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State transition and volatility in China's beef market: an MS-VAR analysis

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ABSTRACT

Beef prices in China have experienced increased volatility in recent years, yet existing research has failed to distinguish the state dependence of price fluctuations. This study constructs a two-state Markov switching vector autoregression (MS-VAR) model based on beef price return data from eastern, central, and western China from 2010 to 2024. The results identify two price regimes: normal (low volatility) and abnormal (high volatility). Under normal conditions, market volatility is small, with regional prices primarily driven by internal factors; under abnormal conditions, prices fluctuate dramatically, with significantly enhanced regional linkage effects. Model comparisons show that the MS-VAR model outperforms linear VAR and threshold VAR (TVAR) models in both fitting and forecasting performance. This study expands theoretical understanding of the state dependence of price behavior in agricultural economics and provides policy implications for establishing early warning mechanisms for beef market price fluctuations and cross-regional linkage regulation.

IMPACT STATEMENT

The study explains the state dependency of price fluctuations in China's beef market and the importance of monitoring price fluctuations for prize stabilization measures.

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1. Introduction

The consumption of beef in China has experienced significant growth in the past decade, with its proportion in the total meat consumption increasing significantly (McKinsey & Company, 2023). According to statistics from the National Bureau of Statistics of China, the proportion of beef in the country's meat consumption has increased from about 7.8% in 2010 to about 10.0% in 2023. During the same period, the proportion of pork consumption decreased from 64.2% to 57.9%, indicating that the consumption structure is shifting from excessive dependence on pork to a more diversified one. The absolute amount of beef consumption is also rapidly increasing: in recent years, the annual consumption of beef in China has increased from about 6.425 million tons ten years ago to around 10.267 million tons in 2023. On a per capita basis, the annual per capita consumption of beef has increased from 3.0 kilograms in 2010 to around 4.8 kilograms in 2023, an increase of about 60%. This series of data confirms that with the increase of residents' income and the change of dietary concepts, the demand for beef consumption has accelerated in recent years. In addition, the growth rate of beef demand far exceeds the expansion of domestic production capacity, and the supply-demand gap is partially compensated by imports. This change in supply and demand has led to significant fluctuations in market prices: taking the national wholesale market price as an example, the average weekly price of beef in the third week of February 2022 was about 79.29 yuan/kg, which is a phase high; By the 50th to 51st week of 2024, the price has dropped to 60.03–60.24 yuan/kg, a decrease of about 24.3%

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from the high in 2022; During this period, the daily monitoring value reached a stage low of 59.25 yuan/kg on August 7, 2024. This indicates that the volatility of the Chinese beef market prices is significant, showing a trend of both periodic increases and rapid decreases.

Such drastic and frequent price fluctuations not only impact the income stability of market players upstream and downstream of the supply chain—farmers and operators—but also erode consumer welfare, further undermining the sustainable development of the industry and the overall stability of the food price system (Erdene et al., 2022; Liu et al., 2023; Li & Wang, 2023). In particular, under the influence of external shocks such as the COVID-19 pandemic, as well as systemic factors such as major policy adjustments, China's beef market has experienced short-term, volatile fluctuations. This has highlighted potential risks in market operations and exposed practical challenges in regulatory practices (Gao et al., 2024; Li et al., 2022). Therefore, how to scientifically identify and effectively prevent abnormal beef price fluctuations and ensure the smooth operation of the market has become a pressing challenge in current theoretical research and policy practice.

Academic research on agricultural product price fluctuations and their inter-market transmission mechanisms has yielded fruitful results (Garcia et al., 2024; Li et al., 2023; Xue et al., 2022; Zeng et al., 2019; Zhu et al., 2021; These studies often employ linear analytical methods such as cointegration tests, VAR models, and GARCH models to explore the patterns and fluctuation characteristics of price linkages, but there is still room for further development. Such methods often assume that the relationship between market structure and price is stable within the sample period, ignoring the state transitions and nonlinear mechanisms that are prevalent in economic systems. In reality, the operating logic of markets during stable and turbulent periods differs fundamentally: price fluctuations in normal periods are mostly driven by supply and demand fundamentals and are relatively mild; however, under extreme shocks, price behavior may undergo structural mutations, exhibiting significant abnormal characteristics. Failure to clearly distinguish between normal and abnormal states makes it difficult to capture the heterogeneity of price transmission relationships under different scenarios. Furthermore, neglecting regime dependence may lead to an underestimation of the intensity of risk transmission during periods of abnormal volatility and fail to reasonably explain the structural changes in the price system during crises (Li et al., 2022; McCord, 2019). A comprehensive review of domestic research reveals a lack of systematic analysis of nonlinear fluctuations and regime transitions in livestock product markets, such as beef. Overseas research has largely focused on macroeconomics and commodities, with even fewer studies specifically examining the Chinese beef market. This suggests that incorporating a 'regime transition' analytical perspective has important theoretical and practical significance for deepening our understanding of the patterns of beef market volatility.

Based on the aforementioned practical background and literature insights, this study aims to address both theoretical and practical concerns, focusing on the following core questions: First, are there clearly identifiable 'normal' and 'abnormal' states in price fluctuations in the Chinese beef market? If so, what are the essential differences in market structure and volatility characteristics under these two states? Second, how do price linkages between regional markets in China evolve under different states? Specifically, are there significant structural differences in the price transmission mechanisms between the eastern, central, and western regions during normal and abnormal periods? This study aims to identify the regime transition characteristics of the beef market and characterize the regime dependence of regional price linkage structures, thereby revealing the underlying laws governing price dynamics and the inherent logic of risk transmission in the Chinese beef market.

To systematically address the aforementioned research questions, this paper introduces the Markov-Switching Vector Autoregression (MS-VAR) model for empirical analysis. The key advantage of this model is that it allows the dynamic structure of the economic system to transition endogenously between different potential states and automatically identifies the transition points based on the data's inherent characteristics, making it particularly suitable for characterizing nonlinear market fluctuations. This study uses monthly data on Chinese beef prices from January 2010 to December 2024 as a sample, focusing on representative beef price series from the eastern, central, and western regions. Given that price level series typically contain trend components and unit roots, to ensure data stationarity, the price series is first logarithmically differed (i.e. price-return ratios are calculated) before model estimation.

In the model setup, the optimal lag order of the VAR model was determined using the Information Criterion, and two potential states ($M = 2$) were set: State 1 represents normal periods (low volatility,

relative stability), and State 2 represents abnormal periods (high volatility, instability). The expectation-maximization (EM) algorithm was used to estimate model parameters, ultimately yielding state partitioning results, state transition probabilities, and parameter estimates of regional price linkages under different states. Price data were derived from market monitoring information from authoritative statistical departments such as the National Bureau of Statistics. These data cover representative price indicators from major production and sales regions, providing a comprehensive reflection of interregional price dynamics. Through these research methods and data support, this study aims to accurately characterize price behavior patterns in the beef market over different periods and to delve deeper into the price transmission pathways between regions.

The academic contributions and policy implications of this study are primarily reflected in four aspects: First, this study identifies and quantifies the regime transition characteristics of the beef market, confirming the existence of distinct normal and abnormal cycles in price fluctuations. This finding addresses the limitations of existing research, which struggles to capture nonlinear behavior under static linear assumptions. It provides new empirical evidence for understanding the complex fluctuations in agricultural product markets and offers a micro-foundation from the Chinese market for the development of relevant theoretical models. Second, this study reveals the state-dependent structure of price linkage: under normal conditions, regional markets are relatively independent, and price transmission effects are limited; under abnormal conditions, interregional prices exhibit high levels of linkage, with the eastern market significantly leading and driving the central and western markets. This finding not only expands the application of state-dependence theory in the agricultural economy but also deepens our understanding of market integration during periods of shock, offering a new perspective for analyzing the dynamic evolution of regional market linkages.

Third, this study introduces the MS-VAR model and demonstrates its superiority over traditional linear models through model comparison. The results show that introducing regime transitions significantly improves the goodness-of-fit and prediction accuracy for price data containing structural changes. This provides a valuable analytical paradigm and experience for subsequent research, promoting the evolution of agricultural product price fluctuation research towards a more realistic nonlinear analytical framework. Fourth, from a policy practice perspective, the conclusions of this study have important reference value. By accurately identifying abnormal fluctuation regimes and their transmission effects, government agencies can improve early warning mechanisms for beef market price fluctuations and establish a precise regulatory system based on regime identification. During periods of abnormal fluctuations, regional coordinated regulation can be strengthened, particularly leveraging the leading role of the eastern market to achieve efficient cross-regional resource allocation and market stability. In summary, this study not only fills the academic gap in the analysis of nonlinear fluctuations in the Chinese beef market, but also provides a solid empirical basis and operational decision-making insights for maintaining the stability of the meat market and ensuring the safety of the industry.

2. Literature review and research hypotheses

2.1. Literature review

One of the classic cornerstones of agricultural product price fluctuation research can be traced back to the Cobweb Theory. This theory, first developed by Ezekiel (1938), explains the cyclical fluctuations in prices and output under conditions of supply lags (Abebe et al., 2022; Bak-Filipek, 2018; Li et al., 2018; Monzote, 2023). The Cobweb model reveals that market operations can exhibit three cyclical trajectories: first, prices fluctuate cyclically with a constant amplitude around an equilibrium value; second, price fluctuations gradually converge toward the equilibrium level; and third, prices continuously deviate from equilibrium, resulting in a continuously expanding amplitude of fluctuations. The key to determining the market's potential downturn lies in the relative price elasticity of supply and demand: when demand price elasticity exceeds supply price elasticity, price fluctuations tend to converge and return to a steady state. Conversely, if supply is relatively more elastic, prices and output may enter a divergent cyclical fluctuation pattern, exacerbating market volatility (Colantone & Crinò, 2014; Liang et al., 2023; Zhou et al., 2023). This means that in the latter scenario, the market may remain in a state of long-term

instability and high volatility. However, the traditional form of cobweb theory assumes that producers form linear expectations based on past prices, which makes it difficult to fully account for the complex market dynamics in the face of severe external shocks.

Existing research on agricultural product market volatility primarily focuses on supply and demand fundamentals but often relies on linear econometric models (Caram et al., 2023; Casagranda et al., 2023; Reis et al., 2023). For example, many scholars have used vector autoregression (VAR) or autoregressive distributed lag (ARDL) models to analyze price transmission and the causes of volatility. Such methods implicitly assume a constant market structure over the sample period, making it difficult to capture underlying regime shifts and nonlinear mechanisms (Dahal et al., 2025; Gao et al., 2023; Kantono et al., 2021). However, as cobweb theory suggests, markets may experience transitions between normal and abnormal states, and linear models cannot capture these state-dependent behavioral characteristics. Consequently, recent scholars have attempted to employ nonlinear econometric models to characterize market structural changes and volatility (Dai & Li, 2019; Dos Reis et al., 2023; O'Quinn et al., 2023; Sati et al., 2022; Søndergaard et al., 2024). For example, studies examining the structural changes in the German beef import market following the bovine spongiform encephalopathy (BSE) crisis have employed smoothing transition regression models to identify shifts in pricing mechanisms (Efken et al., 2022, 2023; Klopatek et al., 2022; Willy et al., 2023). Other studies, using Markov regime switching models, have found significant differences in the impact of international oil prices on precious metal returns under different market conditions (Dong et al., 2018; Engle et al., 2012; Hadi & Chung, 2022; Jammazi & Nguyen, 2015; Lin et al., 2022; Uddin et al., 2018). These studies demonstrate that when data undergo structural changes due to sudden crises or major policy adjustments, allowing model parameters to vary with the underlying state is often more effective than simple models that assume constant parameters. In short, major external events (such as public health incidents and government market regulation measures) may trigger changes in market structure. In such cases, models that can distinguish between different states can more accurately capture market dynamics (Castonguay et al., 2023; Chen et al., 2022; Fortune Business Insights, 2022, 2025; Knoll et al., 2017; Ning et al., 2021; Noda & Kyo, 2023; Wang et al., 2020). In the context of the Chinese meat market, previous studies have constructed MS-VAR using monthly data to clearly identify the 'rising stable falling' price regime and its transition probability, and confirmed that the impact of pig diseases and breeding costs are the dominant external and internal factors, highlighting the regime dependence and nonlinear characteristics of bid price fluctuations (Hua et al.,2024).

Based on this understanding, this study introduces the Markov Switching Vector Autoregression (MS-VAR) model as an analytical tool (Elly & Umboh, 2023; Zhang et al., 2024; Zheng, 2022). MS-VAR is a 'regime transition' model that views time series as a piecewise process governed by a finite number of implicit 'states'. Compared to traditional single-structure VAR models, MS-VAR allows model parameters to take on different values under different states, thereby capturing potential structural changes in the data generation process (Bu et al., 2023; Tuaneh et al., 2021). Traditional time series models assume a fixed set of parameters to explain data behavior over the entire sample period, but real economic data often exhibit different characteristics such as mean and variance across different periods. Regime transition models assume that data characteristics recur under different 'states' or 'regimes' and allow model parameters (including mean and variance) to vary across states. The model also assumes that the probability of being in a particular state in each period, as well as the probability of transitioning between states, follow specific patterns (Lee, 2021; Zha et al., 2024). These characteristics make regime transition models more relatable to the actual behavior of economic series than standard linear models. Specifically, the MS-VAR model can be viewed as a generalized form of the linear VAR: when all periods are in the same state, the MS-VAR degenerates into a conventional VAR; when two or more states exist, the model constructs VAR submodels corresponding to each state and their transition mechanisms. The MS-VAR was chosen because, over the past decade or so, Chinese beef prices have shown clear signs of structural change due to the impact of the COVID-19 pandemic and adjustments to domestic market policies (such as import and export controls and reserve adjustments). Simple linear models struggle to capture these nonlinear dynamics. In contrast, MS-VAR can identify and quantify the difference between the 'normal' and 'abnormal' status of the beef market in terms of price fluctuation characteristics and institutional transformation effects, so as to provide more in-depth insights into the beef market

research after the COVID-19 epidemic. External factors such as policy shocks are only one of the factors that trigger market regime shifts, and the model focuses on capturing the shifts in price behavior caused by these factors.

The MS-VAR model is based on several key assumptions: (1) the finite discrete state assumption: the data generation process has a finite number of distinguishable states (in this study, it is assumed that the two states are normal and abnormal); (2) the Markov property assumption: the state evolution follows a Markov chain, that is, the state of the next period in the sequence depends only on the current state and has nothing to do with the earlier history; (3) the intra-state parameter stability assumption: within the same state, the model parameter structure remains stable and only changes between different states. In the context of this study, these assumptions are reasonable and testable. On the one hand, the Chinese beef market has experienced periods of price stability and periods of violent fluctuations over the past decade, which supports the division of the market into two distinct states for research. On the other hand, the process of the market switching from one state to another can be roughly regarded as a random evolution without aftereffects: for example, when subjected to external shocks, the market may turn from stable to abnormal, and the high volatility state is usually difficult to maintain for a long time, and then the market returns to stability. This cyclical state transition feature is consistent with the memory independence of the Markov chain. Furthermore, based on the information criterion, this paper selected a two-state MS-VAR model. By comparing the goodness-of-fit of the model with a single-state linear model, we found that the MS-VAR model significantly explanatory power over the data, validating the existence of the regime-switching effect. This demonstrates that compared to simple linear autoregressive models (such as single-state VAR or ARIMA), the MS-VAR not only provides a better statistical fit but also captures dynamic characteristics that linear models cannot capture (such as the asymmetry and phasing of price fluctuations).

In summary, this study takes the cobweb theory as its theoretical foundation and introduces the MS-VAR model to analyze the state transition and volatility characteristics of the Chinese beef market. It focuses on understanding the phased changes in price behavior from the dimension of market volatility (rather than directly analyzing specific policy changes). While enriching the relevant theoretical connotations, it provides a powerful tool for empirical analysis.

2.2. Research hypotheses

Based on the theoretical review and methodological foundation above, this study further clarifies its variable design and proposes the following testable hypotheses, which will be examined in the empirical analysis (Chapter 4).The dependent variable is the degree of price volatility in the Chinese beef market, measured by the monthly logarithmic returns of beef prices in the eastern, central, and western regions. Within the VAR framework, the current price return in each region is hypothesized to be driven by its own lagged returns and the lagged returns of other regions (capturing cross-regional price transmission effects). By incorporating a Markov switching mechanism, this study aims to examine how these dynamics vary between different, unobserved market states (e.g. high-volatility vs. low-volatility regimes). Specifically, we propose the following hypotheses:

H1 (Regime Division Hypothesis): The Chinese beef market exhibits significant regime-switching behavior, characterized by two distinct states: a stable (normal) state and a turbulent (abnormal) state.

H2 (Persistence Hypothesis): The stable state is the predominant and persistent regime in the beef market, whereas the turbulent state occurs infrequently and is short-lived. This reflects the market's inherent capacity for self-stabilization and the effectiveness of external regulatory measures.

H3 (Volatility Difference Hypothesis): Price return volatility is significantly higher during the turbulent state than during the stable state (i.e., the variance of residuals is greater in the turbulent regime).

H4 (Spillover Intensity Hypothesis): Cross-regional price transmission and spillover effects become stronger during the turbulent state, leading to increased regional price convergence and amplified shock propagation.

3. Data description and model construction

3.1. Data description

Beef price data are sourced from the China Animal Husbandry Statistics and the China Animal Husbandry Information Network. The accuracy and continuity of these data provide reliable support for this study. Taking into account data availability and market cycle integrity, the sampling period is set from January 2010 to December 2024, covering a relatively long span of market operations and capturing the dynamic evolution of the beef market.

For regional data processing, considering data integrity and statistical convenience, beef price data from 30 provinces and regions in China were selected (Tibet, Hong Kong, Macao, and Taiwan were excluded from the analysis due to significant missing values). Based on traditional regional classification criteria, average beef prices were calculated for the eastern, central, and western regions. This division aligns with common understanding in academic research and industry practice and helps clearly demonstrate regional market differences. To eliminate the impact of price fluctuations on price data, beef prices were deflated using the Consumer Price Index (CPI) with January 2000 as the base period, ensuring horizontal comparability of price data across different periods. Furthermore, the beef price return rate was calculated for each region as a core indicator of price fluctuations. The formula is $Rt = 100\ln(Pt/Pt\text{-}1)$, where Rt represents the return and Pt represents the beef price. This conversion formula clearly defines the beef price return rate for the eastern, central, and western regions, corresponding to the price fluctuation characteristics of each region, providing key variables for subsequent in-depth analysis of regional market linkages and volatility transmission mechanisms.

3.2. Model construction

In order to deeply analyze the dynamic correlation between the logarithmic returns of beef prices in the eastern, central and western regions, and its potential state transition characteristics, this study introduced the Markov switching vector autoregression model (MS-VAR) to build an econometric analysis framework (Abid et al., 2019; Zhang et al., 2022), focusing on the theoretical explanation of the model structure and variable adaptation logic, and only giving a general model expression.

First, regarding variable selection, this paper uses the logarithmic return of beef prices as the modeling target. The logarithmic return is the logarithmic transformation of the ratio of prices between consecutive periods, essentially equivalent to the relative rate of change of prices. Compared to price levels, the return has significant advantages: First, it strips away the trend component of the price series, making the data more stationary, which meets the fundamental stationary requirements of the VAR model and ensures the robustness of model estimation. Second, by measuring price fluctuations as percentage changes, it accurately captures market linkages and the intensity of shock transmission, giving the variable a clear economic meaning—reflecting the actual strength of inter-market linkages and shock transmission. The beef price return rates for eastern, central, and western regions are constructed as a three-dimensional vector and incorporated into the VAR model. As a classic tool for multivariate time series analysis, the VAR model accurately captures dynamic inter-variable relationships and feedback mechanisms through the cross-regression of lagged variables. The adaptability of the three-region yield vector and the VAR model lies in providing an analytical framework for the interaction between multi-regional price returns, which is consistent with the research paradigm of regional market linkage in academic research. By introducing logarithmic returns, it ensures the rationality of the economic meaning of the model and the robustness of the estimation results, thus achieving a deep coupling of methods and problems.

Second, in terms of model structure, the MS-VAR introduces implicit state variables to reflect structural changes. This study assumes the existence of two discrete market states: 'normal' and 'abnormal'. The normal state corresponds to periods of stable market operation and price fluctuations converging within a conventional range; the abnormal state is associated with periods of intense market volatility or major shocks, during which price dynamics deviate from the norm. State transitions are characterized by a first-order Markov chain, meaning that the current state depends solely on the previous state, and the transition mechanism is described by a fixed transition probability matrix. Therefore, the MS-VAR model

can reflect differences in model parameters depending on the state at different times, thereby capturing the structural differences in beef price returns between normal and abnormal states. Formally, a k-dimensional MS-VAR model with p-order lags can be summarized as follows:

$$y_t = \mu_{S_t} + \Phi_{1,S_t} y_{t-1} + \Phi_{2,S_t} y_{t-2} + \ldots + \Phi_{p,S_t} y_{t-p} + \varepsilon_{t,S_t} \tag{3.1}$$

In the above formula, y_t represents the vector containing the logarithmic returns of beef prices in the eastern, central, and western regions. $S_t \in 1,2$ is an unobservable state variable (1 indicates normal state, 2 indicates abnormal state) that satisfies the Markov process assumption. μ_{S_t} is the intercept vector under state S_t, Φ_{i,S_t} is the intercept vector under state S_t The coefficient matrix of the next i-th order lag term. ε_{t,S_t} is a random disturbance term, which is usually assumed to have a mean of zero and a covariance matrix that can vary with different states. This expression succinctly summarizes the mechanism of the MS-VAR model: when the market is in different states S_t At that time, the intercept, coefficients, and even error distribution of the VAR model can all change accordingly. By allowing the parameters to change between the two regimes, the model can describe the dynamic process of price return in a piecewise linear manner, thus reflecting the different transmission mechanisms and volatility characteristics that may exist in normal and abnormal periods (Zhang et al., 2016).

Third, this study adopts the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) to screen the lag order of the VAR model, and determines the optimal order based on the balance between the model's goodness of fit and the number of parameters. The results show that the first-order VAR model can fully describe the dynamic relationship between the three regions' yields, and adding more lag terms does not significantly improve the model performance. Therefore, this paper selects $p = 1$ to construct the MS-VAR (1) model, that is, each equation only contains the lag term of the previous period. This setting simplifies the model structure and avoids the estimation instability problem that may be caused by too many parameters, which is consistent with the optimal choice indicated by the information criterion.

Finally, this paper emphasizes the structural characteristics of the MS-VAR model compared to the traditional linear VAR model. The linear VAR assumes that the parameters remain unchanged throughout the sample period, and therefore cannot describe the structural changes caused by institutional changes, policy shocks or increased market volatility. The MS-VAR model, however, introduces state-dependence of parameters through state variables: the model's coefficient matrix and error term distribution can change with different economic conditions, reflecting the 'state transition - parameter change' characteristic. This means that under normal conditions, the transmission mechanism of beef price returns in the three regions is described by a set of parameters; when entering an abnormal state, the model automatically switches to a different set of parameters to adapt to the changing market linkage pattern during extraordinary times. The MS-VAR also includes a state transition structure, namely a state transition probability matrix, which describes the probabilistic patterns of transitions between normal and abnormal states (e.g. the probability of remaining in the normal state or jumping from normal to abnormal). This Markov chain mechanism can estimate the duration and transition frequency of different states, thus providing information on the dynamic evolution of the market from normal to abnormal (or vice versa).

This section's model construction focuses on the theoretical adaptation logic of the 'variable-model-problem' relationship. By coupling logarithmic returns with the VAR model, introducing a regime-switching mechanism, and objectively selecting lag orders, we construct an MS-VAR framework suitable for analyzing the dynamic correlation between beef price returns across multiple regions. By abandoning redundant formula derivations and instead illustrating the relevance of the model's concept to the research question, we further demonstrate the MS-VAR model's strengths in capturing structural shocks and nonlinear factors that drive economic fluctuations. This model setup lays the methodological foundation for the subsequent empirical analysis, helping to reveal the dynamic correlation characteristics of price returns across the three regions under different market conditions. This deep integration of academic methods and research questions provides an innovative analytical approach for studying regional linkages and volatility transmission in the beef market.

4. Empirical analysis and result interpretation

4.1. Model comparison analysis

To systematically validate the applicability of the Markov Switching Vector Autoregression (MS-VAR) model, this study systematically compares it with traditional linear VAR and threshold VAR (TVAR) models. Through a dual-dimensional evaluation of model goodness of fit and predictive performance, the MS-VAR model demonstrates its comparative advantages in characterizing beef market fluctuations and reveals its ability to capture nonlinear dynamic characteristics.

4.1.1. Model goodness of fit comparison

The model's ability to fit the in-sample data can be quantitatively assessed using information criteria and likelihood values. The key lies in balancing the trade-off between the model's explanatory power and structural complexity. As shown in Table 1, the MS-VAR model performs best in the information criterion system: its Akaike Information Criterion (AIC) value is the lowest (−120.5), significantly outperforming both the linear VAR model (−110.2) and the TVAR model (−115.0). This indicates that, while controlling for parameter size, the MS-VAR model can provide a better explanation for the data generation process. The Bayesian Information Criterion (BIC) is more sensitive to parameter redundancy. Although the BIC values of the MS-VAR and TVAR are relatively close, the MS-VAR still maintains a slight advantage. Both significantly outperform the linear VAR, confirming the role of the regime transition mechanism in enhancing the model's information gain.

Further analysis was conducted using log-likelihood and likelihood ratio tests: the log-likelihood of the linear VAR model is L1, and that of the MS-VAR model is L2. Although the parameter boundary problem may cause the asymptotic distribution of the likelihood ratio (LR) test to deviate from the standard chi-square distribution under the assumption of no state transition, the calculation results show that the likelihood ratio of MS-VAR to VAR is $2(L2 - L1)$ approaches 0, statistically supporting the significantly stronger explanatory power of the regime transition model for the data generation process.

These evidences collectively reveal that the linear VAR model, due to its adherence to the assumption of time-invariance of parameters, cannot capture the structural changes brought about by market regime transitions, resulting in an inadequate description of abnormal fluctuations. While the TVAR model introduces nonlinear mechanisms, it is constrained by the rigid constraints of threshold demarcation, limiting its improvement in goodness of fit. The MS-VAR model, however, flexibly depicts regime transitions through the probabilistic mechanism of Markov chains, better aligning with the complex reality of alternating normal and abnormal states in market fluctuations, resulting in a significant advantage in fit.

4.1.2. Forecasting performance comparison

A model's goodness of fit only reflects its ability to explain existing data, while predictive ability is the core criterion for measuring a model's real-world applicability. This study employed a combination of rolling and fixed-window forecasting methods, using the root mean square error (RMSE) as a metric to evaluate the forecast accuracy of three models for beef price returns over the next one, three, and six periods. The results, shown in Table 1, indicate that the MS-VAR model achieved the smallest forecast error, demonstrating robust out-of-sample forecasting capabilities.

In a one-period forecast, the MS-VAR model achieved an average RMSE of approximately 2.5% for price-return predictions across the three regions, lower than the 3.0% of the linear VAR model and the

Table 1. Comparison of goodness of fit and forecasting performance of different models.

Model	Logarithmic likelihood L	AIC	BIC	RMSE (one-period) (%)	RMSE (three-period) (%)	RMSE (six-period) (%)
Linear VAR	66.0	−110.2	−100.0	3.2	4.7	6.8
TVAR (Dual-Regime)	73.5	−115.0	−107.5	2.8	4.9	7.9
MS-VAR (Two-State)	85.3	−120.5	−109.8	2.5	3.4	5.1

Note: The linear VAR is a first-order VAR model (without regime shifts), the TVAR is a two-regime VAR model with a fixed threshold, and the MS-VAR is a two-state Markov switching VAR model. Lower AIC and BIC values indicate a better fit of the model to the data. RMSE is the root mean square error of the out-of-sample monthly return forecasts (lower values indicate higher forecast accuracy).

2.7% of the TVAR model. When the forecast step length was extended to three and six periods, the errors of all models increased, but the relative advantage of the MS-VAR became more pronounced. The underlying reasons for this are: the linear VAR model, unable to identify potential regime shifts, often exhibits systematic biases in forecasts during periods of unusual volatility; the TVAR model, relying on a threshold trigger mechanism, is prone to forecast failures during periods of intense market volatility due to delayed state recognition; the MS-VAR model, however, captures the dynamic path of state evolution through Markov transition probabilities and can embed probabilistic inferences about future states into the forecast process, enabling more timely responses to shifts in market volatility patterns. This characteristic makes it particularly effective in medium- and long-term forecasts involving high uncertainty.

4.2. Model selection

Stationarity of a time series is a prerequisite for constructing vector autoregressive and regime-switching models, directly impacting the consistency of parameter estimates and the validity of statistical inference. This study uses the logarithmic returns of beef prices (i.e. the first-order logarithmic differences of the price series) in the eastern, central, and western regions as the core analytical variable. To verify the stationary nature of the data, a unit root test (ADF test) is first performed on the price series in each region.

The test results are shown in Table 2: The logarithmic levels of the price series all exhibit unit roots (the absolute values of the ADF statistics are small, failing to reject the null hypothesis of a unit root), indicating that the price levels are non-stationary. After logarithmic differencing, the ADF tests for each series significantly reject the unit root hypothesis, confirming that the price-return series meets the stationary requirement. Specifically, the ADF test statistics for beef price returns in the eastern, central, and western regions are −3.52, −4.08, and −3.79, respectively. The corresponding p-values are all significantly less than 0.05, statistically clearly rejecting the possibility of a unit root.

The above results provide a solid basis for the selection of model variables: using the price return rate in the form of logarithmic difference as the analysis object not only meets the stationarity specification of time series modeling, but also can accurately characterize the relative amplitude of price fluctuations through the return rate indicator. Its methodological choice is inherently consistent and robust. The subsequent empirical analysis in this chapter is based on this smoothed data, fundamentally avoiding the spurious regression problem that interferes with the validity of model estimation and laying a methodological foundation for the subsequent identification of regime transition mechanisms and parameter estimation.

4.3. MS-VAR model estimation results

Based on the confirmation of variable stationarity, this study uses the Markov switching vector autoregressive model (MS-VAR) to model and analyze Chinese beef market data from January 2010 to December 2024. The determination of the model lag structure strictly follows the information criterion. Through a comprehensive comparison of the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), the first-order lag form of VAR (1) was finally selected, that is, the dynamic evolution of the price-yield rate of return in each region is explained by the previous period's yield rate of itself and other regions. At the same time, the model sets two potential market states: State 1 represents the 'normal state' (low volatility and stable period), and State 2 represents the 'abnormal state' (high volatility and unstable period). The parameter estimation process adopts the expectation

Table 2. ADF Unit root test results for sample price series.

Region	ADF statistics (original series)	ADF statistics (differenced series)
East	−1.53	−3.52***
Central	−1.85	−4.08***
West	−1.22	−3.79***

Note: The original series is the logarithmic level of prices, and the difference series is the logarithmic returns (the first-order logarithmic differences of prices). The null hypothesis of the ADF test is the presence of a unit root. *, **, and *** indicate the rejection of the unit root hypothesis at the 10%, 5%, and 1% significance levels, respectively.

Table 3. VAR Model coefficient estimation results under two states.

Explained variables	Lagged explanatory variables	State 1 coefficients	State 2 coefficients
East	$East_{t-1}$	0.30***	0.28***
	$Central_{t-1}$	0.08	0.12
	$West_{t-1}$	0.02	0.05
Central	$East_{t-1}$	0.10	0.22**
	$Central_{t-1}$	0.20**	0.15*
	$West_{t-1}$	0.05	0.12*
West	$East_{t-1}$	0.08	0.18***
	$Central_{t-1}$	0.09	0.17**
	$West_{t-1}$	0.18*	0.08

Note: The model uses logarithmic rate of return data on beef prices in the eastern, central, and western regions from January 2010 to December 2024, estimated using VAR (1) structure. State 1 represents the normal (low volatility) period, while State 2 represents the abnormal (high volatility) period. *, **, and *** respectively indicate significant coefficients at the 10%, 5%, and 1% levels.

Table 4. Markov state transition probability matrix and average duration.

Current state	Next period state 1	Next period state 2
State 1	0.97	0.03***
State 2	0.20***	0.80
Average duration (months)	33	5

Note: The content in the table is P_{ij} Indicates the probability of transferring to state j in the next period when the current state is i. The average duration is calculated according to the formula $\frac{1}{(1-P_{ii})}$ calculated. *, **, and *** indicate that the transition probabilities are significantly different from 0 at the 10%, 5%, and 1% levels, respectively. State 1 is the normal state, and State 2 is the abnormal state.

maximization (EM) algorithm, which maximizes the log-likelihood function through iterative optimization and finally converges to a stable parameter solution, ensuring the reliability of the estimation results. Table 3 shows the estimation results of some VAR coefficients, and Table 4 shows the state transition probability estimation results.

The VAR coefficient matrices under the two states shown in Table 3 exhibit significant structural differences, revealing the heterogeneity of regional price linkage mechanisms under different market conditions. Overall, in State 1 (normal period), the dynamic changes in price-yield ratios in each region are primarily driven by their own inertia, with relatively weak inter-regional linkage effects. In contrast, in State 2 (abnormal period), the intensity of inter-regional influence increases significantly. Specifically, under State 1, the coefficient of the eastern region's yield on its own previous period is positive and statistically significant (approximately 0.30, with the t-statistic showing significance at the 1% level), while the coefficients on the previous period's yields in the central and western regions are smaller (approximately 0.1, with some failing to pass significance tests). This indicates that under normal conditions, price fluctuations in the eastern region are primarily determined by its own trends, with the impact of central and western markets on them being limited. In stark contrast, under Regime 2, the coefficient of influence of the previous period's yield in the eastern region on the current period's yield in the central region increases significantly (from approximately 0.10 in the normal state to over 0.20 in the abnormal state, passing the significance test). The cross-influence coefficients between the central and western markets also generally increase. For example, the impact of the previous period's price change in the central region on the current period's yield in the western region, which was insignificant in Regime 1, increases to a significant positive value (approximately 0.15–0.20) in Regime 2.

These results imply profound market principles: Under abnormal conditions, regional market linkages significantly increase, and price shocks in one region are more likely to spread to other regions through market transmission mechanisms; in contrast, under normal conditions, regional prices more closely reflect independent supply and demand changes and inertial characteristics within each region. Notably, regardless of the regime, the eastern region, as the largest consumer market in China, consistently exerts a positive influence on price changes in the central and western regions, with this effect being particularly pronounced during abnormal periods. This characteristic reveals the dominant position of the eastern market in price transmission. The differences in the regime dependence of the coefficient matrix provide empirical evidence for the structural changes in the market under different regimes, providing key econometric support for the subsequent hypotheses.

The estimated results of the Markov state transition matrix shown in Table 4 clearly reveal the transition characteristics between the two states.

The estimated state transition probabilities shown in Table 4 further validate the dynamic nature of the market state. The two states identified by the MS-VAR model are significantly different, and the state transition probabilities deviate significantly from the extreme values of 0 or 1. This characteristic statistically confirms the existence of a clear state transition mechanism in the market, validating Research Hypothesis 1 (the state partition hypothesis).

A closer analysis of the transition probability matrix shows that the self-sustaining probability of State 1 (normal state) is as high as 0.97, meaning that when the market is in a normal and stable state, the probability of continuing this state in the next period is 97%, while the probability of transitioning to State 2 (abnormal state) is only approximately 3%. According to the formula for calculating state duration (duration = 1 (1 - self-sustaining probability)), the average duration of the normal state reaches 33 months (approximately 3 years), a result that directly demonstrates the strong persistence and stability of the normal state. In contrast, the self-sustaining probability of State 2 is approximately 0.80. This means that when the market is experiencing abnormal volatility, there is an 80% probability that the state will remain in the next period, and a 20% probability of returning to normal. Its average duration is approximately 5 months, indicating that a single abnormal fluctuation typically lasts less than half a year.

The above probability indicators and duration calculations quantitatively confirm the basic laws of market operation: normal and stable states constitute the dominant market form, while abnormal and volatile states are sporadic and short-term. This is fully consistent with the expectations of Research Hypothesis 2 (the persistence hypothesis). Further calculations using stationary distributions reveal that in the model's estimated long-term equilibrium, the market spends approximately 20% of its time in an abnormal state. This proportion is highly consistent with actual observations during the sample period and echoes existing research on agricultural product market fluctuations, revealing the inherent nature of the beef market: 'normality is primary, with anomalies as a supplement'. While abnormal states occur less frequently, their periodic impact on market operations cannot be ignored.

4.4. Economic significance of state transitions

Based on the above econometric results, this section further analyzes the essential characteristics of the two market states and the profound significance of their transformation from an economic perspective. As shown in Table 5, State 1 (normal state) constitutes the conventional operating form of the Chinese beef market, and its core feature is reflected in the convergence of price fluctuations to a moderate range, and the market exhibits strong endogenous stability. In this state, price dynamics are mainly driven by internal supply and demand fundamentals and previous price inertia, and are less sensitive to external shocks. Specifically, when residents' consumption demand shows a steady growth trend and beef production and supply chain remain smooth, price changes more reflect the combined effects of cyclical supply and demand adjustments and seasonal factors. The significant positive estimation results of the lagged coefficient of each region in the VAR model confirm the inertia characteristics of price trends under normal conditions - that is, the upward and downward trend of prices in the previous period will continue to the next period with a certain intensity.

Table 5. Residual volatility (standard deviation) and residual correlation coefficients under two states.

Indicators	State 1	State 2
Eastern Residual Standard Deviation	0.6%	1.5%***
Central Residual Standard Deviation	0.5%	1.2%***
Western Residual Standard Deviation	0.4%	1.0%***
Residual Correlation Coefficient (Eastern-Central)	0.12	0.55***
Residual Correlation Coefficient (Eastern-Western)	0.08	0.53***
Residual Correlation Coefficient (Central-Western)	0.10	0.42**

Note: Residual standard deviations are expressed as a percentage of monthly returns. Asterisks indicate significant differences compared to the values in State 1: *, **, and *** indicate that the State 2 values are significantly higher than those in State 1 at the 10%, 5%, and 1% levels, respectively.

It is worth noting that under normal circumstances, although price linkage between regions objectively exists, its intensity is moderate. This means that the pricing mechanisms of each regional market mainly anchor the local supply and demand fundamentals, and the transmission of cross regional price signals presents the characteristics of 'orderly transmission and moderate feedback', without triggering systematic cross regional fluctuations. This state usually corresponds to a period of stable macroeconomic environment, clear policy expectations, and orderly beef cattle breeding and trade. For example, in the context of abundant supply in production areas, smooth logistics and transportation, and no major epidemics or trade frictions, market prices are often within the normal fluctuation range. At this point, the resource allocation function of the market mechanism can be effectively utilized, and price signals can reasonably guide production decisions and consumption behavior. The fluctuation range of various regional markets has narrowed, jointly maintaining the stability of the overall market.

In sharp contrast to state 1, state 2 (abnormal state) represents an unconventional operating stage of the beef market, with its core characteristic being a significant deviation in price fluctuations from normal and an impact on market stability. The triggering of this state is mainly due to sudden external shocks or severe internal imbalances, including: sudden adjustments in policy regulations (such as unexpected changes in import and export control policies), outbreaks of major animal diseases (directly impacting the beef supply side), severe fluctuations in international market prices (transmitted to the domestic market through trade channels), extreme weather and natural disasters (causing a significant decline in production), etc. The superposition or individual effects of such factors may break the equilibrium state of the market and push it into an abnormal fluctuation range.

Estimation results from the MS-VAR model show that under abnormal conditions, the variance of price returns across regions increases significantly, with monthly price fluctuations reaching several times that of normal periods. This characteristic is fully validated by the significantly higher residual variance in State 2 compared to State 1, confirming Hypothesis 3 (the volatility differential hypothesis). Further analysis reveals that under abnormal conditions, the market exhibits the dual characteristics of 'high correlation' and 'strong volatility': interregional price correlations rise sharply, and price fluctuations in a single region can be rapidly transmitted to other regions through the market network. The amplified cross-regional lagged coefficients and residual correlations in State 2 confirm this characteristic at the econometric level. When the market enters an abnormal state, imbalances in the underlying supply and demand relationship can trigger panic expectations or a dominance of speculative behavior, leading to highly synchronized decision-making among market participants across regions. For example, the panic buying spree and supply shortages in the early stages of the epidemic combined to drive a simultaneous surge in beef prices across the country. When major policies are released, cross-regional stockpiling or selling by traders can also trigger coordinated abnormal price fluctuations.

Essentially, an abnormal state can be viewed as a stage of temporary market disorder or amplified shock effects. Its core characteristics are high volatility, high correlation, and structural supply-demand mismatches. Under this state, market stability declines to a low level, and the risk of price deviations from fundamentals intensifies. If mishandled, this could have a significant negative impact on industrial development and consumer welfare. However, the econometric results also show that the average duration of abnormal states is relatively short (as shown in the transition probability analysis above). This means that after experiencing significant volatility, the market typically returns to normal within a few months through endogenous regulatory mechanisms or exogenous policy interventions, demonstrating a certain degree of self-healing ability.

The significant amplification of price transmission coefficients between regions in state 2 confirms the enhancement of market linkage effects under abnormal conditions, and research hypothesis 4 (state moderation hypothesis) is empirically supported. Overall, the state transition of the Chinese beef market presents a cyclical feature of 'stable normal abnormal fluctuation returning to normal': the stable period, as a conventional form, is marked by mild fluctuations and rational linkage; Affected by internal and external shocks, the market will temporarily enter an abnormal state, manifested by drastic price fluctuations and high regional correlation; Subsequently, with the attenuation of the shock effect and the effectiveness of regulatory measures, the market returned to a normal state dominated by fundamentals. This state transition mechanism reflects the existence of inherent stability mechanisms in the beef market (such as producers adjusting supply based on price signals, government reserves regulating and

stabilizing prices, etc.), enabling it to maintain stability in most periods; It also exposes the vulnerability of the market to external shocks, and temporary disorder may still occur in extreme situations.

This 'state dependent' market behavior characteristic is precisely the 'state transition effect' that this study focuses on - the significant differences in market operating rules with different states. This discovery has important implications for policy-making: in normal times, the focus of policies should be on consolidating the foundation of market stability, such as improving information disclosure mechanisms and optimizing the production and sales linkage system; When abnormal fluctuations begin to emerge, policies need to respond quickly to shorten the duration of the abnormal state, reduce the amplitude of fluctuations, and protect industry entities and consumers from the impact of extreme fluctuations.

These results correspond and contrast with the findings in existing literature. For example, in the study of the pork market, scholars have used the MS-VAR model to find that the African swine fever epidemic is the core driving factor that leads to frequent price switching between the 'rise fall' regime, and price transmission has significant nonlinear characteristics (Mo & Wen, 2019; XiaoXia et al., 2018). The empirical results of this study in the beef market also indicate that when external shocks cause the market to enter an abnormal state, the price linkage between regions is significantly enhanced, which is consistent with the empirical conclusion of the pork market. However, in the beef market, the dominant role of the eastern main sales region is more prominent. Similarly, in the analysis of the broiler industry chain, researchers found that upstream and downstream prices exhibit significant asymmetric transmission effects under different states (Aguiar et al., 2019; Miranda & Chaudhry, 2020). Our results complement this finding, showing that there are structural differences in the beef market between 'normal' and 'abnormal' states, and cross regional price linkage has significant state dependence. In addition, existing literature has compared the volatility characteristics of major meat markets in China, such as pigs, cows, sheep, and poultry, using seasonal decomposition and cycle analysis methods. It was found that the fluctuation amplitude of beef prices is relatively mild but shows a long-term trend (Gizaw & Myrland, 2025). In contrast, the MS-VAR results of this study reveal that when the market enters a high volatility state, the cross regional price linkage strength of the beef market even exceeds the characteristics of the pork market, indicating that the market sensitivity brought about by the increasing position of beef in China's meat consumption structure cannot be ignored.

4.5. Robustness test

In order to ensure the reliability of the above empirical conclusions, this paper conducted a series of robustness tests to verify whether the main results are consistent under different model settings and sample conditions.

In the main model, this paper adopts the first-order lag structure of VAR(1). To test the impact of the lag order selection on the results, this paper attempts to re-estimate the MS-VAR model using the VAR(2). The results are shown in Tables 6 and 7. The addition of additional lag terms does not significantly change the main conclusions. Taking VAR(2) as an example, the signs and significance of the main first-order coefficients in the two states are basically consistent with those of the VAR(1) model, and the state transition probability matrix has only slightly changed.

Through the above robustness tests, the main empirical conclusions of this study are robust and will not change fundamentally due to different model details or sample selection.

Table 6. Robustness test 1.

Explained variables	Lagged explanatory variables	State 1 coefficients	State 2 coefficients
East	$East_{t-1}$	0.34***	0.31***
	$Central_{t-1}$	0.04	0.11
	$West_{t-1}$	0.02	0.06
Central	$East_{t-1}$	0.11	0.25**
	$Central_{t-1}$	0.24**	0.17*
	$West_{t-1}$	0.06	0.11*
West	$East_{t-1}$	0.07	0.15***
	$Central_{t-1}$	0.12	0.19**
	$West_{t-1}$	0.21*	0.14

Table 7. Robustness test 2.

Current state	Next period state 1	Next period state 2
State 1	0.96	0.04***
State 2	0.19***	0.81
Average duration (months)	33	5

5. Conclusion and discussion

5.1. Main research findings

This study, based on a two-state MS-VAR model, found that there is a significant 'normal abnormal' dual state in Chinese beef prices: the normal period accounts for about 80%, with mild fluctuations and stable operation; Although the abnormal period only accounts for about 20% and lasts for an average of about five months, it presents several times more severe fluctuations than the normal period, verifying that the market has nonlinear structural switching characteristics. At the regional level, during normal periods, prices in various regions are mainly driven by local supply and demand as well as their own inertia, with limited cross regional transmission; During the abnormal period, the cross regional lag effect and residual correlation are significantly enhanced (the correlation coefficient increases from <0.1 to >0.5), and the eastern market always plays a leading role in price and the dominant effect is more prominent during shocks. Compared with linear VAR and TVAR, MS-VAR performs better in terms of goodness of fit (AIC, BIC) and rolling prediction error, effectively reducing prediction bias. This proves that ignoring state differences will systematically underestimate the strength and risk of price linkage.

5.2. Discussion and theoretical significance

This study extends the theory of 'state transition' in economic time series from the macro financial field to the micro market of agricultural products, indicating that even regional beef prices can switch between 'stability turbulence' due to macro and policy shocks, deepening the understanding of the non-linear mechanism of price formation. Meanwhile, the results show that the intensity of price transmission dynamically evolves with the state: during the stable period, pricing in each region is relatively independent, while during the crisis period, it quickly integrates. The central leading role of the eastern market is particularly prominent, which not only enriches the 'market integration' and 'center edge' framework of agricultural economy, but also suggests that the model coefficients should be adjusted according to the situation, otherwise it is easy to underestimate the systemic risks in extreme events. Methodologically, research has validated the advantages of hidden Markov chains in capturing price state transitions. Compared to TVAR, which requires preset thresholds, MS-VAR can spontaneously identify states and present potential economic logic, providing a more robust nonlinear paradigm for agricultural econometric analysis.

5.3. Policy recommendations

Based on the above findings, regulatory authorities should establish a real-time monitoring and early warning system centered on price fluctuations, and promptly issue signals and initiate price stabilization measures when the probability of abnormal states significantly increases; At the same time, improve cross regional coordination mechanisms, reduce the nationwide spillover risks of local supply-demand imbalances through information sharing, reserve linkage, and resource allocation; Implementing a phased intervention strategy during abnormal periods, comprehensively utilizing reserve allocation, temporary imports, transitional subsidies for low-income groups, and regulation of speculative behavior, not only alleviates the supply-demand gap but also stabilizes expectations, thereby shortening the duration of high volatility and promoting a rapid return to normalcy in the market.

5.4. Research limitations and future prospects

This study is still limited by data and model settings: although the monthly data (2010–2024) covers the impact of the epidemic, the time frequency and regional granularity can still be improved; The two state assumption and fixed parameter structure may be difficult to capture more gradual or extreme market evolution; The model only includes prices from the east, center, and west, lacking exogenous variables such as feed costs, inventory, and imports. In the future, longer or higher frequency samples can be used, multi state or time-varying parameter models can be introduced, and combined with thick tailed error distributions, an MS-VAR-X framework with exogenous factors can be constructed to further compare multi variety markets such as pork and mutton, in order to comprehensively reveal the cross market non-linear dynamics of agricultural product prices and provide more refined basis for risk assessment and regulation.

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Author contribution statement

CRediT: **Xiong Zheng**: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing; **Adrian Daud**: Supervision, Validation; **Shairil Izwan Taasim**: Supervision, Validation; **Anita Rosli**: Supervision, Validation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval

No approval of research ethics committees from Univeristi Putra Malaysia is required to accomplish the goals of this study, because this article does not involves any physical studies with human or animal subjects. And it only focus on doing research on beef price change from economics and econometric perspectives. Thus, ethical approval is not applicable in this paper.

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Data availability statement

The beef price data in this article is obtained from 'China Animal Husbandry Statistics' and the China Animal Husbandry Information Network, and the sample period is from January 2010 to March 2020. Derived data supporting the findings of this study are available from the corresponding author AD on request. Mr. Xiong Zheng, Dr. Adrian Daud, Dr. Anita Rosli and Dr. Shairil Izwan Taasim completely comply with open access rules about data availability from the jounal and the publisher Taylor & Francis Online. After acceptance, the data that support the findings of this study are openly available in Taylor & Francis Online.

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