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Eggcellent Insights: Co-integration Analysis and Predictive Modeling across Production and Consumption Centers in India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Growing demand for poultry products has captured the attention of market aspects of poultry industry. In this dynamic market, how well the market functionaries are operating, to what extend the price transmissions are captured and delivered to the stakeholders and such queries are vividly explained by this study. The daily wholesale prices of major egg markets, comprising production and consumption centers listed by National Egg Coordination Committee web portal, for a period of

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486 days were taken for the study. Johansen's co-integration test was applied to identify whether the spatially separated markets are co-integrated or not. Post analysis of unit root test by Augmented Dickey Fuller statistic, it is evident that the selected egg markets are co-integrated in the long run. While in the short run dynamics, the Vector Error Correction Model (VECM) explains the price transmission and speed of price adjustment among the egg markets. Granger's causality test showed bidirectional influence of price among selected markets. The currently evolving Long Short-Term Memory (LSTM) model revealed that the model is viable in performing the predictions of future egg prices, but it does not coincide with the National Egg Coordination Committee (NECC) depicted prices. Further improvements could be focused on the egg price prediction process; which ultimately benefits all the stakeholders in this agribusiness.

Keywords: Egg; co-integration; VECM; LSTM.

1. INTRODUCTION

Indian poultry industry is a sunshine industry. In order to cater the food need of the growing population, the poultry industry imparts crucial role. India is the third largest producer of eggs. Egg production has reached 129.60 billion with a compounded annual growth rate (CAGR) of 7.40 percent in the base year 2014-15 (FAOSTAT, 2020). Various factors such as expanding population, change in consumer dietary patterns, increase in disposable income, emergence of food service sector, and balanced intake of nutrients are the key drivers of the poultry sector (Adegbite et al., 2014).

According to the International Marketing Analysis Research and Consulting Group, the Indian poultry market size reached 2099.2 billion rupees in 2023 and expects the market to reach 4620.70 billion rupees by 2032, exhibiting a CAGR of 8.90 percent during 2024-2032 (IMARC, 2023). The per capita availability of egg has increased from 62 to 101 eggs per annum during the period 2014-15 and 2022-23 respectively (PIB, 2023). Andhra Pradesh followed by Tamil Nadu and Maharashtra are the major egg producers.

Considering the importance of egg markets and associated price volatility, NECC was formed in 1982 as an institutional framework for setting up of the prices of egg in various markets of India. It is a consortium of several poultry farmers wherein they are able to access daily egg price in a transparent manner (Saran & Gangwar, 2008; Istiak & Khaliduzzaman, 2022).

Egg production in India is localized, with farmers supplying major market centers. As a result, egg supply to a particular consumption center often comes from multiple production centers, depending on factors like transportation infrastructure, market dynamics, and regional production capabilities.

Spatial market integration is the concept in which the price of the same commodity at a spatially segregated markets tends to move together or exhibiting an integration in their price behavior. Theories suggests that, in long run, the price variables may end up in an equilibrium stage. Well, it is not a static process; sometimes it can be drift the equilibrium, but still the economic forces will bring back the system to the initial equilibrium by means of adjustments (Kaur et al., 2010). Granger (1981), coined the concept of spatial market integration. In case of egg market, there is a great likelihood to witness the co-integration of market and price transmission signals, provided the markets are performing efficiently and effectively.

It is imperative that there are no adequate studies to evaluate the market co-integration of poultry sector. The data sourced from NECC clearly envisage the scope of market integration and price transmission feedback mechanism among the markets (Johansen & Juselius, 1990). Hence, the present study aims to examine the presence of market co-integration among various egg markets, also to capture the feedback mechanism and price transmission among the selected egg markets. There are many predictive analytics tools to track the future price. One of the most popular among the predictive tools is the long short-term memory (LSTM), which is a variation of a recurrent neural network (RNN). So an attempt is made to validate the accuracy of this tool in predicting the future prices of eggs in various market by comparing the actual value to the LSTM predicted value.

2. MATERIALS AND METHODS

Data pertaining to the daily wholesale prices of eggs in various markets were collected from the official website of NECC. A total of eight markets including four production markets (Kolkata, Namakkal, Warangal and West Godavari) and four consumption market (Bengaluru, Delhi, Mumbai and Chennai). These markets were selected on the basis of availability of the data from the website. Those markets were selected on the basis of highest production and highest consumption of eggs respectively. The data on daily wholesale egg price was collected for a period of 486 days (1st January 2023 to 31st April 2024).

Many time series data are characterized by the unit root functionality which may distort the analysis. So, it is preferable to have data with same lag length of differencing. Technically, we are converting non stationary data into stationary for an effective analysis. Traditionally, the market integration was analyzed using correlation coefficient. But now a days, the concept of co-integration test gained popularity due to its efficacy in measuring the concept.

The null hypothesis formulated for testing the co-integration is that 'wholesale price of the eggs in various markets of the country are not co-integrated'. Hence, the alternative hypothesis states that the egg prices of various markets are co-integrated has been tested by employing the Johansens maximum likelihood method of co-integration. Initially, the data is tested for the presence of unit root by employing Augmented Dickey-Fuller (ADF) test in EViews statistical package. The following regression equation were tested for ADF unit root test:

$$\Delta Yt = \beta 1 + \beta 2\ t + \alpha\ Y_{t-1} + \alpha_i \sum_{i=1}^{m} \Delta\ Yt - 1\ + u_t$$

Where, Y_t is a vector for testing co-integration, t is the time, $\Delta Y_t = Y_t - Y_{t-1}$ indicates the level of differencing and u_t is the error term. The null hypothesis indicates that there is unit root or the time series is non-stationary, while the alternative hypothesis signifies that the time series is stationary, thus rejecting the null hypothesis based on the accepted significance level. In a co-integrated equation system,

$$\Delta Y_t = \sum_{i=1}^{k-1} \Gamma_i\, \Delta Y_{t-i} + \alpha\, \beta'\, Y_{t-1} + \epsilon_t$$

Where, ΔY_t is the is the first difference operator ($Y_t - Y_{t-1}$), and $\Pi = \alpha\beta'$ is an n×n matrix with rank r ($0 \le r \le n$). Johansen's method uses a maximum likelihood approach with rank restrictions on Π, determining the rank using the λ_{trace}test statistic,

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

Where, $\lambda_i\hat{}$ are eigenvalues representing the correlation strength between the differenced data and the error-correction term. The hypotheses H_0: rank of Π = r is tested against H_1: rank of Π> r. The test assumes a linear trend in the original data and an intercept in the co-integrating equation.

Following co-integration testing, residual deviations from equilibrium are modelled using the Vector Error Correction Model (VECM) (Brosig *et al*., 2011). This model, applied exclusively to the co-integrated markets, incorporates a linear deterministic trend and specifies the number of co-integration equations between them. It is represented as:

$$\Delta X_t = \alpha_0 + \alpha_1 \Delta Y_t + \alpha_2 u_{t-1} + \epsilon_t$$

Here, X_t and Y_t represent the prices of markets X and Y, respectively, and u_{t-1} is the co-integration vector. The coefficient α_2 of the error correction term u_{t-1}indicates the speed at which the series return to equilibrium. A negative (positive) α_2 implies convergence (divergence) to/from long-run equilibrium. If the estimated coefficient of market Y is negative (positive), it implies that a decrease (increase) in the previous period's equilibrium error leads to a decrease (increase) in the current period's price, and vice versa.

Granger's causality test is applied to explore the lead lag relationship between the prices of pairs of markets. Suppose there are two markets A and B, the null hypotheses states that, A does not granger cause B. Once it is statistically significant, then can conclude the influence of lag values of A over B or vice versa.

In order to predict and validate the accuracy of LSTM model of forecasting, an RNN model is constructed. After various trials and experiments, three lags interval and for a forecast period of 14 days (1st May 2024 to 15th May 2024) were considered. The analysis was conducted using the Python 3.9 statistical package. A simple LSTM equation modelling for 3 lags are illustrated below:

$$X_1, X_2, X_3, X_t, X_{t+1}, X_{t+2}, \ldots, Xt_{+n}$$

$$X_1+X_2+X_3= X_t;\ X_2+X_3+X_t= X_{t+1};\ X_3+X_t+X_{t+1}= X_{t+2}$$

Where, X_1, X_2, X_3 are the past observations and X_t, X_{t+1}, X_{t+2} are the forecast values.

3. RESULTS AND DISCUSSION

3.1 Price Behaviour

The analysis of egg prices across various markets yield significant insights into market dynamics. The major markets were selected purposefully from the various parts of the country (Table 1). Kolkata recorded the highest maximum price at INR 675 per 100 eggs, while Namakkal exhibited the lowest maximum price at INR 585 per 100 eggs (Table 2). The minimum price is lowest in West Godavari at INR 345 per 100 eggs and highest in Chennai at INR 415 per 100 eggs. Delhi demonstrates the greatest price variability with a range of INR 307, whereas Namakkal shows the smallest range at INR 185.

The mean price analysis reveals that Kolkata has the highest average price at INR 541.16 per 100 eggs, indicating a generally more expensive market, while Warangal has the lowest average price at INR 470.59 per 100 eggs, suggesting relatively cheaper prices. Delhi displays the highest price volatility, with a standard deviation of 77.13 and a variance of 5949.65, indicating significant price fluctuations. Conversely, Namakkal shows the least volatility, with a standard deviation of 49.22 and a variance of 2422.27.

Skewness values suggest that most markets have a near-symmetrical distribution of prices, with Delhi showing a slight positive skewness and Kolkata a slight negative skewness. Negative kurtosis values across all cities indicate a flatter distribution with fewer extreme price variations.

3.2 Market Integration

The correlations indicate strong interconnectedness between egg markets in India. The highest correlations are observed between Mumbai and Warangal, Bengaluru and Chennai, and Kolkata and West Godavari, suggesting that prices in these cities move almost in tandem (Table 3). Even the lowest significant correlations (e.g., between Chennai and Kolkata or Delhi and Namakkal) still indicate a substantial degree of price alignment, reflecting an overall integrated market.

The Augmented Dickey-Fuller (ADF) test results (Table 4) reveal that the egg price series for all markets are non-stationary at the level series, as indicated by ADF statistics higher than the critical values. However, after taking the first differences, all markets show ADF statistics significantly lower than the critical values, indicating that the series become stationary. So the price series are stationary at first differencing with an order one, which supports the insights of Saran and Gangwar (2008). This implies that the price data for these markets follow a unit root process and require differencing to achieve stationarity. This process is a precursor for testing the market co-integration.

Johansens co-integration test of both trace test and maximum Eigen value (Table 5) reveals that the null hypothesis of no co-integration among the selected egg markets get rejected with an at most three co-integrating equations at five percent level of probability. Similar results were also shared by Sendhil *et al.,* (2013); Saran and Gangwar, (2008) and Chidananda *et al.,* (2014). The objective of this test is to identify whether the egg markets are co-integrated in the long run and there is an actual price transmission between the markets. Hence, it is clear that there is a long run equilibrium among the selected egg markets.

In a Vector Error Correction Estimation (VECM), the co-integrating equations captures the long-term relationships among the variables, while the error correction terms capture the short-term adjustments to deviations from that long-term equilibrium. Based on the number of highly significant coefficients and a general assumption, Namakkal and Mumbai were assumed as the major egg producing and consuming centres in India respectively (Table 6). So, the long run relationship through VECM of Namakkal and Mumbai egg prices with those of their one period lag prices of other markets is depicted in the following equations:

Namakkal price= 0.002 +0.026*West Godavari +0.241*Warangal price +0.289*Namakkal price +0.052*Mumbai price +0.074*Kolkata price -0.04*8Delhi price -0.133*Chennai price +0.146*Bengaluru price - Eq. (1)

Mumbai price= -0.034 +0.099*West Godavari +0.256*Warangal price +0.026*Namakkal price -0.163*Mumbai price +0.233*Kolkata price -0.034*8Delhi price -0.102*Chennai price +0.273*Bengaluru price - Eq. (2)

Table 1. Egg markets chosen from various states/ Union territories

SN	Market	State	Criteria for selection*
1	Bengaluru	Karnataka	Consumption
2	Chennai	Tamil Nadu	Consumption
3	Delhi	Delhi	Consumption
4	Mumbai	Maharashtra	Consumption
5	Kolkata	West Bengal	Production
6	Namakkal	Tamil Nadu	Production
7	West Godavari	Andhra Pradesh	Production
8	Warangal	Telangana	Production

(Based on highest production/ consumption, the chosen markets were sourced from NECC portal)*

Table 2. Descriptive statistics of egg market prices

Particulars	Bengaluru	Chennai	Delhi	Mumbai	Kolkata	Namakkal	West Godavari	Warangal
Observations (Days)	486	486	486	486	486	486	486	486
Maximum price (INR/100 eggs)	635	640	665	672	675	585	620	609
Minimum price (INR/100 eggs)	400	415	358	410	400	400	345	352
Range (INR/100 eggs)	235	225	307	262	275	185	275	257
Mean price (INR/100 eggs) price	516.07	529.79	491.88	532.84	541.16	481.88	481.84	470.59
Standard deviation	58.34	54.36	77.13	64.88	61.88	49.22	60.45	64.85
Variance	3403.60	2955.11	5949.65	4209.46	3828.62	2422.27	3653.89	4205.04
Skewness	-0.02	0.03	0.27	0.01	-0.13	0.16	-0.09	-0.03
Kurtosis	-1.27	-1.23	-1.11	-1.23	-0.87	-1.22	-1.01	-1.21

Table 3. Correlation in egg prices among selected markets in India

Market (n=486)	Bengaluru	Chennai	Delhi	Mumbai	Kolkata	Namakkal	West Godavari	Warangal
Bengaluru	1							
Chennai	0.99	1						
Delhi	0.87	0.86	1					
Mumbai	0.97	0.96	0.93	1				
Kolkata	0.88	0.85	0.91	0.93	1			
Namakkal	0.96	0.94	0.85	0.95	0.85	1		
West Godavari	0.93	0.91	0.94	0.97	0.98	0.89	1	
Warangal	0.96	0.94	0.93	0.99	0.95	0.94	0.97	1

Table 4. ADF statistic estimate for the unit root test

Market	ADF (Level Series)	ADF (First differenced Series)	Critical value (1%)
Bengaluru	-2.08	-14.44	-3.44
Chennai	-2.17	-10.91	-3.44
Delhi	-1.24	-17.04	-3.44
Mumbai	-1.60	-14.52	-3.44
Kolkata	-2.09	-16.68	-3.44
Namakkal	-2.51	-4.88	-3.48
West Godavari	-1.73	-5.22	-3.48
Warangal	-1.64	-7.38	-3.48

Table 5. Results of Johansen's Unrestricted Co-integration Rank Test (Maximum Eigen Value)

Hypothesized No. of CE(s)	Eigen Value	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None*	0.18	98.81	52.36	0.00
At most 1*	0.14	77.53	46.23	0.00
At most 2*	0.12	62.66	40.07	0.00
At most 3*	0.07	36.74	33.87	0.02
At most 4	0.03	19.36	27.58	0.38
At most 5	0.02	14.45	21.13	0.32
At most 6	0.01	6.46	14.26	0.55
At most 7	0.00	1.69	3.84	0.19

Trace test indicates 4 co-integrating equations at the 0.05 level
** Denotes rejection of the hypothesis at the 0.05 level*
***MacKinnon-Haugh-Michelis (1999) p-values*

The market with positive market price series coefficients indicates the divergence from the equilibrium in short run and the one with negative coefficients converge to the long run equilibrium. The speed of adjustment of egg prices in the long run is expressed by the magnitude of the associated respective coefficients.

In equation (1), the egg price of Namakkal market is corrected by the following markets. In short run, about 0.2 percent of the changes in daily price get corrected by itself. While, the rest of the part is corrected through the influence of the one period lag in Warangal, Mumbai, Kolkata, Chennai and Bengaluru with respect to their significance. There is a positive influence of the lagged market price of Namakkal market to its current price.

In equation (2), the egg price of Mumbai market is corrected by the following markets. In short run, about 3.4 percent of the changes in daily price get corrected by itself. While, the rest of the part is corrected through the influence of the one period lag in Warangal, Kolkata, and Bengaluru with respect to their significance. There is a negative influence of one period lagged market price of Mumbai market to its current price, indicating a self-correcting mechanism.

Similar kind of observations can be drawn from the other producing and consuming egg markets. Among the markets, one period lag of Kolkata and Warangal does have the greatest impact on the current wholesale egg prices of other markets.

3.3 Causal Dependency among the Egg Markets

In order to identify the lead-lag price relationship and price movements between the pairs of egg markets, Granger's causality test was employed (Table 7). For a better understanding, causality test for selected producing and consuming egg markets are depicted separately. The influence of each market pair is indicated by single and double arrow heads. Single arrow head indicates unidirectional influence of the market. While, double arrow head indicates bidirectional influence of the market. In producing market scenario, Namakkal market does not Granger cause Warangal market (Fig. 1). While the rest of markets have bidirectional influence. In the case of consuming markets, there is a proportionate mix of unidirectional and bidirectional price influence (Fig. 2).

Table 6. Results of VECM Estimates for the selected egg markets

Error Correction	Dependent Variable						
	D(log_War)	D(log_Nam)	D(log_Mum)	D(log_Kol)	D(log_Del)	D(log_Che)	D(log_Ben)
ECT	0.022	0.002	-0.034	-0.035	-0.020	-0.001	-0.028
	[0.450]	[0.058]	[-0.495]	[-0.445]	[-0.715]	[-0.033]	[-0.388]
D(log_Wgod(-1))	-0.005	0.026	0.099	0.009	0.036	0.008	0.010
	[-0.140]	[0.886]	[1.901]	[0.153]	[1.692]	[0.217]	[0.193]
D(log_War(-1))	0.419	0.241	0.256	0.146	0.445	0.421	0.348
	[7.987]**	[5.815]**	[3.527]**	[1.759]	[15.013]**	[7.451]**	[4.594]**
D(log_Nam(-1))	0.219	0.289	0.026	-0.241	0.241	0.241	0.241
	[3.727]**	[6.217]**	[0.330]	[5.815]	[5.815]	[5.815]	[5.815]
D(log_Mum(-1))	0.157	0.052	-0.163	-0.122	0.0003	0.098	-0.010
	[2.861]**	[1.194]	[-2.137]**	[-1.398]	[0.009]	[1.647]	[-0.128]
D(log_Kol(-1))	0.177	0.074	0.233	0.329	0.013	0.165	0.238
	[4.824]**	[2.574]**	[4.596]**	[5.670]**	[0.649]	[4.188]**	[4.500]**
D(log_Del(-1))	0.022	-0.048	0.034	0.085	0.028	0.023	0.144
	[0.637]	[-1.741]	[0.709]	[1.554]	[1.456]	[0.617]	[2.877]**
D(log_Che(-1))	-0.039	-0.133	-0.102	-0.030	-0.031	0.015	-0.044
	[-0.801]	[-3.414]**	[-1.493]	[-0.389]	[-1.120]	[0.299]	[-0.628]
D(log_Ben(-1))	-0.029	0.146	0.273	0.151	0.113	0.0003	0.045
	[-0.452]	[2.887]**	[3.084]**	[1.486]	[3.121]**	[0.005]	[0.490]
R- Squared	0.488	0.609	0.279	0.203	0.803	0.307	0.218
F-Statistic	37.416	61.349	15.241	10.010	160.734	23.119	10.958

*Notes: **Denotes the significance of coefficient at the five percent level of probability*
ECT= Error Correction Term
D= First Difference Operator; [ ] t-statistic

Table 7. Results of causal dependency of the selected egg markets

Null Hypothesis	Obs.	F-Statistics	Prob.	Reject H_0
CHENNAI does not Granger Cause BENGALURU	484	1.749	0.174	No
BENGALURU does not Granger Cause CHENNAI		182.804	1.E-59	Yes
DELHI does not Granger Cause BENGALURU	484	15.996	2.E-07	Yes
BENGALURU does not Granger Cause DELHI		24.34	9.E-11	Yes

Null Hypothesis	Obs.	F-Statistics	Prob.	Reject H_0
KOLKATA does not Granger Cause BENGALURU	484	38.783	2.E-16	Yes
BENGALURU does not Granger Cause KOLKATA		4.367	0.013	Yes
MUMBAI does not Granger Cause BENGALURU	484	22.830	3.E-10	Yes
BENGALURU does not Granger Cause MUMBAI		38.820	2.E-16	Yes
NAMAKKAL does not Granger Cause BENGALURU	484	20.403	3.E-09	Yes
BENGALURU does not Granger Cause NAMAKKAL		6.963	0.001	Yes
WARANGAL does not Granger Cause BENGALURU	484	118.880	1.E-42	Yes
BENGALURU does not Granger Cause WARANGAL		1.308	0.271	No
WGODAVARI does not Granger Cause BENGALURU	484	22.763	4.E-10	Yes
BENGALURU does not Granger Cause WGODAVARI		20.318	3.E-09	Yes
DELHI does not Granger Cause CHENNAI	484	6.931	0.001	Yes
CHENNAI does not Granger Cause DELHI		2.541	0.079	No
KOLKATA does not Granger Cause CHENNAI	484	21.064	2.E-09	Yes
CHENNAI does not Granger Cause KOLKATA		0.022	0.977	No
MUMBAI does not Granger Cause CHENNAI	484	35.225	5.E-15	Yes
CHENNAI does not Granger Cause MUMBAI		4.354	0.013	Yes
NAMAKKAL does not Granger Cause CHENNAI	484	182.523	1.E-59	Yes
CHENNAI does not Granger Cause NAMAKKAL		7.116	0.001	Yes
WARANGAL does not Granger Cause CHENNAI	484	95.446	1.E-35	Yes
CHENNAI does not Granger Cause WARANGAL		2.436	0.088	No
WGODAVARI does not Granger Cause CHENNAI	484	37.236	9.E-16	Yes
CHENNAI does not Granger Cause WGODAVARI		18.234	2.E-08	Yes
KOLKATA does not Granger Cause DELHI	484	35.995	3.E-15	Yes
DELHI does not Granger Cause KOLKATA		3.869	0.021	Yes
MUMBAI does not Granger Cause DELHI	484	2.655	0.071	No
DELHI does not Granger Cause MUMBAI		27.863	4.E-12	Yes
NAMAKKAL does not Granger Cause DELHI	484	19.579	7.E-09	Yes
DELHI does not Granger Cause NAMAKKAL		20.633	3.E-09	Yes
WARANGAL does not Granger Cause DELHI	484	36.565	2.E-15	Yes
DELHI does not Granger Cause WARANGAL		11.661	1.E-05	Yes
WGODAVARI does not Granger Cause DELHI	484	20.441	3.E-09	Yes
DELHI does not Granger Cause WGODAVARI		18.550	2.E-08	Yes
MUMBAI does not Granger Cause KOLKATA	484	1.795	0.167	No
KOLKATA does not Granger Cause MUMBAI		55.893	2.E-22	Yes

Null Hypothesis	Obs.	F-Statistics	Prob.	Reject H_0
NAMAKKAL does not Granger Cause KOLKATA	484	4.256	0.014	Yes
KOLKATA does not Granger Cause NAMAKKAL		44.033	3.E-18	Yes
WARANGAL does not Granger Cause KOLKATA	484	18.311	2.E-08	Yes
KOLKATA does not Granger Cause WARANGAL		27.567	5.E-12	Yes
WGODAVARI does not Granger Cause KOLKATA	484	9.043	0.000	Yes
KOLKATA does not Granger Cause WGODAVARI		161.960	2.E-54	Yes
NAMAKKAL does not Granger Cause MUMBAI	484	42.861	8.E-18	Yes
MUMBAI does not Granger Cause NAMAKKAL		14.841	6.E-07	Yes
WARANGAL does not Granger Cause MUMBAI	484	676.193	3.E-140	Yes
MUMBAI does not Granger Cause WARANGAL		3.417	0.033	Yes
WGODAVARI does not Granger Cause MUMBAI	484	38.176	4.E-16	Yes
MUMBAI does not Granger Cause WGODAVARI		9.852	6.E-05	Yes
WARANGAL does not Granger Cause NAMAKKAL	484	86.977	6.E-33	Yes
NAMAKKAL does not Granger Cause WARANGAL		0.827	0.438	No
WGODAVARI does not Granger Cause NAMAKKAL	484	18.363	2.E-08	Yes
NAMAKKAL does not Granger Cause WGODAVARI		12.460	5.E-06	Yes
WGODAVARI does not Granger Cause WARANGAL	484	5.250	0.005	Yes
WARANGAL does not Granger Cause WGODAVARI		81.477	3.E-31	Yes

Table 8. Actual and forecasted (LSTM prediction) egg price of selected markets in India

	Actual Price (Forecasted Price)							
Day	**Bengaluru**	**Chennai**	**Delhi**	**Mumbai**	**Kolkata**	**Namakkal**	**WGodavari**	**Warangal**
01-05-2024	450 (444)	475 (461)	390 (374)	435 (427)	415 (418)	420 (417)	370 (352)	367 (362)
02-05-2024	470 (447)	485 (462)	410 (378)	455 (428)	440 (426)	440 (419)	385 (354)	402 (367)
03-05-2024	490 (450)	500 (463)	450 (381)	475 (429)	470 (435)	460 (422)	440 (364)	427 (372)
04-05-2024	520 (454)	530 (464)	450 (384)	495 (431)	480 (443)	480 (424)	450 (384)	447 (378)
05-05-2024	540 (457)	550 (465)	450 (388)	520 (432)	480 (451)	500 (427)	460 (410)	467 (382)
06-05-2024	550 (460)	570 (466)	450 (391)	530 (433)	495 (459)	510 (429)	460 (418)	477 (386)
07-05-2024	555 (463)	570 (467)	475 (394)	535 (434)	510 (466)	515 (431)	460 (420)	482 (388)
08-05-2024	560 (465)	570 (468)	475 (396)	540 (435)	525 (472)	520 (433)	465 (421)	487 (390)
09-05-2024	565 (468)	580 (469)	490 (399)	545 (436)	560 (478)	525 (435)	485 (420)	492 (390)
10-05-2024	580 (470)	580 (470)	530 (401)	575 (437)	605 (481)	535 (437)	525 (419)	512 (390)
11-05-2024	590 (473)	605 (471)	540 (403)	590 (438)	605 (485)	545 (439)	540 (417)	527 (389)

	Actual Price (Forecasted Price)							
Day	**Bengaluru**	**Chennai**	**Delhi**	**Mumbai**	**Kolkata**	**Namakkal**	**WGodavari**	**Warangal**
12-05-2024	595 (476)	615 (472)	540 (405)	595 (439)	605 (489)	550 (440)	540 (417)	532 (388)
13-05-2024	605 (478)	615 (472)	540 (407)	601 (439)	605 (492)	555 (441)	540 (416)	537 (387)
14-05-2024	610 (480)	615 (473)	500 (408)	605 (440)	605 (495)	560 (443)	540 (416)	542 (386)
15-05-2024	615 (482)	625 (474)	500 (410)	610 (440)	575 (498)	565 (444)	540 (414)	547 (385)

Table 9. Validation of LSTM forecast values using various metrics

Metrics	Bengaluru	Chennai	Delhi	Mumbai	Kolkata	Namakkal	WGodavari	Warangal
Mean Absolute Error (MAE)	88.53	97.87	84.73	105.87	66.20	79.93	77.20	100.33
Mean Squared Error (MSE)	9271.73	11449.60	8446.20	13741.20	6029.00	7594.07	7437.60	12062.33
Root Mean Squared Error (RMSE)	96.29	107.00	91.90	117.22	77.65	87.14	86.24	109.83
Mean Absolute Percentage Error (MAPE)	15.48	16.75	17.12	18.80	11.60	15.11	15.43	19.95
R-squared (Coefficient of Determination)	0.96	0.94	0.82	0.99	0.91	0.97	0.75	0.76

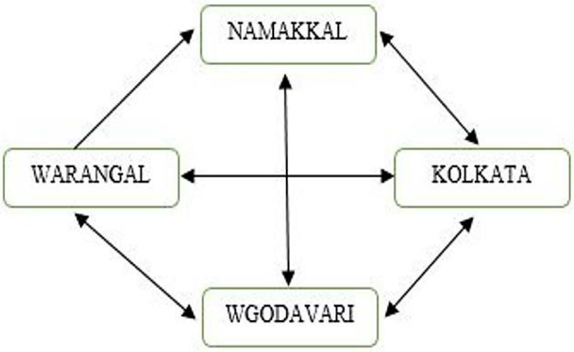

Fig. 1. Causal dependency of the selected egg production markets

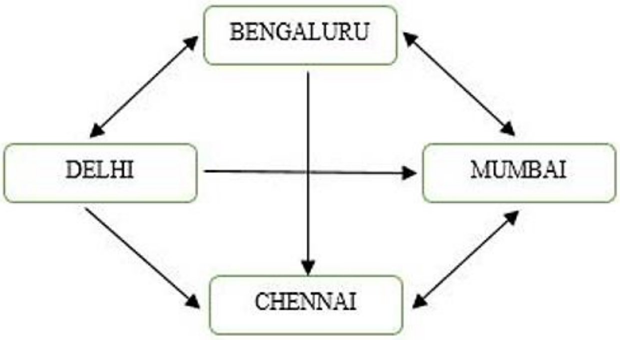

Fig. 2. Causal dependency of the selected egg consumption markets

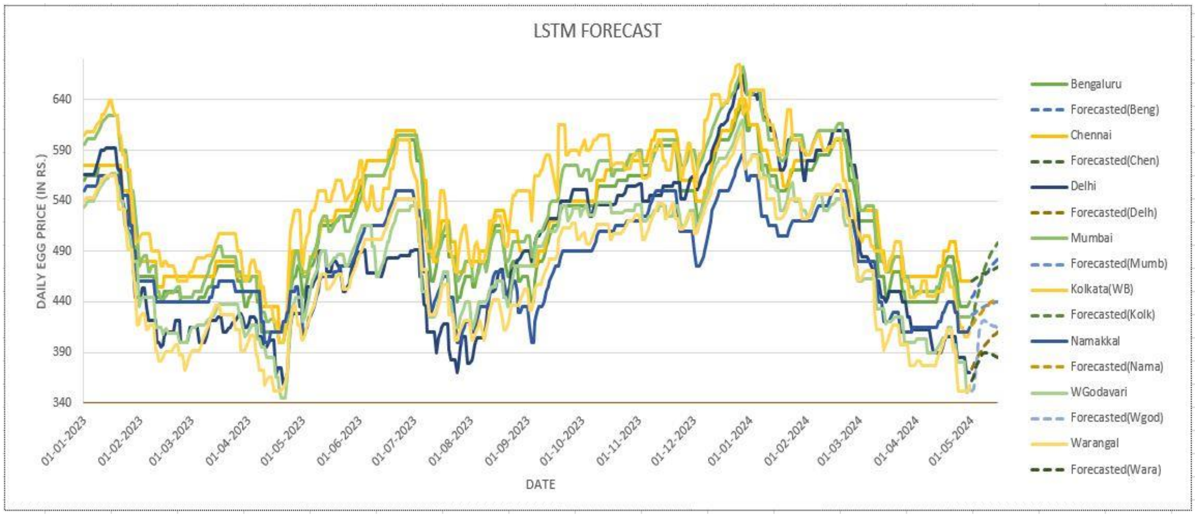

Fig. 3. Actual and forecasted egg price of the selected markets in India

3.4 Validation of LSTM Forecast

The actual and predicted value of wholesale egg price of the selected egg markets are represented in Table 8 and Fig. 3. Several metrics like MAE, MSE, RMSE, MAPE, and R-squared values are used to measure the performance of LSTM model for predicting the egg prices (Table 9). Based on the results of various metrics, markets such as Bengaluru, Chennai, Namakkal, and Mumbai exhibits high accuracy and explanatory power. These markets are having higher R squared value along with acceptable value limits of MAE, RMSE and MAPE. While Delhi and Kolkata exhibit moderate accuracy followed by West Godavari and Warangal. Overall, technically the LSTM model demonstrates robust performance in prediction, but in comparison with the price depicted by NECC, there is a significant gap between these two predictions which are contrary in nature.

4. CONCLUSIONS

Johansen's co-integration test has been used to study the co-integration among various wholesale egg markets in the country. In order to identify the stationarity of data, the price series where subjected to ADF testing and revealed that selected markets are stationary at first differencing of order one. The maximum Eigen value test suggested the existence of four co-integrating equations implying the long run equilibrium among the selected egg markets. The VECM estimates has explained the speed of corrections and price transmission among the markets in the short run. It was found that the egg markets are highly co-integrated and there is unidirectional and bidirectional flow of market information among the egg markets which is evident by Granger's causality test. The LSTM prediction of future egg prices deciphered that the model is viable in performing the predictions, but it does not coincide with the depiction of NECC proposed prices. The prediction gap is explained by the inability of this model to work in a highly fluctuating data. Further improvements could be focused on the egg price prediction process; which ultimately benefits all the stakeholders in this agribusiness.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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