | 3173.68 | 1716.13 | 291.60 | 2991.158 | 2896.0 | 4292 | 2116 | 579.192 |
| Lucknow | 2335.130 | 2321.6 | 2959.67 | 1837.89 | 250.68 | 2710.368 | 2700.0 | 4250 | 2100 | 439.323 |
| Ludhiana | 2486.816 | 2500.0 | 2803.45 | 2050.00 | 185.56 | 3068.368 | 3159.0 | 3993 | 2300 | 426.456 |
| Mumbai | 2515.179 | 2500.0 | 3046.67 | 2088.64 | 159.50 | 3139.193 | 3060.5 | 3747 | 2900 | 204.010 |
| New Delhi | 2565.772 | 2575.2 | 3193.55 | 2193.10 | 207.60 | 3224.333 | 3200.0 | 3900 | 2767 | 260.764 |
| Patna | 2804.768 | 2800.0 | 3483.33 | 2100.00 | 353.24 | 3105.509 | 3200.0 | 3967 | 2400 | 407.159 |
| Visakhapatnam | 2912.209 | 2900.0 | 4800.00 | 2100.00 | 568.95 | 3379.939 | 3200.0 | 5152 | 2500 | 694.951 |

Table 2 ADF test result for the series

| | Wholesale Prices | | Retail Prices | |
|---|---|---|---|---|
| | At level | First difference | At level | First difference |
| Kolkata | -1.353284<br>(0.6026) | -9.923782***<br>(0.000) | -0.014816<br>(0.9546) | -9.958302***<br>(0.000) |
| Chennai | -0.591979<br>(0.8670) | -9.637350***<br>(0.000) | -0.204465<br>(0.9335) | -9.786740***<br>(0.000) |
| Lucknow | -1.777220<br>(0.3901) | -10.38829***<br>(0.000) | -1.663259<br>(0.4471) | -20.41339***<br>(0.000) |
| Ludhiana | -2.460669<br>(0.1279) | -10.41005***<br>(0.000) | -1.801707<br>(0.3781) | -11.47138***<br>(0.000) |
| Visakhapatnam | -1.007166<br>(0.7489) | -8.546444***<br>(0.000) | -0.670016<br>(0.8489) | -8.231284***<br>(0.000) |
| Delhi | -1.650035<br>(0.4538) | -9.706107***<br>(0.000) | -0.940075<br>(0.7721) | -9.384663***<br>(0.000) |
| Mumbai | -0.378012<br>(0.9080) | -10.85720***<br>(0.000) | -0.257221<br>(0.9264) | -10.86828***<br>(0.000) |
| Patna | -1.086481<br>(0.7194) | -10.49137***<br>(0.000) | -1.456254<br>(0.5521) | -11.53691***<br>(0.000) |

***P<0.01, Figures in the paratheses are the p-values

The descriptive statistics provide a preliminary glimpse into the rice price formations across the major Indian wholesale and retail markets. The average prices indicate widespread cointegration between the markets. For instance, wholesale centres like Kolkata and Mumbai have remarkably similar average prices of Rs. 2451.66 and Rs. 2515.18 respectively, suggesting these regional hubs influence each other. Meanwhile, prices are noticeably higher on average in southern and eastern markets - Chennai, Visakhapatnam and Patna. This indicates some degree of geographic segmentation.

A closer examination reveals nuances to this cointegrated behaviour. While average prices are comparable in many paired markets, the extent of volatility varies considerably. For example, Mumbai wholesale prices exhibit very low standard deviation of Rs. 159.50 compared to Kolkata's Rs. 291.60. This implies Mumbai prices adjust smoothly to shocks, acting as an anchor market influencing stability in its neighbour hood. On the other hand, higher deviations in Visakhapatnam prices of Rs. 568.95 portray it as a volatile swing market. Such divergences in volatility across ostensibly cointegrated markets need further probing.

Even within the same city, wholesale and retail average prices maintain a plausible gap. Retail centres charge a premium over wholesale anywhere between 5.5% in Mumbai to 16.5% in Chennai. However, the distribution of highest and lowest recorded prices tells a story of occasional disconnects. For instance, wholesale in Chennai touched a maximum Rs. 5093.33 while retail scaled Rs. 6100 - an extraordinary 18% retail margin. Similarly, Visakhapatnam averaged 2912.21 in wholesale but retailed at 3379.94 during peak months. These outliers warrant closer scrutiny to understand breakdowns.

*Test of stationarity*

Before verifying the existence of an equilibrium relationship between the variables, the order of integration of the data used was verified. To conduct the unit root test the Dickey-Fuller test was performed. (Table 2) below presents the results of the augmented Dickey fuller test.

According to the results presented in (Table 2), it is observed that all series are non-stationary in level, given that the null hypothesis that the series has unit root was not rejected at the level of 1% significance. However, the first difference of all the variables analyzed is stationary, due to the rejection of the null hypothesis.

Thus, the results indicated that both the wholesale and retail prices in the 8 major Rice producing and consumption centres of India centre are integrated of the order 1 i.e., I (1), since they are non-stationary in level and stationary in the first difference.

*Cointegration test*

The cointegration test was used in order to determine whether the price series used are part of the same economic market, that is, the national rice market. For this, it is first necessary to identify the number of lags that should be included in the model, analyzing the criteria of likelihood ratio (IR), final prediction error (FPE), Akaike (AIC), Schwartz (SC) and Hannam-Quin (HQ). It is verified that for the series of wholesale prices, three of the five tests pointed to the inclusion of one lag. The FPE, SC and HQ criteria indicated the use of 1 lag in the model and the LR and AIC criteria indicated six and eight lags respectively. Thus, it was decided to include 1 lag in the model. Similarly, the model for retail prices also indicated the appropriate number of lags to be 1.

After the stationarity test and the appropriate number of lags for the VAR was defined, the cointegration test was performed, based on the method of Johansen [20], with the objective of finding, if any, a long-term relationship between the series, the cointegration vector(s). To ensure that there are no spurious effects, the Johansen Cointegration test is performed using the recommended specification for deterministic trend specification in the intercept, and in the intercept and trend allowing a deterministic linear trend specification [23]. The cointegration test combines two tests: trace and maximum Eigenvalue. In this test, the following null hypotheses are used: there are no cointegration vectors (r = 0), at most 1 cointegration vector (r = 1), and at most 2 cointegration vectors (r = 2).

Table 3 Johansen test to identify the number of co-integration relationships

Retail market

| Hypothesized No. of CE(s) | Eigenvalue | Trace statistic | Prob. | Max-Eigen statistic | Prob. |
|---|---|---|---|---|---|
| None* (r = 0) | 0.397784 | 165.1344 | 0.0238* | 56.79964 | 0.0165* |
| At most 1 (r = 1) | 0.253212 | 108.3348 | 0.3445 | 32.70114 | 0.6112 |
| At most 2 (r = 2) | 0.222683 | 75.63365 | 0.5200 | 28.21362 | 0.5466 |

Wholesale markets

| Hypothesized No. of CE(s) | Eigenvalue | Trace statistic | Prob. | Max-Eigen statistic | Prob. |
|---|---|---|---|---|---|
| None* (r = 0) | 0.341843 | 161.6809 | 0.038* | 56.85098 | 0.0445* |
| At most 1 (r = 1) | 0.245051 | 114.8299 | 0.188 | 36.48377 | 0.4906 |
| At most 2 (r = 2) | 0.212011 | 83.34611 | 0.2617 | 27.68641 | 0.655 |

* P<0.05

The results in (Table 3) show that, in both tests for both wholesale and retail markets, the null hypothesis that the rank of the cointegration matrix is null (r = 0) is rejected at 5% significance. In these terms, it is possible to accept the alternative hypothesis that there is at least 1 cointegration vector at 5% significance. This result is sufficient to accept the alternative hypothesis that there is at least one cointegration vector, and that the model variables are in long-term equilibrium. Cointegration implies that, however different the behavior of time series may be in the short term, in the long term, the movement of one series relative to another is stable. Therefore, there is a significant long-term relationship among the variables, with no deterministic trend and a lag length of one, suggesting the existence of a long-term equilibrium relationship between the variables can be confirmed, since a cointegration vector was identified.

*Granger causality test*

As previously identified using a Johansen cointegration test, a long-run relationship is present between the variables in both the markets. The next step is to identify existence if short run relationships and the source of variation between prices in the price transmission model using the Granger causality test. This test suggests an origin for the source of price changes and in which direction they are transmitted. The method tests the null hypothesis that one price does not cause the other, and the alternative hypothesis is that one price does causes the other. The results of this test are outlined in (Table 4) below.

The results indicate that for the wholesale market, Kolkata emerges as an influential pricing centre, Granger causing Lucknow, Delhi, Mumbai and Patna. Chennai, Ludhiana, and Visakhapatnam also demonstrate price leadership over other markets. However, there are also interdependencies observed between some market pairs like Kolkata-Mumbai and Chennai-Visakhapatnam that have bidirectional causality. Overall, the wholesale market results point to the emergence of major supply/consumption hubs like Kolkata, Chennai and Punjab's Ludhiana as pricing leaders that drive prices nationally [24].

In retail markets, similar trends are observed, but pricing leadership appears more diffused. Chennai, Visakhapatnam, Kolkata and Ludhiana emerge as markets that Granger cause and drive prices in several other major retail centres. But they are also responsive to pricing signals from other major markets. Kolkata especially stands out as market with national pricing power, Granger causing Lucknow, Mumbai, Delhi and Patna. Ludhiana also demonstrates strong linkages, driving prices in Lucknow, Mumbai, Delhi and Patna [25]. It's worth noting that these trends may be influenced by various factors such as economic activities, supply chains, consumer preferences, and regional market dynamics.

Table 4 Result of Granger's causality test

| Null hypothesis | Wholesale prices | | Retail prices | |
|---|---|---|---|---|
| | F-Statistic | Prob. | F-Statistic | Prob. |
| LUCKNOW does not Granger Cause CHENNAI | 7.71098 | 0.0065** | 3.54361 | 0.0624 |
| CHENNAI does not Granger Cause LUCKNOW | 2.44885 | 0.1205 | 16.8524 | 0.0000** |
| MUMBAI does not Granger Cause CHENNAI | 1.05162 | 0.3074 | 2.5138 | 0.1157 |
| CHENNAI does not Granger Cause MUMBAI | 4.80691 | 0.0305* | 13.3508 | 0.0004** |
| VISAKHAPATANAM does not Granger Cause CHENNAI | 3.47151 | 0.0651 | 6.0959 | 0.0151* |
| CHENNAI does not Granger Cause VISAKHAPATANAM | 3.39402 | 0.0681 | 4.5539 | 0.0351* |
| LUCKNOW does not Granger Cause KOLKATA | 3.12387 | 0.0799 | 0.94394 | 0.3334 |
| KOLKATA does not Granger Cause LUCKNOW | 4.2326 | 0.042* | 9.81543 | 0.0022** |
| MUMBAI does not Granger Cause KOLKATA | 7.19596 | 0.0084** | 2.8851 | 0.0922 |
| KOLKATA does not Granger Cause MUMBAI | 5.78819 | 0.0178* | 15.5009 | 0.0001** |
| NEW_DELHI does not Granger Cause KOLKATA | 3.39335 | 0.0682 | 0.02431 | 0.8764 |
| KOLKATA does not Granger Cause NEW_DELHI | 6.06334 | 0.0154* | 7.69454 | 0.0065** |
| PATNA does not Granger Cause KOLKATA | 13.2607 | 0.0004** | 0.65066 | 0.4216 |
| KOLKATA does not Granger Cause PATNA | 0.62423 | 0.4312 | 5.50203 | 0.0208* |
| LUDHIANA does not Granger Cause LUCKNOW | 1.85857 | 0.1756 | 8.93656 | 0.0034** |
| LUCKNOW does not Granger Cause LUDHIANA | 0.24942 | 0.6185 | 1.49645 | 0.2238 |
| MUMBAI does not Granger Cause LUCKNOW | 17.101 | 0.0000** | 9.36383 | 0.0028** |
| LUCKNOW does not Granger Cause MUMBAI | 0.91922 | 0.3398 | 0.02203 | 0.8823 |
| PATNA does not Granger Cause LUCKNOW | 6.02013 | 0.0157* | 11.5659 | 0.0009** |
| LUCKNOW does not Granger Cause PATNA | 2.92486 | 0.09 | 0.95195 | 0.3314 |
| VISAKHAPATANAM does not Granger Cause LUCKNOW | 3.94758 | 0.0494* | 19.7587 | 0.000** |
| LUCKNOW does not Granger Cause VISAKHAPATANAM | 2.64659 | 0.1066 | 3.82729 | 0.053 |
| NEW_DELHI does not Granger Cause LUDHIANA | 0.33351 | 0.5648 | 0.01081 | 0.9174 |
| LUDHIANA does not Granger Cause NEW_DELHI | 5.31267 | 0.023* | 4.4482 | 0.0372* |
| PATNA does not Granger Cause LUDHIANA | 0.02891 | 0.8653 | 0.08639 | 0.7694 |
| LUDHIANA does not Granger Cause PATNA | 5.84058 | 0.0173* | 8.9454 | 0.0034** |
| PATNA does not Granger Cause MUMBAI | 4.46665 | 0.0368* | 4.09783 | 0.0454* |
| MUMBAI does not Granger Cause PATNA | 1.79055 | 0.1836 | 2.705 | 0.1029 |
| VISAKHAPATANAM does not Granger Cause MUMBAI | 5.50239 | 0.0208* | 9.18969 | 0.003** |
| MUMBAI does not Granger Cause VISAKHAPATANAM | 2.13538 | 0.1468 | 0.42101 | 0.5178 |
| PATNA does not Granger Cause NEW_DELHI | 18.4108 | 0.000** | 8.45595 | 0.0044** |
| NEW_DELHI does not Granger Cause PATNA | 0.11523 | 0.7349 | 3.16935 | 0.0778 |
| VISAKHAPATANAM does not Granger Cause PATNA | 5.58352 | 0.0199* | 5.00379 | 0.0273* |
| PATNA does not Granger Cause VISAKHAPATANAM | 0.01641 | 0.8983 | 0.21095 | 0.6469 |

** P<0.01, and * P<0.05

But besides these lead markets, there are significant interdependencies observed between major market pairs. Chennai and Visakhapatnam have a bidirectional relationship, mutually responding to each other's pricing signals. Mumbai is reactive to Kolkata, Ludhiana and Patna but also Granger causes Lucknow. Lucknow appears as a lagging market, reflecting prices set in Chennai, Kolkata, Ludhiana, Delhi, Patna and Visakhapatnam. A few differences emerge between wholesale and retail market linkages. In wholesale trade, Ludhiana is more of a price leader compared to retail markets. But in both wholesale and retail, Kolkata and Chennai emerge as influential markets. Mumbai has more of a lagging response in retail trade than in wholesale. But in general, the broad lead-lag relationships are similar in wholesale and retail segments.

The emergence of certain wholesale and retail markets like Kolkata, Chennai and Ludhiana as pricing leaders has important implications in light of the geographic segmentation of rice production and consumption across India. The strong role of Kolkata in price discovery aligns with West Bengal's position as the largest rice producing state in India, accounting for approximately 13% of the total grain production in 2020-21 crop year. As a major rice bowl, the Kolkata market reflects pricing signals from across Eastern India's production catchment. Its linkage with Mumbai and other consumption centres indicates efficient arbitrage between surplus east and deficit western regions. Chennai's and Visakhapatnam's influence across southern and western retail markets similarly underscores its importance as the gateway for Tamil Nadu and Andhra Pradesh's rice output. Chennai's pricing power across retail markets like Mumbai and Lucknow points to strong pan-India integration. Punjab is India's second largest rice producer after West Bengal, with Ludhiana at the heart of its grain trade. Ludhiana emerging as a pricing leader in wholesale and retail markets of Central and western India. highlights the integration of Punjab's grain markets with national trends [26-27].

The lagged response of markets like Lucknow and Patna point to potential deficiencies in transmission from producing regions to these large consumption centres. Lucknow is the capital of Uttar Pradesh, India's largest rice consuming state, dependent on supplies from Punjab, Haryana, Bihar and Madhya Pradesh. The weak price linkages indicate infrastructure bottlenecks may be hindering efficient arbitrage and transmission of pricing signals from surplus to deficit regions. Similar infrastructure constraints may be impacting price discovery in Patna, catering to the large rice consumption base of Bihar. As Bihar is also a major rice producer, the lack of lead-lag influence with other markets points towards potential deficiencies in market linkages. The interdependent relationships between cities like Kolkata-Mumbai, Chennai-Visakhapatnam indicate efficient arbitrage between major coastal demand and supply centres [28-29]. The findings shed light on the geographic segmentation of India's rice markets along regional lines. Key production clusters are able to exert pricing power over other regions. But second-tier markets are not effectively transmitting pricing signals between surplus and deficit areas. This has implications for infrastructure development policies. Investments in transportation, storage and marketing infra can help integrate disjointed markets and improve price discovery [30]. Targeted investments can strengthen pan-India integration and transmission efficiency.

## CONCLUSION

This study aimed to examine the degree of horizontal price transmission and market integration across eight major rice markets in India. By employing the cointegration and Granger causality approach, the research provides valuable insights into the linkages between these key markets for both wholesale and retail prices over the period 2014-2023. The findings of long-run cointegration amongst the market prices confirm the existence of a stable long-term equilibrium relationship between the eight selected markets. This signifies that these markets move together over time, responding to common supply and demand shocks. The results of the Granger causality tests reveal the presence of both unilateral and bidirectional causal relationships, pointing to significant two-way interactions between many market pairs. Certain centres such as Kolkata, Chennai and Ludhiana emerge as clear pricing leaders, highlighting their importance in price discovery. On the other hand, markets like Lucknow and Patna demonstrate lagged responsiveness, underscoring potential weaknesses in transmission from surplus to deficit regions. The analysis carries useful policy implications. It provides insights into efficient arbitrage relationships as well as infrastructure gaps affecting linkage between key surplus and deficit areas. The study's findings underscore the need for targeted regional development policies that strengthen interconnectivity between disjointed production clusters and consumption hubs. If addressed appropriately, such measures can boost price signals across India's rice value chain. Similar methodology can be applied to other agricultural commodities in India to identify infrastructure needs and frame appropriate market linkage policies. The study provides valuable insights into the dynamics of rice markets in India, emphasizing the importance of certain centers, identifying areas for improvement in market linkages and suggesting policy directions for regional development and strengthened connectivity within the supply chain.

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