

Article

Time Series Analysis of Potato Prices in Türkiye: Forecasting with the Holt–Winters Exponential Smoothing Model

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Abstract

This study examines the behavior of monthly potato producer prices in Türkiye and evaluates the forecasting performance of Holt–Winters exponential smoothing models. Using publicly available data from 2015 to 2024, the analysis reveals a clear structural shift in price levels after 2020, characterized by a strong upward trend, increased volatility, and more pronounced seasonal fluctuations. To model these dynamics, both additive and multiplicative Holt–Winters specifications were estimated using a training period of 2015–2021 and validated against out-of-sample observations from 2022–2024. The results show that the multiplicative model outperforms the additive version across all forecast accuracy measures, indicating that seasonal variations scale with the level of the series. Visual comparisons further confirm that the multiplicative approach provides a closer fit to the observed price movements, particularly during periods of elevated market volatility. A twelve-month-ahead forecast for 2025 suggests that prices are likely to remain high but relatively stable. The findings demonstrate that the Holt–Winters method offers a practical and transparent framework for short-term forecasting in agricultural markets, while highlighting the challenges posed by structural changes and sudden shocks. The study contributes to the literature by providing an updated assessment of price dynamics in Türkiye’s potato market and by identifying a suitable forecasting approach for commodities with strong seasonal patterns.

Keywords: Potato Prices; Time Series Analysis; Holt–Winters Exponential Smoothing; Seasonal Forecasting

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1. Introduction

Agricultural prices substantially influence farmers’ production decisions, income levels, and market behavior [1,2]. In Türkiye, potatoes are a crucial vegetable commodity, with price fluctuations in this sector often reflecting changes in supply, storage conditions, weather patterns, and seasonal production trends [3]. These price variations can complicate planning for producers and consumers, underscoring the necessity for reliable short-term price forecasts.

Ranked as the fourth most essential food crop worldwide, following wheat, rice, and maize, potatoes are esteemed for their high yield and nutritional advantages [4]. In Turkey, potatoes are cultivated across 75 provinces, with Niğde province being the leading producer, yielding 915,734 tons from an area of 264,830 da. Collectively, the provinces of Niğde, Kayseri, Konya, and Afyonkarahisar contribute approximately 45% of Turkey’s potato production and account for 43% of the land allocated for potato farming [5]. While this study concentrates on national potato producer prices, the situation in Niğde

warrants particular attention. Niğde consistently ranks among Türkiye's leading provinces in potato production in terms of cultivated area and total yield. The province's production volume, storage facilities, and well-established supply networks enable it to significantly influence seasonal price trends nationwide. Consequently, fluctuations in national potato prices often reflect the conditions in key production areas, such as Niğde. Highlighting the importance of this region provides a more grounded understanding of the findings and reinforces the connection between national price trends and regional production conditions in the country. This context motivated the present study, which aims to offer practical insights that could be advantageous to farmers and other stakeholders in the region.

Time-series analysis has become a central tool in many research areas, ranging from economics and agricultural studies to engineering and the social sciences [6]. Time series models are widely employed in agricultural market analysis because they facilitate the identification of trends and seasonal variations in pricing data [7]. Potato prices, in particular, demonstrate distinct seasonal patterns, rendering models that incorporate seasonality especially suitable for this analysis [8]. Holt–Winters smoothing is frequently applied in forecasting tasks because it jointly estimates the level, underlying trend, and recurring seasonal behavior in a unified model [9].

This study analyzes the monthly prices received by potato producers in Türkiye from 2015 to 2024 and generates short-term forecasts using the Holt–Winters method. The accuracy of the model was evaluated to determine its effectiveness in reflecting actual price trends. The findings are expected to contribute to enhanced planning and decision-making, particularly in regions such as Niğde, where potato cultivation is a significant aspect of local agriculture.

2. Materials and Methods

This study employs the Holt–Winters Exponential Smoothing model to forecast monthly potato producer prices in Türkiye, as indicated by its title. It evaluates both the additive (Holt–Winters Additive, HWA) and multiplicative (Holt–Winters Multiplicative, HWM) versions of the model to effectively capture the trends and seasonal patterns of the series. The contributions of this study are twofold: (a) to analyze the fundamental components of the price data using different Holt–Winters specifications, and (b) to identify the model that delivers the most precise short-term predictions. By focusing on the

Holt–Winters framework, this study provides a clear and practical forecasting method for understanding price dynamics in significant agricultural markets, such as potatoes.

2.1 Input Data

The data employed in this study were obtained from the Turkish Statistical Institute [10], which provides monthly statistics on agricultural producers' prices. The dataset comprises monthly potato producer prices from January 2015 to December 2024, yielding 120 data points. This continuous time series facilitates the analysis of seasonal trends and the development of short-term forecasting models.

2.2 Forecasting Methods

Forecasting methodologies have become increasingly vital in the analysis of agricultural markets, where price fluctuations frequently exhibit distinct seasonal patterns. Among the various techniques available, exponential smoothing is often utilized because of its adaptability, transparency, and ease of application for short-term forecasts. This study models monthly potato producer prices using the Holt–Winters Exponential Smoothing approach, which incorporates level, trend, and seasonal components. Both the additive and multiplicative versions of the Holt–Winters model were analyzed to comprehend the series' structure and assess how different configurations affect forecasting accuracy. These methods are preferred for their simplicity and robustness in handling seasonally fluctuating agricultural-price data. The forecasting techniques employed in this study are described below.

In this study, the Holt–Winters approach was selected to model the behavior of the time-series data. All estimations and related computations were carried out using the EViews 10 econometrics software. Although many forecasting techniques exist, the analysis focuses specifically on the Holt–Winters exponential smoothing procedure. When a series displays both a trend component and recurring seasonal movements, the seasonal version of the Holt–Winters method provides an appropriate framework for generating forecasts.

Trends are theoretically categorized into three types: linear, exponential, and damped. A linear trend is characterized by a consistent absolute increase or decrease from one period to the next period. An exponential trend involves a consistent relative increase or decrease in the trend over time. A damped trend combines elements of both linear and exponential trends. Seasonality is described

as a recurring pattern, such as every "Sth" period [11]. According to previous studies [12–14], the Holt–Winters method is suitable for forecasting time series data that exhibit both trend and seasonal characteristics.

Conceptually, the Holt–Winters approach is implemented in two forms: additive and multiplicative. In the additive specification (HWA), seasonal effects are treated as fixed amounts that are simply added to the underlying level of the series. In contrast, the multiplicative version (HWM) assumes that seasonal movements scale with the magnitude of the series; seasonal fluctuations become larger when the overall level is high and smaller when the level declines. Thus, additive models are appropriate when seasonal patterns remain relatively stable over time, whereas multiplicative models are more suitable when the intensity of seasonality varies in proportion to the series level [11].

The HWA model is represented by Equations (1)–(4). A seasonal component is incorporated into Holt’s linear method equations as follows:

$$\text{Level: } L_t = \alpha (y_t - S_{t-s}) + (1 - \alpha)(L_{t-1} + b_{t-1}) \quad (1)$$

$$\text{Trend: } b_t = \beta (L_t - L_{t-1}) + (1 - \beta)b_{t-1} \quad (2)$$

$$\text{Seasonal: } S_t = \gamma (y_t - L_t) + (1 - \gamma)S_{t-s} \quad (3)$$

$$\text{Forecast: } F_{t+k} = L_t + k b_t + S_{t+k-s} \quad (4)$$

In this context, "s" represents the duration of the seasonal cycle, with the constraints $0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$, and $0 \leq \gamma \leq 1$. In the Holt–Winters framework, the smoothing parameters α , β , and γ must be estimated. Their optimal values are typically selected by minimizing a forecasting accuracy measure such as the root mean square error (RMSE) or the mean absolute percentage error (MAPE).

A second form of the Holt–Winters method applies seasonal factors multiplicatively to the forecast. The equations for this alternative specification are given below:

$$\text{Level: } L_t = \alpha (y_t / S_{t-s}) + (1 - \alpha)(L_{t-1} + b_{t-1}) \quad (5)$$

$$\text{Trend: } b_t = \beta (L_t - L_{t-1}) + (1 - \beta) b_{t-1} \quad (6)$$

$$\text{Seasonal: } S_t = \gamma (y_t / L_t) + (1 - \gamma) S_{t-s} \quad (7)$$

$$\text{Forecast: } F_{t+k} = (L_t + k b_t) S_{t+k-s} \quad (8)$$

As previously stated, "s" represents the duration of the seasonal cycle, with $0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$, and $0 \leq \gamma \leq 1$, respectively. The initial values of L_t and b_t matched those used in the HWA model. However, the initial seasonal estimates differ from those of the HWA model and are expressed as follows: $S_t = y_t / L_t$.

3. Results

3.1 Time Series Characteristics

Figure 1 shows the monthly potato producer prices in Türkiye for the period 2015–2024. The series starts at relatively low and stable levels between 2015 and 2019, with monthly prices mostly below 3 TRY/kg. From 2020 onwards, prices increased sharply and exhibited higher volatility, frequently exceeding 5 TRY/kg and reaching values above 10 TRY/kg in some months. This pattern indicates a clear upward trend combined with stronger short-term fluctuations in the later part of the sample.

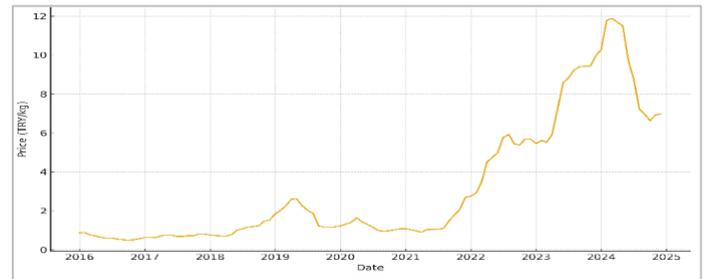


Figure 1. Monthly Potato Producer Prices in Türkiye (2015–2024)

The division of the data into training (2015–2021) and test (2022–2024) periods is illustrated in Figure 2. The training period captures the initial low-price regime and the beginning of the upward movement, whereas the test period corresponds to the high-price and more volatile regime. This split allows the forecasting models to be estimated under relatively moderate conditions and then evaluated in a more challenging environment characterized by rapid price increases and pronounced variability.

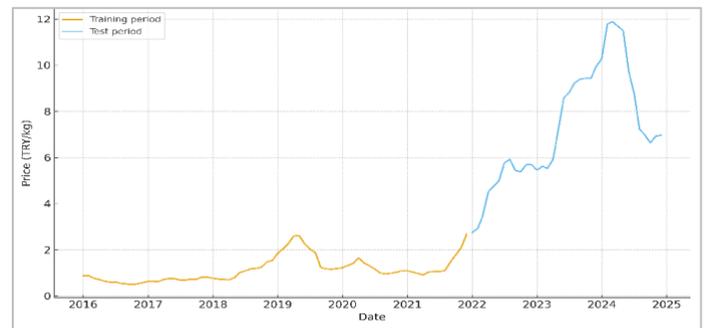


Figure 2. Training and test split used in model estimation

Table 1 presents the descriptive statistics for monthly potato producer prices in Türkiye covering the period 2015–2024, as well as two sub-periods reflecting different market conditions. Across the entire period, the average monthly price is 2.98 TRY/kg, with values ranging between 0.49 TRY/kg and 11.88 TRY/kg. The relatively high

standard deviation indicates notable variability in the series.

A clear structural change becomes evident when comparing the two five-year sub-periods. During 2015–2019, prices remained relatively stable, with a mean of 1.07 TRY/kg and limited variability. In contrast, the 2020–2024 period shows a sharp increase in both price levels and volatility, with the mean rising to 4.88 TRY/kg and the maximum reaching 11.88 TRY/kg. This shift reflects broader economic developments, including rising production costs, inflationary pressures, and disruptions affecting agricultural supply chains.

Median values also illustrate this divergence. The median price increases from 0.88 TRY/kg in the first sub-period to 5.18 TRY/kg in the second, suggesting that the upward movement is systematic rather than driven by outliers.

Table 1. Descriptive Statistics of Monthly Potato Producer Prices (2015–2024)

Statistic	Entire Period (2015–2024)	Sub-Period 1: 2015–2019	Sub-Period 2: 2020–2024
Observations	120	60	60
Mean (TRY/kg)	2.98	1.07	4.88
Standard Deviation	3.17	0.53	3.56
Minimum	0.49	0.49	0.91
Median	1.24	0.88	5.18
Maximum	11.88	2.62	11.88

Together with the descriptive statistics reported in Table 1, the graphical analysis confirms that the series is nonstationary in level, with both trend and seasonal components. This justifies the use of a seasonal Holt–Winters exponential smoothing approach, which explicitly accounts for level, trend, and seasonality in the modeling framework.

3.2. Forecast Accuracy of Holt–Winters Models

The additive (HWA) and multiplicative (HWM) Holt–Winters models were estimated using the training period (January 2015–December 2021). Out-of-sample forecasts were then generated for the test period (January 2022–December 2024). Forecast performance was evaluated using three standard accuracy measures: mean absolute error (MAE), root mean squared error (RMSE), and mean absolute percentage error (MAPE).

As reported in Table 2, both models display relatively high forecast errors, which is expected given the structural change in price levels after 2020. However, the multiplicative Holt–Winters model performs consistently better than the additive specification. The HWM yields lower MAE, RMSE, and MAPE values, indicating that it is more successful in tracking the magnitude of seasonal swings when prices are high. This result is consistent with the idea that seasonal fluctuations are proportional to the level of the series rather than constant in absolute terms.

Table 2. Forecast Accuracy of Holt–Winters Models (Test Period: 2022–2024)

Model	MAE	RMSE	MAPE (%)
Holt–Winters Additive (HWA)	3.15	4.38	43.44
Holt–Winters Multiplicative (HWM)	3.02	4.03	41.88

3.3. Visual Evaluation of Forecast Performance

Figure 3 compares the actual monthly potato prices in the test period with the forecasts produced by the additive and multiplicative Holt–Winters models. Both models underpredict the sharp increase in prices during the early part of the test period, reflecting the difficulty of anticipating sudden structural shifts based solely on past observations. Nevertheless, the multiplicative model tracks the amplitude of price movements more closely than the additive model, especially in months when the level of prices is relatively high.

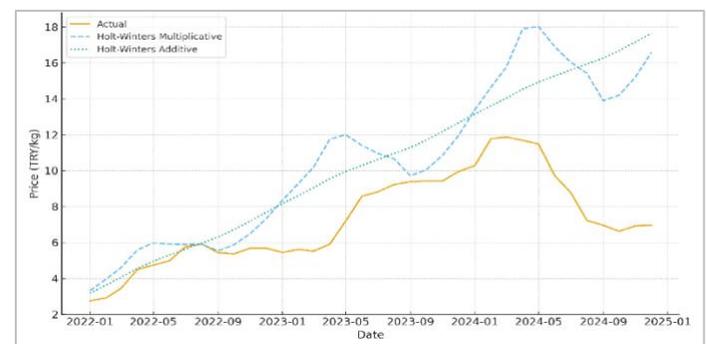


Figure 3. Comparison of actual and forecasted values for 2022–2024

In the latter part of the test period, forecast errors remain noticeable but tend to stabilize, with the multiplicative model staying closer to the actual series. This visual inspection supports the quantitative accuracy measures and further confirms the superiority of the multiplicative Holt–Winters specification for this dataset.

3.4. Twelve-Month Ahead Forecasts for 2025

Using the full sample from January 2015 to December 2024, the multiplicative Holt–Winters model was re-estimated and employed to generate 12-month-ahead forecasts for January–December 2025. The results are presented in Figure 4. The model projects that monthly potato producer prices will remain within a band of approximately 5.8–8.0 TRY/kg.

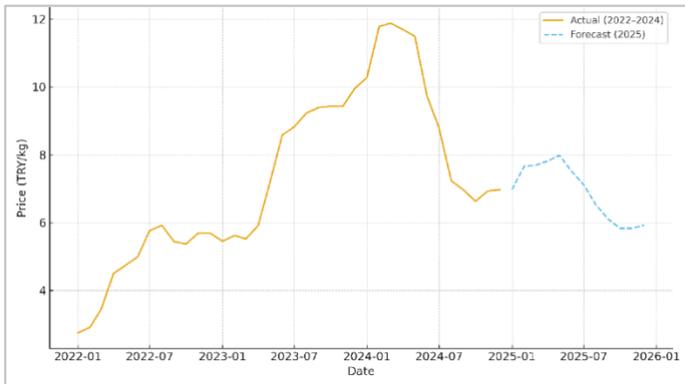


Figure 4. Twelve-month-ahead forecasts generated by the Holt–Winters multiplicative model

Forecasts are relatively higher during the first half of 2025, with values around 7.0–8.0 TRY/kg, and gradually decline in the second half of the year, approaching levels slightly below 6.0 TRY/kg by the end of the forecast horizon. The pattern suggests a continuation of elevated, but somewhat moderating, price levels compared with the peak values observed in 2022–2023. These projections should be interpreted as baseline expectations under the assumption that no major new shocks affect the market. Even with this caveat, the forecasts provide useful guidance for production planning, storage decisions, and price risk management in the potato sector.

4. Discussion

The empirical findings of this study confirm that potato producer prices in Türkiye exhibit a combination of trend, volatility, and seasonal dynamics, particularly pronounced after 2020. Similar patterns have been documented in agricultural markets exposed to macroeconomic instability, rising production costs, and supply disruptions. For example, some studies emphasize that agricultural prices tend to become more volatile in periods of global uncertainty [15,16], while another study reports increasing variability in Turkish crop prices following cost-driven inflation [17]. The structural shift observed between the 2015–2019 and 2020–2024 sub-periods in this study is consistent with these broader

trends, indicating that potato prices have transitioned into a higher and more unstable regime.

The comparison of Holt–Winters additive and multiplicative models provides important insights into how seasonality behaves in agricultural price series. The superior performance of the multiplicative model aligns with earlier studies [18–20], which note that multiplicative seasonality is more appropriate when seasonal fluctuations increase proportionally with the level of the series. Agricultural products like potatoes often show this scaling behavior due to production cycles, storage constraints, and market responses to changing price levels. Similar conclusions were reached by some researchers [21,22], who also report that multiplicative Holt–Winters models yield more accurate forecasts for commodity prices with pronounced and level-dependent seasonality.

The difficulties encountered during forecasting the test period (2022–2024) illustrate the limitations of exponential smoothing methods during episodes of structural shocks. Both Holt–Winters models underpredicted the rapid rise in prices, reflecting the well-known sensitivity of smoothing-based models to abrupt level shifts. Previous studies highlight that exponential smoothing performs best under stable conditions but tends to lag when sudden shocks—such as global supply disruptions, energy price surges, or extreme weather events—intervene [23,24]. This behavior aligns with the observations in this study, where the multiplicative model performed better overall but still struggled to fully capture the exceptional dynamics of 2022.

The twelve-month-ahead forecasts generated using the multiplicative Holt–Winters model indicate a moderate stabilization of prices in 2025, though at a higher baseline compared with pre-2020 levels. Forecasts of this kind are valuable for short-term planning, yet they must be interpreted with caution. As noted in earlier studies, historical time-series models have inherent limitations when forecasting in environments characterized by structural change [25,26]. External factors—such as weather variability, input cost inflation, policy interventions, or regional supply shocks—may significantly alter the forecast trajectory. Therefore, while Holt–Winters smoothing is a transparent and practical method for agricultural price forecasting, future research may consider integrating hybrid approaches or models capable of capturing structural breaks, such as ARIMA-X, state-space models, or machine learning methods.

Overall, this study contributes to the literature by demonstrating that potato prices in Türkiye follow a

nonstationary, seasonally varying process with structural shifts that affect forecasting performance. The results are consistent with earlier empirical findings in agricultural economics and further highlight the need for flexible, seasonally adaptive forecasting tools. In this regard, the multiplicative Holt–Winters model provides a robust baseline for short-term price prediction in markets where seasonality intensifies with rising price levels, as observed in key agricultural commodities.

5. Conclusion

This study investigated the patterns of monthly potato producer prices in Türkiye and evaluated the predictive accuracy of the additive and multiplicative Holt–Winters exponential smoothing models. The descriptive findings and graphical analyses revealed a distinct upward trend, more pronounced seasonal fluctuations, and increased volatility post-2020. This structural change reflects the broader economic conditions affecting agricultural markets in recent years and underscores the necessity of employing forecasting methods that can adapt to shifts in the level and seasonal amplitude.

A comparison between the two Holt–Winters models demonstrated that the multiplicative model provided more precise forecasts than the additive model. This distinction is particularly evident during periods of high prices and the proportional expansion of seasonal variations. Although both models encountered challenges in fully capturing the sharp price surges at the start of the test period, the multiplicative model more closely followed the overall series pattern and generated more reliable, short-term forecasts.

The 12-month-ahead forecasts for 2025 suggest that potato prices are expected to remain high but relatively stable compared with the peak levels of 2022 and 2023. These findings can serve as valuable references for producers, traders, and policymakers, particularly in regions such as Niğde, where potato production is significant to the local economy. However, the forecasts should be approached with caution, as unforeseen shocks, such as extreme weather, rapid changes in input costs, or shifts in market policy, could impact future price dynamics. Overall, this study illustrates that the Holt–Winters exponential smoothing method is a practical and accessible tool for predicting agricultural prices with strong seasonal components. Future research should consider enhancing this approach with models that incorporate structural breaks, external variables, or

machine learning techniques to improve forecast performance in rapidly changing market conditions.

In light of these findings, several implications emerge for practitioners and policymakers. Producers and traders may utilize short-term forecasts from the multiplicative Holt–Winters model to optimize harvest timing, storage decisions, and market entry strategies, especially during periods of heightened price volatility. For policymakers, the clear structural change observed after 2020 highlights the need for improved market monitoring systems, timely dissemination of price information, and targeted support measures to stabilize input costs. Developing early-warning tools that incorporate seasonal patterns and trend shifts could further assist in mitigating unexpected price spikes and strengthening the resilience of the potato supply chain.

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Informed Consent Statement: Not applicable, as the study does not involve human participants.

Data Availability Statement: The dataset analyzed in this study consists of monthly agricultural producer prices obtained from the Turkish Statistical Institute (TÜİK). These data are publicly accessible through the TÜİK statistical database. No new data were created in this study.

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