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Effect of public stockholding on wheat price dynamics in India: A quantile autoregression approach

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Abstract

The study investigates the effects of public stockholding on price dynamics and volatility in the Indian wheat market. A quantile autoregression method is used as a flexible representation of price dynamics and is based on a reduced-form methodology. The findings reveal that public stockholdings have significant price effects, but the results vary significantly in price distribution. Further, we show local dynamic stability in the price distribution for all quantiles. However, dynamic adjustments tend to be qualitatively different across stockholding regimes, suggesting that price stability becomes less pronounced when stocks are low. Given the limitation of public stockholding in smoothing price fluctuations over time and the program's high costs, our analysis highlights the need to explore other alternative mechanisms such as trade, for example, in achieving stability in food prices.

KEYWORDS

dynamics, minimum support price, price distribution, quantile, volatility

JEL CLASSIFICATION

C13, Q18, E3

1 | INTRODUCTION

Price volatility, which generally reflects the market response to unanticipated shocks under inelastic short-run supply and demand, is also affected by the behaviour of inventory holders, private and public, in reaction to anticipated price movements. For instance, stockholders, including public stockholding, can reduce the prospects of future price spikes and thereby smooth consumption (Benirschka & Binkley, 1995; Cafiero et al., 2011; Chavas & Li, 2020; Deaton & Laroque, 1992, 1996; Gardner, 1979; Gouel, 2013; Gustafson, 1958; Knittel & Pindyck, 2016; Williams & Wright, 1991). The empirical evidence suggests that price spikes tend to coincide with low stock-to-use ratio (Bobenrieth et al., 2013; von Braun & Torero, 2009;

Wright, 2011), leading to a government's intervention in commodity markets (Gouel, 2013; Headey, 2011; Newbery & Stiglitz, 1981). Government intervention in setting or influencing agricultural prices is pervasive around the world. Perhaps more noteworthy is India's agricultural policy that relies heavily on price support programs and public stockholding policies for food grains.[1]

In India, food price sensitivity arises from the fact that food represents a significant share (around 45%) of the expenditure of average households.[2] Thus, price changes have a larger effect on the purchasing power and standard of living of Indian households than on families in other countries (National Sample Survey Office (NSSO), 2013). On the production side, even today, more than half of the country's agricultural land depends on monsoons for precipitation. Any deviation in the amount of monsoon rain from its long-period average raises serious concerns for the government (Gulati & Saini, 2015). In addition, large price changes have significant implications for welfare. Specifically, high prices (upper tail of the price distribution) negatively impact buyers, whereas low prices (lower tail of the price distribution) negatively impact sellers. Thus, it is unsurprising that intervening in the food grains market has been an age-old practice in India with a significant economic impact.

India currently operates the world's largest public stockpiling and distribution program for agricultural commodities, covering approximately two-thirds of the population[3] (Banga & Sekhar, 2015; Hopewell, 2021). The objectives of the public stockpiling program include regulating the domestic supply of food grains through adjustments in procurement, distribution and stockholding levels, thus ensuring price stability, providing food security for millions of Indian consumers and supporting farmers' income and livelihood (ICTSD, 2016). India's reliance on public stockholding programs has risen significantly over the last decades, cementing the government's greater involvement in the marketplace (Figure 1). For instance, between 2007–2008 and 2012–2013, public stockholding levels in food grains tripled and are still well above the buffer norms set by the government. The trajectory of the stock-to-use ratio and the wholesale market price of wheat reveals that price spikes coincide with a low stock-to-use ratio (Figure 1). Figure 1 indicates that between 1991 and 2020, wheat prices spiked in the mid-1990s and went through several booms and busts after 2006. However, the impact of public stockpiling of food grains on price stabilisation in India is still an unanswered question. The difficulty arises because government operations in India do not follow formal price band stabilisation rules. In case of price band stabilisation, the government maintains the market price within a specified band by increasing stockholding when the market price falls below the support price and releasing grain in the market by depleting public stockholding if the market price exceeds the ceiling price (Gardner, 1987). In India, however, the focus is more on income redistribution in favour of people experiencing poverty by lowering the food price for the eligible group (Dorosh, 2008). To the best of our knowledge, in the context of India, the effect of public stockholding on commodity prices remains a poorly understood subject. Specifically, the role of public stockholding in commodity price dynamics and volatility remains unclear.

Thus, the objective of the study was to examine how previous stockholding levels can affect the distribution and volatility of the market price. The study uses data from the 1991–2020 Indian wheat market. We use a reduced-form representation of price dynamics to analyse the effect of a stockholding program on commodity price dynamics and volatility. We find that public stockholding practice significantly affects the events located in the tail of price distribution. The support price essentially censors the lower tail of the price distribution.

[1]Many countries worldwide have reduced or eliminated the practice of public stockholding as a part of their structural adjustment measures and market liberalization in the 1980s and 1990s (Anderson et al., 2013).

[2]India is perhaps the only country where an increase in onion prices can lead to a government's failure (Desai, 1999).

[3]Expanded significantly with the introduction of the Food Security Act of 2013.

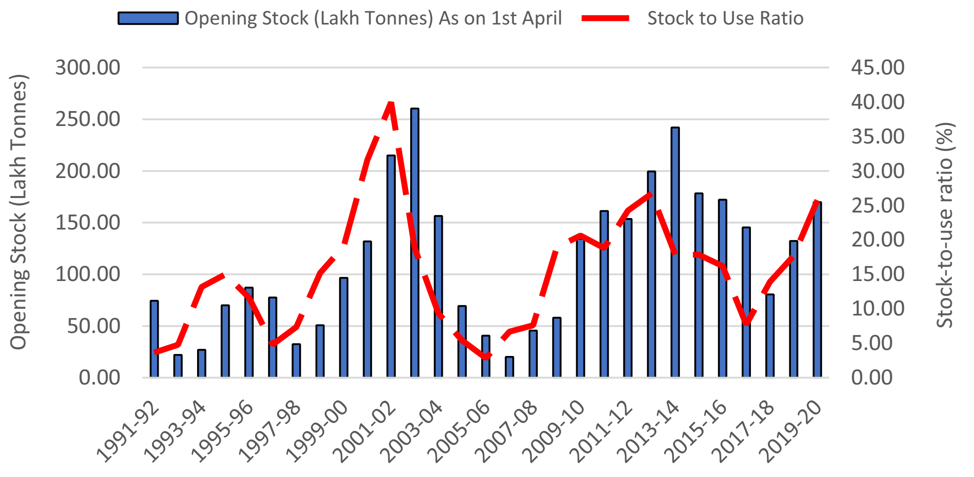

FIGURE 1 Trend in wheat opening stock (in lakh tonnes) and stock-to-use ratio, India 1991–2020. 1 lakh tonne = 100,000 metric tonnes. *Source*: Reserve Bank of India. [Colour figure can be viewed at wileyonlinelibrary.com]

Consequently, public stock accumulation influences the market price by lowering exposure to downside price risk. Further, we find that releasing the previous stockholding censors the upper tail of the price distribution, reducing the exposure to upside price risk. This indicates the need to estimate the dynamics of the whole price distribution, conditional on stockholding held in the previous period and its linkage with price volatility. It requires the extension of standard time series models typically focussing on the dynamics of mean and median (Enders, 2010; Hamilton, 1994). To this end, our approach relies on a quantile autoregression (QAR) model proposed by Koenker and Xiao (2006). We use the methodology developed by Chavas and Li (2020), who were the first to apply the QAR model to investigate the dynamics of agricultural price volatility in the United States, conditional on stocks held in the previous period. However, this study contributes to the broader literature beyond applying Chavas and Li's (2020) method to the context of Indian wheat prices.

The research adds to the body of literature in several ways. Firstly, the study applies the QAR methodology to examine the effects of public stockholding on Indian wheat price dynamics and volatility. Unlike Chavas and Li's (2020) study of the stocks in the US market, the Indian stockholding practices do not follow formal price band stabilisation rules. Additionally, India's price stability policy focusses more on income redistribution by providing food grains at subsidised prices to people experiencing poverty. The study uses the most recent data available and the QAR approach in commodity price analysis in the Indian context. The findings from this study have policy implications for other countries in South and Southeast Asia that occasionally use restrictive trade policies, including an export ban, and rely on public stockholdings to address price volatility and food shortages. Secondly, the study assesses the effectiveness of public stockholdings in mitigating price volatility (price spikes and price crashes). Thirdly, since any release of public stockholding affects the current availability of the commodity, it puts downward pressure on prices. Thus, the study provides a framework to investigate the effects of public stockholding policy on market price dynamics and volatility. Finally, the study uses a quantile regression approach to capture the heterogeneous effects of the public stockholding policy on the price distribution. As mentioned above, quantile regression provides much more information about the conditional distribution of a response variable.

The paper is organised into six sections: Section 2 describes India's wheat market; Section 3 outlines the econometric model used in the study; Section 4 reports the data used in the analysis; Section 5 deals with the econometric estimates; Section 6 reports the implications of the analysis results for price dynamics and their volatility; and Section 7 draws some conclusions that emerge from the analysis.

2 | INDIA'S WHEAT MARKET

The development of India's wheat market illustrates the agricultural sector's significant changes since 1960. India has gone from being a persistent recipient of food aid to an often sizable net exporter (Gulati et al., 2013). Through the Green Revolution, via the use of modern seed varieties, irrigation facilities (canals and reduced or free electricity to farmers for tube wells), input subsidies, tools to manage production and marketing risks and linking of domestic and global prices, Indian agriculture has seen an era of unprecedented growth in agricultural productivity. In addition to market intervention, the Government of India has engaged in public stockpiling of food grains, to protect poor and vulnerable consumers through the Public Distribution System (PDS) and National Food Security Program. High levels of trade intervention, including tariffs and recurrent quantitative restrictions, have been added to the regulations. The policy changes, which aim to boost supply and lower price volatility simultaneously, have succeeded in stabilising wheat prices in India relative to global prices (Gouel et al., 2016; Hoda & Gulati, 2013; Pursell et al., 2009; Shreedhar et al., 2012; Srinivasan & Jha, 2001).

Wheat farmers in India receive support from the government in the form of market price support and budgetary support (Mullen et al., 2005). Market price support[4] captures the effect of India's minimum support price (MSP) and trade policies (quantitative restrictions and tariffs). Budgetary support from the government includes electricity, fertiliser and irrigation water subsidies for wheat's share of farm output. The Food Corporation of India (FCI), founded in 1965, responds to nationwide grain shortages and oversees the market price support strategy. The objectives of the FCI are to ensure 'remunerative prices' to producers, provide people experiencing poverty with subsidised grains and build buffer stocks.

For wheat, farm price support is met through the use of minimum support price—announced before the harvest season for the fair-to-average quality grain and defended by the government's purchase in the surplus area during the harvest. The price is paid directly to farmers by the FCI in the primary markets where they sell their produce. The procurement of wheat by the FCI is open-ended as it buys all the quantity offered by farmers at the minimum support price, provided grains meet certain quality specifications. The procured wheat leads to the accumulation of public stocks, which include both operational and strategic stocks.[5] The Cabinet Committee on Economic Affairs (CCEA) of the Government of India sets the stocking norms for every quarter. The stocking criteria indicate the minimum quantity of wheat to be maintained in the central pool at the beginning of each quarter to meet month-to-month distribution requirements under the Targeted Public Distribution System (TPDS) and Other Welfare Schemes (OWS), along with any shortfalls in procurement. The operational stockholding model is specified yearly at different levels on the first day of January, April, July and October. In contrast, the standard for keeping strategic stock is set for the entire year.

[4]This price is calculated using India's farm gate prices and suitable global reference prices, while taking account of global and country marketing costs.

[5]A distinction is made between operational stock and strategic stocks. Operational stocks are used for the distribution of wheat through the Public Distribution System (PDS), which is comprised of the Targeted Public Distribution System (TPDS) and the Other Welfare Scheme (OWS). Strategic (food security) stocks are kept to meet shortfalls in procurement due, for example, to natural calamities. Earlier, this concept was termed the Buffer Norms and Strategic Reserve.

The central government releases the accumulated wheat stock to state governments for distributing wheat to consumers at subsidised prices (i.e. the Central Issue Price, or CIP). Currently, policies are implemented through the National Food Security Act (NFSA), which came into force in September 2013. The NFSA extended the existing TPDS by guaranteeing the provision of subsidised grain to more than 60% of the population.[6] The TPDS came into existence in 1997 by replacing the existing PDS. Table S1, in the online supplementary material provides a timeline of the policy measures adopted for the distribution of wheat to consumers. Under NFSA, 75% of the rural and 50% of the urban population are eligible to receive 5 kg per person per month of food grains at a cost of INR 3 per kg for rice, INR 2 per kg for wheat and INR 1 per kg for coarse grains (Directorate General of Food, 2016).[7] The existing *Antyodaya Anna Yojana* (AAY) families continue to receive monthly 35 kilograms of food grains.[8] The NFSA has been in effect since November 2016 in all 36 states and union territories (Government of India, 2016). As a result, to meet increased distribution needs, wheat buffer stock norms increased from 20.01 million metric tonnes to 27.58 million metric tonnes from 1 July 2014 (Figure 2). Since 2015, 22–23 million metric tonnes of wheat have been sold annually under the NFSA, accounting for about 24% of production and about 90% of total wheat offtake from the central pool. The PDS is a key source of grain for consumers, but it is not the only source, as less than half of the output is marketed (due to producers' self-consumption). As a result, price stability is maintained by adjustments in procurement, distribution and stockholding levels.

Although the stocking norms specify minimum quantities, actual stock holdings are usually higher than the norms. For instance, during the late 2000s and early 2010s, the continuous

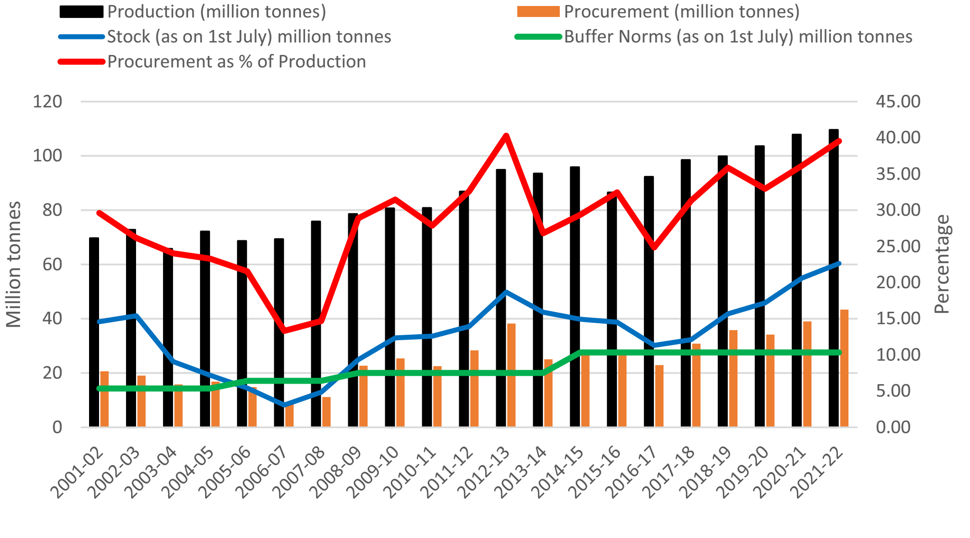

FIGURE 2 Wheat production, procurement, public stockholding level and buffer norms in India, 2001–2021. Buffer norms refers to minimum quantity of wheat that has to be maintained in the central pool at the beginning of each quarter to meet month-to-month distribution requirement under Targeted Public Distribution System (TPDS) and Other Welfare Scheme (OWS) along with any shortfalls in procurement. *Source*: Reserve Bank of India. [Colour figure can be viewed at wileyonlinelibrary.com]

[6]The TPDS, which targets food-insecure households, the Mid-Day Meal Scheme, a school-based feeding program for children ages 6–14, and Integrated Child Development Services, a supplemental feeding program for infants and young children, as well as pregnant and nursing women, are combined into the NFSA.

[7]In 2016 on average, 1 Indian Rupee was equal to 0.0200 Australian Dollar and 0.0149 USD.

[8]Antyodaya Anna Yojana" (AAY) was launched in November 2000. The program involved the identification of one crore (10 million) poorest of the poor families from amongst the number of below poverty line (BPL) families covered under TPDS. It provides food grains at a highly subsidized rate of Rs.2 per kg for wheat and Rs.3 per kg for rice.

rise in wheat procurement prices, the FCI's obligation to purchase all grains offered by farmers and trade restrictions during the 2008 food price crisis led to an accumulation of wheat stockholdings with public agencies. Public wheat stockholding levels increased by more than three-and-a-half times between 2007–2008 and 2012–2013 and reached 49.81 million metric tonnes by July 2012—much above the recommended optimal stocks of 20.01 million metric tonnes (Figure 2). With wheat production reaching a record level of 109.59 million metric tonnes in 2020–2021, there is a larger build-up of public wheat stockholdings in the country than the prescribed buffer norms under the central pool.

Wheat stockholdings in the central pool reached 60.36 million metric tonnes in 2021, more than 118% of the stockholding norms (27.6 million metric tonnes) on 1 July 2021. A record wheat production and larger public stockholdings will put downward pressure on domestic wheat prices if wheat prices remain lower than the world price. It is widely accepted in the literature that the significant increase in wheat stockholding by governmental agencies is a result of the trade and stockholding policies, which seem to have been at odds with one another throughout the periods of high global prices.[9] Comprehensive reviews of India's policy responses to the 2008 food price crisis and its impact are available in the literature (Acharya et al., 2012; Dasgupta et al., 2011; Gulati & Saini, 2015; Yu & Bandara, 2017).

3 | EMPIRICAL FRAMEWORK

The empirical model used in this study is adopted from Chavas and Li (2020). In the literature, agricultural price modelling consists of two main approaches: the structural approach estimates supply, demand and market equilibrium, and the nonstructural approach is a reduced-form representation of variables from time series data. The reduced-form representation has an advantage over the structural approach because direct measurement of the demand-and-supply equation is not required. A reduced-form equation gives a valid representation of the net effects of past prices and stockholding policy S_t on current price P_t at time t as given by Equation (1)

$$P_t = f\left(P_{t-1} \ldots . P_{t-n,}\ S_t, e_t\right) \tag{1}$$

where $P_t \in \mathbb{R}_+$ is the commodity market price at time t. We assume that price (P_t) evolves according to an nth-order difference equation. The variable S_t reflects the nature of government stockholding policy. e_t is an independent and identically distributed random variable with a given distribution function and represents the effects of unobservable factors. Equation (1) is a reduced-form representation for price determination (Zellner & Palm, 1974) and consistent with the structural model in which the price is determined by equating supply (i.e. production minus the change in stockholding) with demand. The specification in Equation (1) allows for dynamics in prices (P_t), exogenous changes (i.e. change in public stockholding) captured by S_t, along with a stochastic shock represented by the random variable (e_t).

The variable S_t, is measured by the level of lagged stockholding with the public agency. The inclusion of lagged stockholding allows one to investigate the effect of the previous stockholding level on current pricing. The release of the previous stockholding increases the current availability and is likely to put downward pressure on current prices. Therefore, lagged stockholdings S_{t-1} are included as predetermined explanatory variables.

[9]Indeed, India's trade policy measures have driven domestic prices lower relative to the global prices. Thus, minimum support price became the market price leading to a higher stockpiling of food grains.

Alternatively, Equation (1) can be written in the form of a first-order difference equation:

$$w_t \equiv \begin{bmatrix} p_t \\ p_{t-1} \\ . \\ . \\ . \\ p_{t-n+1} \end{bmatrix} = \begin{bmatrix} f\left(p_{t-1,}p_{t-n,}\ S_t, e_t\right) \\ p_{t-1} \\ . \\ . \\ . \\ p_{t-n+1} \end{bmatrix} \equiv H\left(w_{t-1}, S_t, e_t\right) \tag{2}$$

Assuming differentiability of $H\left(w_{t-1}, S_t, e_t\right)$, the derivative of $H\left(w_{t-1}, S_t, e_t\right)$ with respect to w_{t-1} describes the nature of price dynamics. Assuming that $\lambda_1\left(w_{t-1}, S_t, e_t\right)$ is the root of the dynamic system, the system is considered locally stable when its root is less than 1 and locally unstable when its root is greater than 1. In this context, the value of the modulus of the root provides information with respect to the speed of dynamic adjustments and its logarithm regarding the rate of divergence of prices (P_t) along a forward path in the neighbourhood.

Based on the reduced-form equation in (1) or (2), the conditional distribution function can be defined as $F\left(c|P_{t-1} \dots P_{t-n}; S_t\right) = Prob\left[P_t \leq c|P_{t-1} \dots P_{t-n}; S_t\right] = Prob\left[f\left(P_{t-1} \dots . P_{t-n}; S_t, e_t\right) \leq c|P_{t-1:\dots} \dots P_{t-n}; S_t\right]$. Its inverse function corresponds to the associated conditional quantile function, which can be denoted as $q\left(\tau \,|\, P_{t-1} \cdots P_{t-n}; S_t\right) \equiv inf_c\left\{c: F\left(c|\, P_{t-1} \cdots P_{t-n}:, S_t\right) \geq \tau\right\}$ where τ is the τth quantile, τ € (0, 1). When $\tau = 0.5$, this refers to a special case of the conditional median $q\left(P_{t-1} \cdots P_{t-n}; S_t\right)$.[10] Under the general specification of price dynamics as given in Equation (1), a complete characterisation of price dynamics can be presented by both the distribution function $F\left(c|\, P_{t-1} \cdots P_{t-n}: S_t, t\right)$ and the quantile function $q\left(\tau \,|\, P_{t-1} \cdots P_{t-n}; S_t, t\right)$. While analysing the effect of stockholding policy on the price dynamics P_t, we extensively used the quantile function $q\left(\tau \,|\, P_{t-1} \cdots P_{t-n}; S_t, t\right)$. We have considered the following specification for the quantile function:

$$Q\left(q \,|\, Y_{t-1}, S_t\right) = \alpha(q) + \beta(q) Y_{t-1} + \gamma(q) h\left(Y_{t-1}, S_t\right) \tag{3}$$

where $Y_{t-1} = P_{t-1} \cdots P_{t-n}$. Equation (3) is linear in the parameters (α, β, γ). Equation (3) can be estimated using quantile regression as proposed by Koenker (2005) and Koenker and Xiao (2006) for a given specification of (h) and conditional on $\left(Y_{t-1}, S_t\right)$. It provides a flexible representation of price dynamics. For instance, $Q\left(0.5 \,|\, Y_{t-1}, S_t\right)$ corresponds to estimating the median price conditional on $\left(Y_{t-1}, S_t\right)$ and under symmetric price distribution this would be the conditional mean. Quantile regression estimates the quantile function conditional on a set of explanatory variables (Buchinsky, 2001). In particular, it enables us to assess the probability of being in the tails (both lower and upper) of the price distribution (including skewness and kurtosis). The probability of being in the tails of the price distribution is relevant because both price busts and price spikes increase price volatility. By allowing for non-linear dynamics, it also documents the presence of local dynamic instability and the effects of stockholdings on price instability.

In a broader sense, the quantile regression produces estimates of the entire function as it varies between 0 and 1 (with the distribution function acting as its inverse). Based on the observed values of the explanatory variables, this can be used to assess the trajectory of the

[10]The quantiles are values that divide the distribution such that there is a given proportion of observations below the quantile. For example, the value of 0.1 quantile of the price distribution shows that one-tenth of the observations have a value less than or equal to the cut-off value at the 10th quantile. Similarly, the value of 0.9 quantile of price distribution shows 90% per cent of the data have values less than or equal to the cut-off value at the 90th quantile.

TABLE 1 Summary statistics, wheat price and public stock, India, 1991–2020.

	Mean	Max	Min	Std. dev.	Skewness	Kurtosis	Observations	Unit root text (ADF test statistics)
Wheat price (Rs/qtl)[a]	133.68	167.64	111.87	12.16	0.81	2.91	118	−4.604***
Wheat public stock (stock-to-use ratio, %)	3.20	29.53	0.13	3.71	3.87	24.88	118	−3.182**

Note: The significance level at: *10% level, ** 5% level and *** 1% level.

[a]Prices deflated using the consumer price index, 1982 = 100.

Source: Authors' calculation.

price distribution over the period. The path is expressed in terms of mean, standard deviation, skewness and kurtosis—known as the moments of the price distribution. It provides useful information regarding the evolution of price volatility and/or the likelihood of rare events located in the tails of the price distributions. The quantile estimates of Equation (3) provide the information to evaluate the dynamic stability of wheat prices. This can be carried out by obtaining the characteristic roots of the dynamic system. In Equation (3), the marginal effect of Y_{t-1}, dY_t/dY_{t-1} provides useful information about the nature and speed of dynamic adjustments. Note that $|dY_t/dY_{t-1}|$ is the root of the dynamic system. The system's local stability (instability) occurs when its root is less than 1 (greater than 1).

4 | DESCRIPTION OF DATA

The QAR model is applied to quarterly data of wheat market prices from April 1991 to September 2020. These data on monthly prices were taken from the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India (GoI), and referred to the month-end wholesale market price of the farm/Mexican/red wheat in Punjab. The analysis is based on real prices, that is market prices divided by the Consumer Price Index (CPI = 100 in 1982). We have deflated the nominal price with the CPI to remove the effect of inflation, as the primary concern while analysing the volatility tends to rest with the unpredictable or stochastic component of the data.[11] Since the study analyses the impact of the previous stockholding level on the current price dynamics, the quarterly data on public stockholding for wheat were collected from the database on food grains stockholding in the central pool maintained by the FCI. We defined public stockholding, S_t, as the stock-to-use ratio in the Indian market at time t. The total use is defined as total supply (i.e. opening stock + production + import) minus end stock. Summary statistics of the variables used in the analysis are reported in Table 1.

5 | RESULTS AND DISCUSSION

The analysis result in Table 2 shows the effect of lagged public stockholding, S_{t-1}, on the current price P_t. The evaluation of the effects of public stockholding on the distribution of agricultural prices is based on the QAR model as specified in Equation (3). We assessed the underlying price dynamics by estimating autoregressive (AR (m)) processes. Table 2 reports

[11]Chavas and Li (2020) used real prices to investigating the dynamics of agricultural price volatility based on a QAR model.

TABLE 2 Estimates of parameter for selected autoregressive processes, wheat, India.

Variables	AR (1)	AR (2)	AR (3)	AR (4)
Intercept	84.099*** (13.198)	72.334*** (14.130)	71.882*** (14.830)	59.733*** (15.936)
P_{t-1}	0.416*** (0.096)	0.239* (0.132)	0.228 (0.139)	0.212 (0.137)
P_{t-2}		0.258** (0.119)	0.276* (0.147)	0.255* (0.141)
P_{t-3}			−0.005 (0.146)	−0.037 (0.176)
P_{t-4}				0.150 (0.128)
S_{t-1}	−11.502** (3.644)	−8.080** (3.899)	−8.412** (3.947)	−6.810* (4.153)
S^2_{t-1}	−0.003 (0.022)	0.002 (0.022)	0.005 (0.033)	0.003 (0.032)
$S_{t-1} * P_{t-1}$	0.088*** (0.027)	0.168*** (0.046)	0.166*** (0.050)	0.152*** (0.049)
$S_{t-1} * P_{t-2}$		−0.105** (0.046)	−0.093* (0.050)	−0.090* (0.049)
$S_{t-1} * P_{t-3}$			−0.007 (0.039)	−0.001 (0.053)
$S_{t-1} * P_{t-4}$				−0.007 (0.034)
Q_1	−8.895*** (2.105)	−8.386*** (2.086)	−8.347*** (2.111)	−6.542*** (2.120)
Q_2	−5.074* (2.584)	−5.899** (2.716)	−5.955** (2.758)	−4.590* (2.681)
Q_3	−3.505* (2.089)	−3.175 (2.068)	−3.469 (2.201)	−2.060 (2.358)
T	−5.162*** (1.593)	−4.287*** (1.617)	−4.119** (1.641)	−3.627** (1.578)
BIC	7.154	7.188	7.263	7.243
D-W statistics	2.085	1.971	1.952	1.832
R-square	0.839	0.859	0.863	0.878

Note: The standard errors are reported in parentheses. The significance level at: * 10% level, ** 5% level and *** 1% level.
Abbreviations: AR, autoregressive; BIC, Bayesian Information Criterion.

the estimates of AR (m) models for lagged prices up to m periods, $m=1, 2, 3, 4$. The model includes lagged stockholding, S_{t-1}, quarterly dummy variables (Q_{1t}, Q_{2t}, Q_{3t}) to account for seasonality,[12] where $Q_{it}=1$ when the tth observation occurs in the ith quarter, $i=1, 2, 3$, and a dummy for time trend (T) capturing structural break starting in 2010, reflecting government's greater involvement in food grain market including public stockholding policies. In addition, the model specification includes an interaction term of lagged public stockholding, S_{t-1}, and

[12]Graphical analysis shows the lowest wheat price at harvest (during the month of April, May and June). However, as the marketing season proceeds, wheat prices start rising and keep rising until they peak in February and March, just prior to the annual harvest. We use Q4 as the base group for the analysis.

lagged price—capturing the stockholding effect on price dynamics—, and the square of lagged stockholding reflecting the non-linear effects.

The results of alternative AR (*m*) models are reported in Table 2. The results show that the AR models have good explanatory power: The *R* square varies between 0.83 and 0.87. It provides strong evidence of price dynamics as the estimated coefficients are significant. Also, a significant coefficient associated with lagged stockholding shows that stockholding affects the price. Finally, the analysis shows that time trends and seasonal dummies significantly affect price distribution. The Bayesian Information Criterion (BIC) applied to alternative AR (*m*) models shows that the BIC value is at the minimum for $m=1$. This indicates that the AR (1) model provides a good representation of wheat price dynamics in India. Therefore, the subsequent analysis of price dynamics is based on the AR (1) model with a single price lag.

Next, the QAR model was estimated with one price lag, as specified in Equation (3). The QAR provides estimates of the conditional distribution functions for wheat prices. In turn, this gives us a basis to investigate the distribution of wheat prices and the factors affecting its evolution over time. The QAR estimates are presented in Table 3 for selected quantiles $q=(0.1, 0.3, 0.5, 0.7, 0.9)$ along with the ordinary least squares (OLS) estimate for comparison purposes. As expected, the lagged-one price shows a statistically significant coefficient for all selected quantiles varying from 0.302 to 0.564, thereby revealing the importance of the dynamics. Table 3 also reports the effect of public stockholding on wheat price distribution. Results show that lagged public stockholding, S_{t-1}, affects wheat prices. However, the effect varies across the entire price distribution (quantiles). For instance, the stockholding coefficient is statistically significant for quantiles $q=0.1$ (i.e. −11.082) and $q=0.7$ (i.e. −13.339) but not for $q=0.9$. This indicates that the public stockholding policy design and implementation helped to prevent very low prices but had limitations when prices were high.

This could be attributed to India's agricultural price policy of providing farmers only with a price floor for commodities such as wheat and rice. In addition, the quantity of wheat sold

TABLE 3 Quantile regression estimates, wheat price and selected quantiles, 1991–2020.

Variables	OLS	$q=0.1$	$q=0.3$	$q=0.5$	$q=0.7$	$q=0.9$
Intercept	84.099***	87.743***	55.379***	69.069***	82.782***	111.157***
	(13.19)	(19.11)	(20.96)	(25.27)	(17.89)	(30.18)
P_{t-1}	0.416***	0.302**	0.564***	0.477**	0.461***	0.349
	(0.09)	(0.14)	(0.16)	(0.19)	(0.13)	(0.22)
S_{t-1}	−11.502***	−11.082**	−5.065	−8.417	−13.339**	−10.767
	(3.64)	(4.39)	(4.50)	(6.49)	(5.65)	(11.62)
S^2_{t-1}	−0.003	−0.009	−0.027	−0.029	0.016	0.0130
	(0.02)	(0.06)	(0.06)	(0.06)	(0.11)	(0.17)
$S_{t-1} * P_{t-1}$	0.087***	0.088***	0.045	0.071	0.095**	0.073
	(0.03)	(0.03)	(0.04)	(0.05)	(0.04)	(0.08)
Q_1	−8.895***	−6.840***	−8.619***	−2.691	−4.856	−12.199**
	(2.11)	(1.95)	(2.56)	(3.09)	(3.98)	(5.68)
Q_2	−5.074*	−2.881	−1.559	0.134	−4.732	−13.500**
	(2.58)	(3.15)	(2.18)	(2.76)	(5.96)	(6.27)
Q_3	−3.505*	−1.453	−2.935*	−3.731	−0.723	−7.123
	(2.09)	(1.26)	(1.64)	(2.33)	(3.77)	(4.96)
T	−5.162***	−1.899	−2.855*	−4.096**	−7.553***	−10.283**
	(1.59)	(1.61)	(1.49)	(2.05)	(2.79)	(4.08)

Note: Bootstrapped standard errors are used to test the hypothesis. The standard errors are reported in parentheses. The significance level at: * 10% level, ** 5% level and *** 1% level.

Abbreviation: OLS, ordinary least square.

through the PDS is determined independently of the quantity needed to achieve a specific target of the open market price. The strategy focusses more on income redistribution in favour of people experiencing poverty by lowering the food price for eligible consumer groups. However, public stockholding accumulation affects the wheat market price by censoring the lower tail of the price distribution (at the price support level), thus reducing exposure to downside price risk. Since it is voluntary to sell wheat to the government, successful procurement demands that the procurement price not be less than the market price. However, as the marketing season proceeds, wheat market prices move above the procurement price due to increased storage costs. They keep rising until they peak in February and March, just before the annual harvest (Balakrishnan & Ramaswami, 1995, 2002). Nonetheless, the OLS estimate shows a significant impact of stockholding on the mean price.

To assess the statistical relevance of the analysis, we conducted a series of tests on the estimated QAR (1) model, as reported in Table 4. First, we tested whether parameter estimates vary across quantiles, with a null hypothesis of no parameter variation across quantiles. Using a Wald test, the result shows strong evidence that parameter estimates vary across quantiles (0.1–0.9), with a p-value of 0.00. We obtained a similar effect when testing only for selected quantiles, that is 0.3, 0.5, 0.7 and 0.9. This indicates that price dynamics vary across the quantiles, that is different parts of the price distribution.

Second, the estimated model was also tested for seasonality and the effects of lagged stockholding. Results in Table 4 show strong statistical evidence of seasonality, reflecting the seasonality of agricultural production. However, the lower tail of the price distribution (e.g. $q=0.1$ and $q=0.3$) shows strong evidence of such effects. The test result also provides statistical evidence of lagged public stockholding, S_{t-1}, affecting current prices. In particular, the previous year's public stockholding (lagged stockholding variable) was statistically significant in quantiles $q=0.1$ and $q=0.7$. The next section of the paper discusses the economic implications of these effects.

TABLE 4 Hypothesis testing for quantile, seasonality and stockholding, wheat, India.

Testing items	Estimate method		p-value
Same coefficients across quantiles	QR		0.000***
Seasonality	QR	$q=0.1$	0.006***
		$q=0.3$	0.005***
		$q=0.5$	0.380
		$q=0.7$	0.616
		$q=0.9$	0.113*
Effects of lagged stockholding, S_{t-1}	QR	$q=0.1$	0.043***
		$q=0.3$	0.513
		$q=0.5$	0.348
		$q=0.7$	0.063**
		$q=0.9$	0.581
Interaction effects between lagged stockholdings and lagged price	QR	$q=0.1$	0.009***
		$q=0.3$	0.215
		$q=0.5$	0.142*
		$q=0.7$	0.036***
		$q=0.9$	0.369

Note: The significance level at: * 15% level, ** 10% level and *** at the 5% level.

6 | IMPLICATIONS OF POLICY EFFECTS ON PRICE DISTRIBUTION

The quantile estimation provides useful information on the effect of the stockholding program on market price distribution and its dynamics. To evaluate, we re-estimated the QAR (1) model for all quantiles, providing the basis to assess the conditional distribution function of prices. Considered at three data points (i.e. 2000, 2010 and 2020) for the January to March quarter, the estimated distribution functions are reported in Figure 3. Figure 3 shows that the distribution function shifted between 2000, 2010 and 2020: They have much higher medians in 2010 than in 2000 and 2020, showing the highest wheat price increase in 2010. Figure 4 depicts the estimated conditional distribution for the chosen quantiles (0.1, 0.3, 0.5, 0.7, 0.9) over the sample period, that is 1991–2020. The simulated median wheat price shown in Figure 4 is very close to the actual price, indicating that the QAR model provides a very good fit for the data.

Using QAR estimates of the price distribution, we assessed the associated moments of the price variable. The estimated standard deviation and skewness of the price over the period 1991–2020 are reported in Figure 5. The small standard deviation of the price reported in Figure 5 indicates that the QAR model fits the data well. The trajectory of the price distribution further reveals a positively skewed distribution, reflecting that the probability of being in the upper tail ('high price') of the distribution is higher than the probability of being in the lower tail ('low price') of the distribution. We rejected the null hypothesis of zero skewness at the 10% level. The finding suggests the need to go beyond mean and variance in the analysis of price dynamics. These results underscore the flexibility of the QAR approach in accessing policy effects on price risk.

Further, we used the estimated quantile functions to simulate an alternative public stockholding scenario to evaluate the counterfactual effects on the price distribution, holding other variables constant. To simulate the price distribution, we considered two scenarios, namely average stockholding (stockholding distributions between 0.35 and 0.70 quantiles) and high stockholding (greater than 0.70 quantiles) from the sample data. The analysis takes the lagged prices as given, thus referring to short-term analysis. We evaluated both

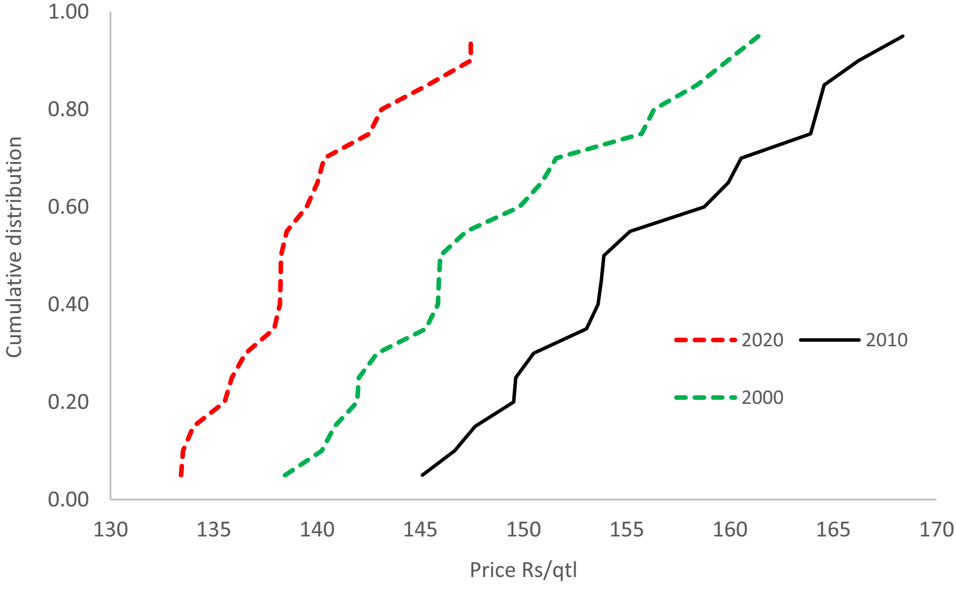

FIGURE 3 Estimated distributions of the wheat price: January–March 2000, 2010 and 2020, India. *Source*: Authors' calculation. [Colour figure can be viewed at wileyonlinelibrary.com]

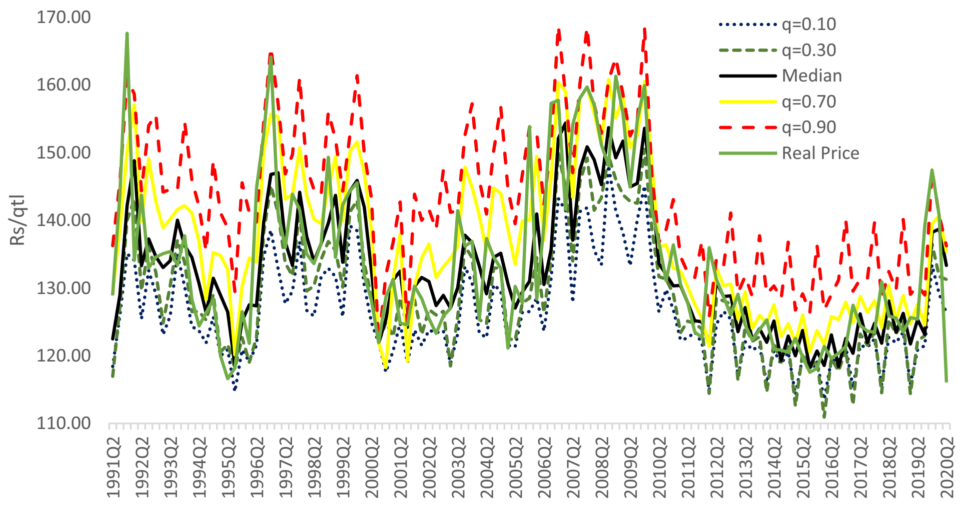

FIGURE 4 Quantile estimates of the distribution of wheat price, India, 1991–2020. Quantile estimates correspond to the estimated price for each quantile conditional on lagged stock and lagged price. *Source*: Authors' calculation. [Colour figure can be viewed at wileyonlinelibrary.com]

scenarios corresponding to a point, that is January–March 2000.[13] Figure 6 illustrates the simulated short-term distribution of wheat prices under two stockholding scenarios. The figure shows that a higher previous stock-to-use ratio shifts the price distribution to the left. However, the effects are more pronounced around lower and median wheat price distribution. This is expected because stockholding extends the lower tail of the price distribution and reduces the likelihood of price increases. A plausible explanation is that India's public stockholding focusses more on providing food to poor people at lower prices. The finding confirms the earlier result that public stockholding policy is more effective when prices are very low. Alternatively, the price distribution tends to shift to the right with a decrease in public stockholding, S_{t-1}.

Table 5 reports the summary statistics of the simulated price distribution. A positive skewness of price distribution under all scenarios shows asymmetric distribution, with a higher probability of a price increase than a price decrease. The table also reveals increased skewness, indicating a likelihood of price increases in the short run. A plausible explanation is that the government's decision to release wheat stock in the event of high market prices is made independently of the quantity needed to achieve a specific open market price. Thus, public stockholding resulted in a sudden increase in wheat prices (spikes) in the short run. However, the simulated price distribution shows no evidence of excess kurtosis, suggesting a low probability of extremely low and high prices.

The nature and speed of dynamic adjustments can be assessed by evaluating the marginal effect of P_{t-1}, that is $\partial P_t/\partial P_{t-1}$ and captured by the coefficient of lagged price P_{t-1}. It varies across both quantiles and the levels of stockholding. $|\partial P_t/\partial P_{t-1}|$ is the root of the dynamic system, and when the root is less than 1 (higher than 1), the system is locally stable (unstable), respectively. We assessed the dominant root under various stockholding scenarios using the quantile estimations from Equation (3). The estimated roots are presented in Figure 7 for different quantiles. It shows some interesting patterns. First, the root is below 1 for all quantiles under both stock scenarios, meaning wheat market price exhibits dynamic

[13]We also considered the alternative evaluation points to check the robustness of our analysis. However, our qualitative findings did not change and were similar.

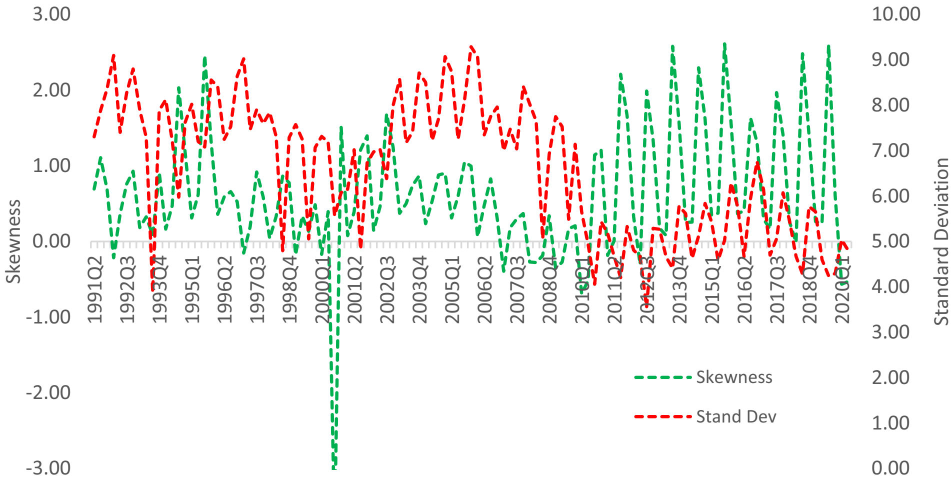

FIGURE 5 Estimates of moments of the wheat price distributions, India, 1991–2020. *Source*: Authors' calculation. [Colour figure can be viewed at wileyonlinelibrary.com]

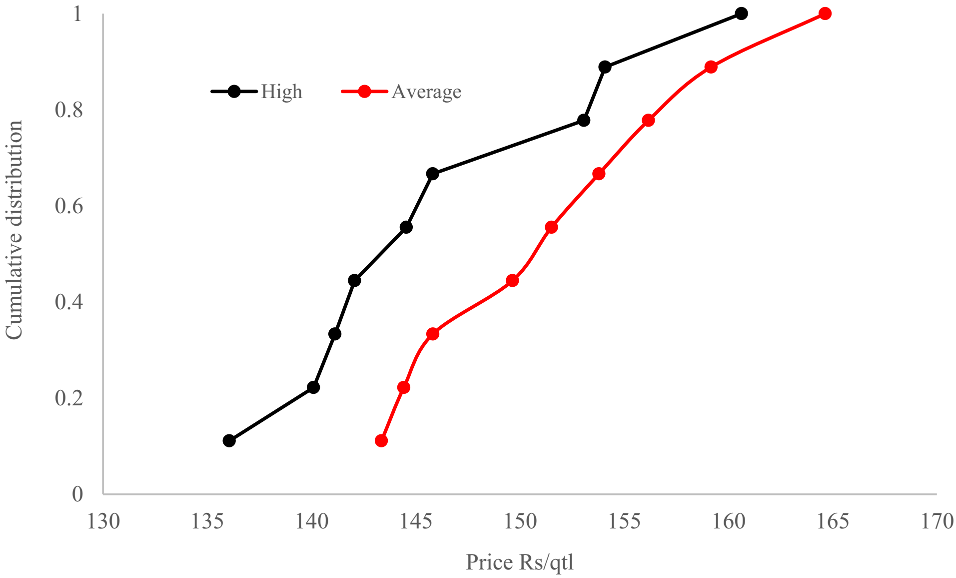

FIGURE 6 Simulated short-term distribution of wheat price under alternative stockholding scenarios, wheat, India. *Source*: Authors' calculation. [Colour figure can be viewed at wileyonlinelibrary.com]

stability. Second, the root tends to be smaller under the high stock regime, indicating that dynamic adjustments in market prices are more stable when stocks are in the upper quantile of the stockholding distribution. Third, even under a high public stockholding regime, the root tends to be smaller for lower and higher quantiles of the price distribution. This indicates that a higher public stockholding level is more effective in bringing dynamic stability when market prices are in the lower and upper tail of the distribution. Fourth, when stocks are in the lower quantile of their distribution, the root tends to be close to unity for median and higher quantiles. Thus, under a low stockholding regime, the dynamics appear to be locally more stable but only in the lower tail of the price distribution. Hence, it reflects that

TABLE 5 Summary of simulated price distributions under different stock-to-use scenarios, wheat, India.

Scenario	Mean	Standard deviation	Skewness	Kurtosis
Low stock	145.52	6.48	0.22*** (0.002)	−0.14** (0.020)
Average stock	152.06	7.14	0.47*** (0.005)	−0.59** (0.031)
High stock	146.39	7.93	0.66*** (0.004)	−0.46** (0.043)

Note: (1) Lower, average and high stockholding represents stockholding distributions less than 0.35 quantiles, between 0.35 and 0.70 quantiles and greater than 0.70 quantiles from the sample data, respectively. (2) Values in parentheses below are *p*-values. (3) The significance level at: * 10% level, ** 5% level and *** 1% level.

Source: Authors' calculation.

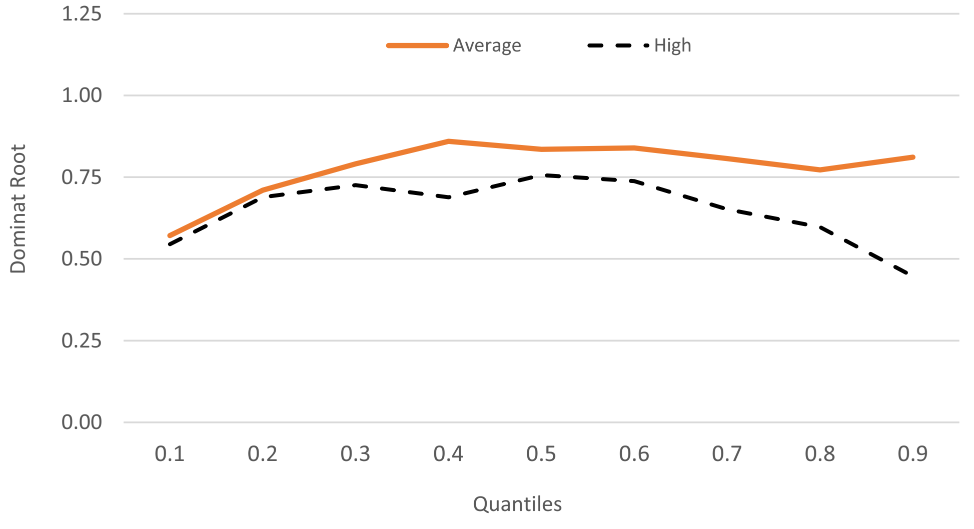

FIGURE 7 Dynamics of wheat price: dominant root under different stockholding level scenarios, wheat, India. The dominant roots are plotted across quantiles under different stockholding levels. A dominant root at or above 1 indicates instability. *Source*: Authors' calculation. [Colour figure can be viewed at wileyonlinelibrary.com]

dynamic adjustment tends to be qualitatively different across stock regimes with evidence of a reduction in dynamic local stability, especially under the low stockholding regime and when $q \geq 0.5$. A plausible explanation is that once stocks are low, they cannot impact the market via government sales intervention.

7 | CONCLUSIONS

This paper examined the effect of public stockholding on wheat price dynamics and volatility in India. The analysis relied on a reduced-form representation of price dynamics based on the QAR model. The study highlights some important observations regarding the role of public stockholding of wheat and its effect on prices in India for 1991–2020. First, the previous year's public stockholding significantly affected current wheat prices. However, the effects vary when considering the entire price distribution. Our results showed that public stockholding had a stronger negative impact on the lower tail of price distribution than on the upper tail of the distribution. This could be attributed to India's policy of selling wheat and other major crops through the public distribution system determined independently of the quantity needed to achieve a specific wheat price target in the open market. The focus of the stockholding strategy is more on income redistribution. Second, the associated moments of price distribution show the effect of public stockholding on the tails of the price distribution. The analysis shows that public stockholding reduced variation in market price distribution, as indicated by a smaller standard deviation. However, positive skewness estimates suggest that the probability of facing a price increase is higher than a price decrease. Third, the research suggests that a higher previous stock-to-use ratio shifts the whole price distribution to the left by increasing the quantity of currently available wheat, putting downward pressure on wheat prices. Further, analysis shows that increasing public stockholding increases the probability of price increases in the short run. This finding could be attributed to the government's decision to release wheat stocks independent of the wheat price levels in the market.

Thus, the findings of this study reveal that public stockholding exerts a stronger effect on wheat prices in the lower tail of price distribution. Alternatively, the price distribution tends to shift to the right with a decrease in the previous year's stockholding of wheat. The analysis provides evidence of local dynamic stability in price distribution for all quantiles under both stockholding scenarios. However, dynamic price adjustments are locally more stable when stockholdings are in the upper quantile of their distribution. Thus, reflecting that dynamic price adjustments tend to be qualitatively different across stockholding regimes.

The analysis and results concerning the implementation of public stockholding in the case of the Indian wheat market show that the stockholding policy has a strong effect when market prices are in the lower tail of distribution than in the upper quantiles. However, it has increased the odds of price spikes in the short run. Perhaps the focus of the Indian government's agricultural policy is on distributing food grains at subsidised prices to eligible groups (for example, TPDS and OWS) rather than price stabilisation. Therefore, public stockholdings are effective only in mitigating the risk of price crashes. The findings of this study have policy implications for India and other countries in Southeast Asia. Using restrictive trade policies and relying on public stockholding to address price volatility and food shortages is common practice in these countries—for instance, during the episodes of the food price surge in 2007–2008 and more recently in 2022. Additionally, implementing public stockholding takes substantial resources to manage food grain procurement, storage and distribution, thus creating a heavy fiscal burden and welfare costs. Furthermore, export restrictions negatively impact food security by reducing world market supply and exacerbating high world prices. Accordingly, export restrictions have far-reaching implications regarding production and investment incentives for domestic producers. Perhaps policymakers should refrain from using restrictive trade policies and rely on the market to guarantee a stable food supply.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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