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Volatility in Indian Cereal Prices: A Panel Data Analysis Using the Cobweb Model

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Abstract

Purpose: The purpose of this study is to examine price volatility in India's cereal markets through the theoretical lens of the Cobweb Model. It aims to determine whether cereal prices exhibit convergence toward equilibrium or persistent instability, with implications for market coordination and agricultural policy. ***Design/Methodology/Approach:*** The analysis covers thirteen major cereal-producing states in India, using panel data for the years 2005, 2006, 2011, 2022, and 2023. Cereal consumption and production are used as proxies for demand and supply, respectively. A fixed effects regression model is employed to assess how current demand and supply respond to price signals, including a lag structure to capture delayed supply responses. The convergence coefficient (β) derived from the model is used to evaluate price behavior over time. ***Findings:*** The results show that demand declines when current prices rise, while supply increases in response to prices from the previous year. The estimated convergence coefficient ($\beta = -0.39$) indicates that cereal prices tend to stabilize over time rather than diverge or cycle unpredictably. The analysis also reveals that consumer responses to price changes occur more rapidly than producer responses, reflecting asymmetries due to structural and seasonal production constraints. These findings validate the applicability of the Cobweb Model in the Indian agricultural context. ***Originality:*** This study contributes to the limited empirical literature on the Cobweb Model in Indian agriculture by applying it within a panel data framework. It offers new evidence on cereal price behavior and supply-demand interactions across time and regions. The research also highlights the policy relevance of improving price forecasting systems, enhancing market infrastructure, and implementing coordinated interventions to support price stability and agricultural resilience in India.

Keywords: Cereal price volatility, Cobweb Model, Agricultural Supply Response, Panel Data.

1. INTRODUCTION

Cereal crops such as rice, wheat, and maize hold a central position in India's agricultural economy. These crops are essential for ensuring national food security and for supporting the livelihoods of millions of farmers. As one of the world's largest producers and consumers of cereals (IMF & UNCTAD, 2011), India faces both opportunities and challenges in managing the performance of these markets. One of the major challenges is cereal price volatility, which affects both consumers and producers. High prices reduce affordability for low-income households, while low prices suppress farm incomes and discourage future production decisions (Balcombe, 2009; IMF and UNCTAD, 2011). Price instability in India often arises due to structural and external factors such as unpredictable climate conditions, shifts in public policy, changing consumption patterns, and exposure to global market conditions (Gouel, 2012; Sharma *et al.*, 2023). Despite policy interventions like Minimum Support Prices (MSP) and public procurement, volatility remains widespread. These fluctuations affect both farmer welfare and consumer access to food (Arora and Chander, 2016; Lanfranchi *et al.*, 2019). One of the primary reasons for these fluctuations is the time gap between price signals and supply responses. In agriculture, producers must make decisions in advance, and cannot revise them once the season begins. This causes mismatches between supply and demand in subsequent periods (Waugh, 1964; Chavas and Li, 2020). The Cobweb Model helps explain such cycles, where current supply decisions depend on previous prices rather than present demand conditions. The model, first introduced by Ezekiel (1938), was later refined by Waugh (1964) and Jha and Maji (1971) to describe how agricultural producers respond to lagged price information. For example, high prices in one year encourage producers to plant more in the next, which may then lead to excess supply and a drop in prices. This process can repeat across multiple seasons, causing recurring price fluctuations (Poitras, 2023; Mehmood and Khan, 2022).

In India, farmers often base their production decisions on past price experiences, due to limited access to market forecasts or real-time information. This pattern contributes to a mismatch between actual demand and the quantity supplied, particularly in cereal markets. The findings of Bhat and Choure (2015) and Sen *et al.,* (2018) support the existence of such behavior in South Asia. Although public schemes like buffer stocks and subsidies offer temporary relief, they do not resolve the deeper sources of market instability. Anokye and Oduro (2013) showed that poor inventory management can aggravate volatility. Matsumoto and Szidarovszky (2024) argued that when markets operate with delayed adjustments across multiple commodities, the level of instability can become more severe than what classical models predict. Therefore, a more detailed empirical analysis is needed in the Indian context. This study applies the Cobweb Model to explore cereal price volatility in India, with attention to the link between past prices, supply responses, and current market behavior.

The main objective of this study is to identify recurring price patterns in the cereal market and to determine whether these markets tend to stabilize or become more volatile over time. The results seek to support policies that promote more stable price environments and improve resilience in the agricultural sector of India.

2. LITERATURE REVIEW

Price volatility in agricultural markets has attracted sustained academic interest due to its implications for producers, consumers, and policy effectiveness. The Cobweb Model, first proposed by Ezekiel (1938), provides a theoretical basis for explaining cyclical price movements that arise from delayed supply responses to price changes. Early refinements of this model, such as those by Waugh (1964), emphasized the role of elasticity differences in determining whether price adjustments converge or diverge. Jha and Maji (1971) found evidence of cyclical behavior in sugarcane acreage in North Bihar, driven by supply lags. Bhat and Chore (2015) reported similar effects in cocoon production in Jammu and Kashmir. Sen *et al.,* (2018) confirmed the existence of cobweb dynamics in vegetable markets in Bangladesh. Although these studies validate the model's applicability in agricultural contexts, they do not provide simultaneous estimation of both demand and supply elasticities across multiple regions.

In addition to theoretical extensions, several studies address the role of institutional mechanisms in moderating price instability. Sharma *et al.,* (2023) concluded that Minimum Support Prices reduce short-term volatility but fail to address seasonal price swings. Arora and Chander (2016) highlighted persistent inefficiencies in Indian agricultural markets and emphasized the need for better integration between state and national systems. Mustafa *et al.,* (2024) attributed agricultural price fluctuations to external shocks, including climate variability, trade disruptions, and speculative activity. Balcombe (2009) supported this view by linking volatility to macroeconomic factors. However, these studies seldom examine whether such external influences result in systematic convergence or divergence in prices when modeled empirically within a cobweb framework.

Related studies focus on policy instruments and storage systems. Anokye and Oduro (2013) applied the Cobweb Model to Ghana's tomato market and found that poorly managed inventories exacerbated price fluctuations. Similarly, FAO (2011) and Tothova (2011) reported that inadequate storage infrastructure weakens price stabilization efforts. Vashishtha (2020) assessed futures markets and concluded that while futures trading improves price signals, it does not fully prevent volatility, especially under speculative conditions. These contributions address external controls but often overlook whether agricultural markets exhibit internal self-correcting mechanisms, particularly in large and diverse economies such as India.

The broader economic effects of price instability have also received considerable attention. Lanfranchi *et al.,* (2019) showed that volatility in agricultural prices reduces farm income and hinders long-term investment. Buguk *et al.,* (2003) observed volatility spillovers across commodity markets in the United States. Chavas and Li (2020) associated large price shocks with prolonged instability. Maffei-Faccioli (2025) linked supply- and demand-side shocks to overall macroeconomic slowdown. However, most of these studies do not empirically test whether domestic cereal markets adjust toward stability in the absence of external interventions.

Finally, several studies extend the Cobweb Model itself. Koech *et al.,* (2013) analyzed maize markets in Kenya and connected unstable supply patterns to food insecurity. Matsumoto and Szidarovszky (2024) proposed a delayed multi-market cobweb model, showing that extended time lags can amplify price instability. Gemraill (1978) developed an asymmetric cobweb model for international sugar markets and argued that uneven adjustment speeds distort outcomes. Poitras (2023) reviewed the theoretical evolution of cobweb models and reaffirmed their continued relevance when adapted to policy and behavioral considerations.

In light of the above, it can be concluded that very few studies are available in the Indian context. Furthermore, most existing research relies on crop-specific time series or theoretical assumptions without empirically validating market stability across states. This study addresses these limitations by applying fixed effects panel regression to estimate price responsiveness and by incorporating the results into the Cobweb Model to assess dynamic stability. It enhances the understanding of price adjustment mechanisms and contributes meaningfully to both economic theory and agricultural policy formulation.

3. METHODOLOGY

This study investigates the dynamics of price volatility in cereal products across thirteen major cereal-producing Indian states: Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Maharashtra, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana, and Gujarat. These states were selected based on their consistent and significant contributions to national cereal output. In particular, the study examines the relationship between demand, supply, and prices for the years 2005, 2006, 2011, 2022, and 2023. The selection of these specific years is based on the availability of data. To analyze the dynamics of price volatility, the study examines both demand and supply factors. On the demand side, per capita cereal consumption is used as a proxy, while cereal production serves as a proxy for supply. Data on per capita cereal consumption are obtained from the Household Consumption Expenditure Survey (HCES), published by the Ministry of Statistics and Programme Implementation (MoSPI). On the supply side, cereal production data are sourced from Agmarknet, under the Ministry of Agriculture and Farmers Welfare, while cereal price data are collected from the Handbook of Statistics on the Indian Economy, published by the Reserve Bank of India.

The analysis proceeds by the construction of the demand and supply equations, where the interplay between cereal prices, consumption, and production is examined to understand the dynamics of price volatility, with the use of the following equations:

$Q_d = f(P_t)$ 1

$Q_s = f(P_{t-1})$ 2

(Where Q_d and Q_s represent the demand and supply of cereal product where as P_t and P_{t-1} represent the prices of current and previous year respectively).

To estimate the parameters of the demand and supply functions, specifically the slope and intercept, the fixed effects method is employed, as recommended by the Hausman test.

Demand Function

$DC_{it} = \alpha_{0i} + \alpha_1 P_t + \varepsilon_{it}$ 3

Supply Function

$SC_{it} = \beta_{0i} + \beta_1 P_{t-1} + \varepsilon_{it}$ 4

(DC_{it} is the consumption expenditure on cereals for and SC_{it} is the production on cereals for selected states at time 't'. α_{0i} and β_{0i} represents the individual fixed effects for selected states (time invariant factors) α_1 and β_1 are the coefficient of cereals prices. P_t represents the prices of the cereals for selected states at time t. ε_{it} is the error term due to heterogeneity among states).

After obtained the slope and coefficients for both equations with the help of fixed effect model, the next step is to substitute these values into the cobweb demand and supply framework to determine the equilibrium price and analyze whether prices stabilize, continue oscillating, or become more volatile over time. This can be done using the following mathematical equations of the cobweb model.

$D_c = a - bP_t$ 5

$S_c = c - dP_{t-1}$ 6

Where, –b and α represent the slope and intercept, respectively, for the demand curve, and d, and c represent the corresponding slope and constants for the supply curve (Ezekiel, 1938; Goldberg, 1986). By substituting into the equilibrium condition, where $D_c = S_c$, we derive the first-order linear differential equation:

$P_t = (P_0 - \frac{\alpha}{1-\beta})^{bt} + \frac{\alpha}{1-\beta}$ 7

The assumptions made for consecutive time periods are as follows:

The supply in period k (where k=1, 2, 3) is a linear function of the price in the previous period (k−1), and supply increases as prices rise.

Similarly, the demand in period k is a linear function of the price in period k, with demand decreasing as prices increase.

Consequently, the market price is determined by the available supply, with exchanges taking place at the price that equates demand and supply.

These assumptions are integral to understanding the market dynamics under the Cobweb model. The market price is determined by the available supply, with exchanges occurring at the price that equates demand and supply. By analyzing the interaction between these two factors, we can predict whether prices will stabilize over time, continue to oscillate, or increase in volatility based on the supply-demand relationship. The empirical findings of these equations are presented in the Results section, where the estimated parameters of the demand and supply functions are discussed, and their implications for price volatility dynamics are explored.

4. RESULTS AND ANALYSIS

The empirical results of the Cobweb Model on price volatility and supply change in India's cereal market are presented in this section. The analysis begins with the Hausman test, which confirms that the fixed effects model captures state-level variation accurately. After this, the Cobweb framework is applied using the estimated demand and supply elasticities to assess market stability.

Table 1: Hausman Test Results

Panel (A): For Demand Function			
Test Summary	**Chi-Sq. Statistic**	**Chi-Sq. DF**	**Prob.**
Cross-section random	21.672746	1	0.0000
Panel (B): For Supply Function			
Cross-section random	5.590409	1	0.0181

Source: Calculated by Author

The Hausman test results for the demand and supply functions show a p-value less than 0.05, which is significant at the 5% level. These p-values suggest that the random effects model, which assumes no correlation between individual effects and the explanatory variables, is not valid (Le and Sénégas, 2023). Thus, fixed effects model would be preferred over the random effects model for capturing the unique effects specific to each state in the data.

Table 2: Empirical Findings from Fixed Effects Model

Panel (A): Demand Function			
Variable	**Coefficient**	**Std. Error**	**Prob.**
LNP_t	-0.277466	0.021791	0.0000
C	6.836076	0.164511	0.0000
Panel (B): Supply Function			
LNP_{t-1}	0.110378	0.047332	0.0231
C	4.390792	0.337987	0.0000

Source: Calculated by Author

Table 2 presents the fixed effects estimation results for the demand and supply functions. Panel A shows that the price coefficient in the demand equation is negative and statistically significant at the 1% level, with a value of −0.2775. This result implies that a 1% increase in cereal prices leads to a 0.28% decrease in consumption demand. The negative elasticity reflects the expected inverse relationship between price and demand and contributes to the downward slope of the demand curve in the Cobweb Model. Panel B reports the results for the supply function. The price coefficient is positive and statistically significant at the 5% level, with a value of 0.1104. This indicates that a 1% increase in the previous year's price results in a 0.11% increase in the quantity supplied in the current period. The positive relationship is consistent with the model's assumption that producers' base current production decisions on past price signals.

Overall, the results show that the absolute value of the demand elasticity exceeds that of the supply elasticity. This condition leads to a convergence coefficient β=−0.39, which satisfies the stability condition |β|<1|. Consequently, price and quantity adjustments tend to converge over time rather than diverge. These estimated coefficients are then used within the Cobweb framework to simulate price behavior and assess the long-run stability of the Indian cereal market.

4.1 Cobweb Model

To examine the cobweb model, we substitute the values of α and β into equations (3) and (4).

$$D_c = 6.84 - 0.28P_t \qquad 5$$

$$S_c = 4.4 + 0.11P_{t-1} \qquad 6$$

By equating equations (5) and (6), we obtain a first-order linear differential equation.

$$\mathrm{P_t} = -0.39\mathrm{P_{t-1}} + 8.61 \qquad 7$$

The solution of the first-order equation (7) is expressed as follows.

$$\mathrm{P_t} = (\mathrm{P_0} - \frac{\alpha}{1-\beta})^{\beta t} + \frac{\alpha}{1-\beta} \qquad 8$$

By solving equation (8), we obtain the nature of equilibrium as well as the intertemporal equilibrium price.

$$\mathrm{P_t} = (\mathrm{P_0} - \frac{8.61}{1+0.39})^{(-0.39)t} + \frac{8.61}{1+0.39}$$

$$\mathrm{P_t} = (\mathrm{P_0} - \frac{8.61}{1.39})^{(-0.39)t} + \frac{8.61}{1.39}$$

$$\mathrm{P_t} = (\mathrm{P_0} - 6.19)^{(-0.39)t} + 6.19$$

$$|\boldsymbol{\beta}| < \mathbf{1} = \mathbf{0.39}$$

The obtained value of β is -0.39, which is less than 1. This indicates that the slope of the consumption demand curve for cereal prices is greater than the slope of the production curve. As a result, price fluctuations reduce over time and eventually reach the equilibrium point. Further, the intertemporal equilibrium price settles at 6.19, and the market adjusts efficiently. The overall result shows the Indian cereal market remains stable, as prices show no signs of persistent volatility. This trend suggests that the interaction between demand and supply creates a self-correcting mechanism and ensures that prices settle rather than move unpredictably.

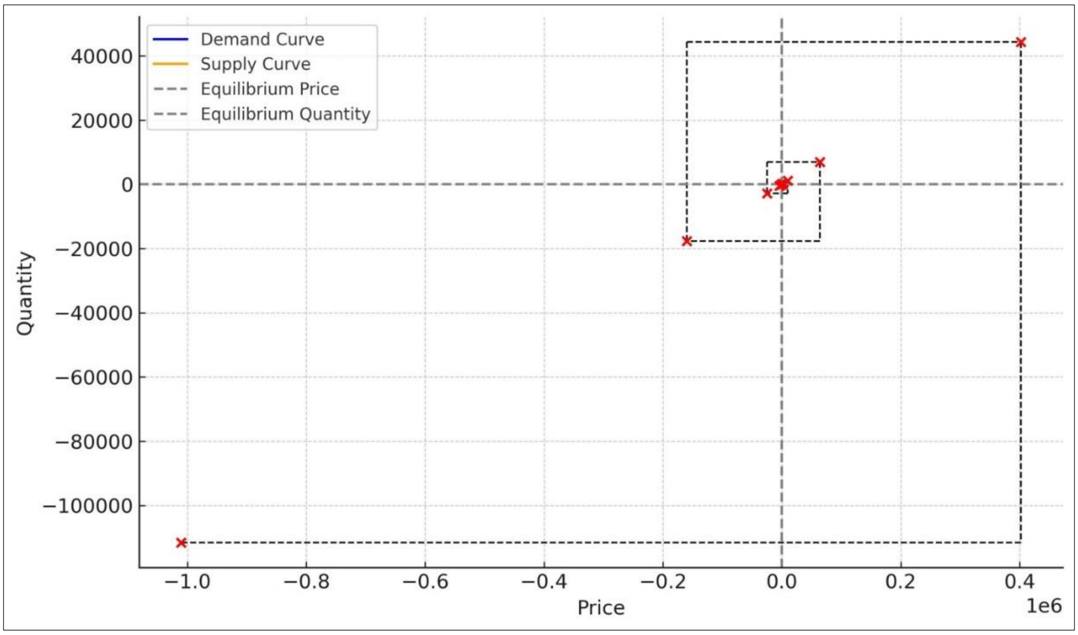

Figure 1: Cobweb Dynamics in Indian Cereals
Source: Constructed by Author

Figure 1 presents the stepwise adjustment of price and quantity under the Cobweb Model, based on estimated demand and supply coefficients. The simulation begins with an initial price above the equilibrium level (P* = 6.30; Q* = 5.09). Producers respond to past prices when determining output, whereas consumers react to current prices when forming demand. As a result, the mark*et al*ternates between excess supply and excess demand. Each point on the zig-zag path reflects the sequence of these adjustments. Furthermore, the trajectory gradually moves toward the equilibrium intersection of the supply and demand curves. Since the absolute value of the convergence coefficient |β|=0.39| remains below one, the system displays a stable pattern. Therefore, the figure confirms that cereal prices in India tend to stabilize over time, despite the presence of delayed supply responses.

5. DISCUSSION

The empirical findings confirm that price movements in India's cereal markets follow a convergent pattern. Specifically, the estimated price elasticity of demand is −0.28, whereas the price elasticity of supply is 0.11. Since the absolute value of the demand coefficient exceeds that of the supply coefficient, the Cobweb Model yields a convergence coefficient of β = −0.39, thereby satisfying the condition |β|<1. Therefore, the model suggests that price fluctuations gradually diminish and ultimately stabilize around an intertemporal equilibrium price of approximately 6.30. Consequently, the results indicate that cereal prices do not diverge persistently when subjected to shocks. Instead, the market exhibits a self-correcting adjustment process. After an initial deviation from equilibrium, producers revise supply based on earlier prices, while consumers adjust demand in response to current prices. As a result, the price and quantity series alternate between overshooting and correction. The graphical simulation of cobweb dynamics further reinforces this interpretation, as the adjustment path converges visibly toward a steady-state solution. Moreover, the estimated elasticities are consistent with structural characteristics observed in agricultural markets. On the one hand, the relatively low supply elasticity suggests that producers adjust production slowly due to biological, seasonal, and infrastructural constraints. On the other hand, the comparatively higher demand elasticity indicates that consumers reduce cereal consumption more rapidly in response to price increases. Accordingly, this asymmetry contributes to the dampening of fluctuations, as the demand side corrects more sharply than the supply side reacts.

In addition, these empirical results have direct policy relevance. A stable price environment helps reduce uncertainty for both producers and consumers. As a consequence, farmers can make more informed and predictable production decisions, while consumers face fewer disruptions in food access. However, the limited responsiveness of supply highlights the need for better forecasting tools, improved infrastructure, and real-time access to price information. Finally, although the model captures the essential dynamics of cereal price adjustments, the observed convergence does not imply perfect market efficiency. For example, factors such as support prices, procurement mechanisms, and state-level policy heterogeneity may still introduce distortions in short-term market behavior. Nevertheless, in the absence of major exogenous shocks, the results suggest that India's cereal markets possess an inherent tendency to return to equilibrium through internal adjustments.

6. CONCLUSION

This paper applies the Cobweb Model to examine cereal price volatility across major agricultural states in India. The analysis, based on fixed effects estimation, yields demand and supply elasticities of −0.28 and 0.11 respectively. When these coefficients are incorporated into the cobweb framework, the resulting convergence parameter $\beta = -0.39$ which indicates a stable price adjustment process. Consequently, the market does not exhibit explosive or sustained oscillations, but rather tends to return to equilibrium after deviations. The empirical results support the hypothesis that supply responses in Indian cereal markets are delayed but not ineffective. Moreover, the demand side exhibits greater responsiveness to price changes, which facilitates convergence. These characteristics suggest that the cereal market possesses a degree of inherent resilience, even in the presence of seasonal and institutional rigidities. Nonetheless, the relatively low supply elasticity underscores the need for improved infrastructure, market access, and real-time information systems. Furthermore, although the model demonstrates stability, external shocks such as climate events or policy shifts could still disrupt the equilibrium path. Therefore, policy measures that enhance adaptive capacity and reduce lagged supply responses could further strengthen price stability.

Overall, the study provides empirical evidence that supports the theoretical predictions of the Cobweb Model in the context of Indian agriculture. It also provides a framework through which policymakers can evaluate the market's natural adjustment mechanisms and determine where strategic interventions may be most effective.

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