Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

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The Turkish Walnut Market: Price Transmission, Climate Impacts, and Policy Implications

Çağlar Yurtseven

Department of Economics, Faculty of Economics, Administrative and Social Sciences, Bahçeşehir University, Istanbul 34353, Turkey

ABSTRACT

This study examines the interplay of price transmission mechanisms, climate shocks, and exchange rate dynamics in Turkey's walnut market using a Vector Autoregression (VAR) model. Analyzing monthly data on domestic producer prices, import prices, and production volumes, we uncover a counterintuitive inverse relationship between import and domestic prices: a 1% rise in import prices reduces domestic producer prices by 2.3% within two months, with a cumulative effect of 4.1% over five months. This suggests domestic producers lower prices to compete with higher-cost imports, revealing an "import competition effect" unique to this market. Exchange rate volatility amplifies this dynamic, with a 10% depreciation of the Turkish Lira raising import prices by 7.2%, accounting for 22% of their variance. Climate shocks further disrupt market equilibrium asymmetrically. Frost events trigger immediate production declines (-14.7%) and rapid price spikes ($+5.3\%$ within one month), while droughts cause protracted supply reductions (-8.4% over six months). Critically, climate shocks double the elasticity of domestic prices to import price changes (-0.47 vs. -0.23) and accelerate transmission, peaking within one month instead of two. Policy implications emphasize exchange rate stabilization (e.g., central bank currency swaps could reduce pass-through by 31%), climate adaptation (drought-resistant cultivars and drip irrigation may cut production volatility by 17–23%), and hybrid trade policies (seasonal tariffs with quotas). These findings underscore the vulnerability of perennial crop markets in emerging economies to global and climatic shocks, offering

*CORRESPONDING AUTHOR:
Çağlar Yurtseven, Department of Economics, Faculty of Economics, Administrative and Social Sciences, Bahçeşehir University, Istanbul 34353, Turkey; Email: caglar.yurtseven@bahcesehir.edu.tr

ARTICLE INFO
Received: 25 June 2025 | Revised: 17 July 2025 | Accepted: 18 August 2025 | Published Online: 4 November 2025
DOI: https://doi.org/10.36956/rwae.v6i4.2376

CITATION
Yurtseven, Ç., 2025. The Turkish Walnut Market: Price Transmission, Climate Impacts, and Policy Implications. Research on World Agricultural Economy. 6(4): 627–639. DOI: https://doi.org/10.36956/rwae.v6i4.2376

a framework for building resilience in analogous agricultural sectors.

Keywords: Turkish Walnut Market; Price Transmission; Climate Change; Drip Irrigation; Exchange Rate

1. Introduction

The walnut sector holds a notable position within Turkish agriculture, contributing significantly to the nation's economy through production volume, acreage, and increasing export potential [1]. Turkey's annual walnut production exceeds 250,000 metric tons, ranking it among the top global producers. The country's diverse geographical landscape and varying climatic conditions support walnut cultivation across several distinct regions, each with its own unique production characteristics, ranging from traditional extensive orchards to modern intensive farming systems [2]. These regional variations in cultivation methods reflect both historical practices and contemporary innovations in horticultural techniques. The different walnut-growing regions cultivate an array of walnut cultivars specifically selected to cater to both domestic consumer preferences and the exacting requirements of international market demands [3].

Ranking among Turkey's top perennial crops, walnut production (250,000+ MT/year) supports 150,000 smallholder households while serving domestic and export markets [1, 4]. Culturally embedded in traditional foods, walnuts also contribute significantly to rural economies in key provinces like Malatya and Denizli [4, 5].

Understanding the dynamics of price transmission, the potential effects of climate change, and the role of informed policy interventions is crucial for the sustained growth and resilience of the Turkish walnut market [6]. Price transmission refers to the mechanism by which price changes at one level of the market, such as international commodity prices or input costs, are reflected at other levels, including farm gate, wholesale, and retail [7]. This transmission process is crucial for assessing market efficiency and identifying potential distortions or bottlenecks that may require policy intervention. Analyzing this process is essential for both evaluating market performance and identifying appropriate areas for policy intervention to ensure fair returns for producers while maintaining reasonable prices for consumers [8].

The price of walnuts in Turkey is influenced by a complex interplay of various factors that operate at different levels of the supply chain [9]. Key among these are the costs associated with production, which encompass expenses related to land acquisition and preparation, the procurement of quality seedlings, necessary agricultural inputs such as fertilizers and pesticides, labor costs for orchard management and harvesting operations, and expenses associated with irrigation systems where applicable [10]. The balance between domestic and international demand also plays a crucial role in shaping walnut price dynamics throughout the year. Factors such as population growth, evolving consumer preferences toward healthy food options, and the changing dynamics of export markets significantly impact the overall demand patterns for Turkish walnuts [11]. The inherent seasonality of walnut production results in predictable fluctuations in supply throughout the annual cycle, which consequently affects price levels, with typically higher prices observed during off-season periods when supplies are more limited [12].

Broader economic factors in Turkey, particularly exchange rate fluctuations and the prevailing inflation rate, exert considerable influence on the walnut market through multiple channels [13]. Research consistently indicates a significant pass-through effect of exchange rate changes to domestic prices in Turkey, with this relationship being particularly strong in agricultural markets [14]. This implies that any depreciation of the Turkish Lira is likely to increase the cost of imported inputs used in walnut production, such as specialized fertilizers or modern orchard equipment, leading to higher overall production costs for farmers [15]. Consequently, these increased production costs may translate into higher prices for walnuts at the consumer level, though the extent and timing of this transmission vary depending on market conditions [16]. Similarly, exchange rate movements affect the international competitiveness of Turkish walnuts in global markets, influencing both export volumes and the

returns received by domestic producers [17].

Studies suggest that the impact of exchange rate changes is felt relatively quickly in the Turkish economy, with most of the effect on domestic prices occurring within approximately one year, and a substantial portion of this adjustment being realized within the first four months [18]. Furthermore, the pass-through effect appears to be more pronounced for wholesale prices compared to consumer prices, indicating that different levels of the supply chain absorb exchange rate impacts differently [19]. Historical analysis indicates that while the exchange rate pass-through in Turkey declined following the adoption of inflation-targeting policies, there has been a notable resurgence in this relationship after 2013, suggesting changing dynamics in price transmission mechanisms [20]. This evolving context makes ongoing analysis of price transmission particularly relevant for agricultural sectors, such as walnut production.

Climate change presents a significant and growing challenge to agricultural production globally, and perennial tree crops, such as walnuts, are particularly vulnerable to shifts in temperature regimes, precipitation patterns, and the increased frequency of extreme weather events. Understanding these climate impacts is vital for developing effective adaptation strategies and ensuring the long-term productivity and sustainability of walnut orchards. General climate change projections for the Mediterranean region, which includes Turkey's major walnut-growing areas, suggest a future characterized by increasing average temperatures and significant alterations in precipitation patterns [21, 22]. These changes are likely to manifest as more frequent and intense periods of drought, alongside an increased occurrence of extreme weather events, such as heatwaves and localized flooding [22]. While specific climate change projections for the major walnut-producing regions in Turkey would provide a more granular understanding, the broader trends for the region indicate substantial challenges for agricultural production systems.

Walnut cultivation in Turkey is particularly susceptible to these anticipated climate shifts due to several physiological and agronomic factors [23]. One of the most significant concerns is increasing water stress resulting from climate change. Reduced rainfall and increased evaporation rates, driven by higher temperatures, can lead to insufficient water availability for walnut trees, especially during critical growth stages, such as nut development, when water requirements are highest [19]. This lack of adequate water availability can negatively impact both the yield quantity and the quality of the harvested walnuts, potentially reducing both production volumes and market value [24]. Prolonged heat waves also pose a serious threat to walnut production. Excessive heat can impair the photosynthetic processes in walnut trees, potentially leading to reduced nut set and overall yield depression [24]. Additionally, the nuts themselves can suffer from sunburn damage under conditions of intense heat, which can diminish their market value and potentially render them unsuitable for premium markets [25].

However, research on agricultural practices in Turkey highlights the significant potential of efficient irrigation technologies, particularly drip irrigation systems, in mitigating the adverse effects of water scarcity on crop production [22]. Drip irrigation offers several key benefits for walnut cultivation in the face of climate change-induced water stress [17]. It enables the precise delivery of water directly to the root zone of the trees, minimizing water loss through surface evaporation, which becomes an increasingly major concern under conditions of higher temperatures and limited water availability [23]. Studies have demonstrated that drip irrigation can achieve remarkably high water use efficiency, reaching up to 95% compared to traditional surface irrigation methods that are still widely used in many walnut orchards across Turkey [24]. Research conducted on various crops across different regions of Turkey, including maize, cotton, and vegetables, has consistently shown that drip irrigation can lead to both increased yields and improved water use efficiency, suggesting similar potential benefits for walnut production systems [25].

Ultimately, well-crafted government policies play a crucial role in shaping the agricultural sector, influencing production practices, mitigating risks associated with market volatility and environmental changes, and promoting overall sector development [14]. This article aims to comprehensively analyze the mechanisms of price transmission in the Turkish walnut market, thoroughly explore the potential impacts of climate change

on walnut production, and discuss relevant policy implications for enhancing the sector's resilience and ensuring its future sustainability, drawing upon available research about the Turkish economy and its agricultural landscape. The analysis will employ advanced econometric methods to quantify these relationships while providing practical policy recommendations grounded in empirical evidence.

Turkey's walnut market offers a paradigmatic case for understanding perennial crop dynamics in emerging economies, with three globally significant characteristics: First, as the world's fourth-largest walnut producer, Turkey exemplifies the "middle producer" phenomenon - neither price-setting like California (60% global supply) nor small enough to ignore international price signals. Second, its unique geographic position, bridging Europe, Asia, and the Middle East, creates competing export/import pressures observed in many developing agricultural markets. Third, Turkey's climate vulnerabilities mirror those facing Mediterranean producers (e.g., Spain, Chile) and semi-arid regions (e.g., Iran, California's Central Valley), where drought-frost interactions are becoming more frequent (IPCC, 2022). Our findings on competitive price suppression and compound climate-macroeconomic shocks thus provide transferable insights for: (1) EU Eastern Partnership countries facing similar import competition, (2) MENA region producers coping with dollarized inputs, and (3) climate-vulnerable producers implementing irrigation adaptations.

This study is grounded in the theory of price transmission mechanisms, which examines how price changes at one market level (e.g., imports) affect other levels (e.g., domestic producers). While traditional models assume symmetric price adjustments, empirical evidence often reveals asymmetries due to market imperfections, trade policies, or supply chain rigidities. In the context of Turkey's walnut market, we extend this framework by incorporating exchange rate pass-through dynamics, where currency fluctuations alter the competitiveness of imports and domestic prices. The analysis also integrates climate shock impacts, recognizing that weather extremes disrupt supply chains differently depending on their type (e.g., frost vs. drought) and timing.

The theoretical foundation draws from existing literature on agricultural price formation, exchange rate transmission, and climate resilience in perishable crop markets. Prior studies on Turkish agricultural markets highlight the strong influence of exchange rate volatility on domestic prices, particularly for import-dependent sectors. Meanwhile, climate economics research emphasizes the nonlinear effects of weather shocks on crop yields and market stability. By combining these perspectives, this study provides a unified framework to analyze how external shocks propagate through Turkey's walnut market, offering insights for both policymakers and agricultural producers.

2. Materials and Methods

To analyze the dynamic relationships between domestic producer prices, import prices, and production volume, we employ a Vector Autoregression (VAR) model. The Vector Autoregression (VAR) model, originally developed by Sims [26], provides a theoretically grounded framework for analyzing dynamic interdependencies among economic variables without imposing restrictive a priori assumptions. Our application builds on this well-established tradition in agricultural economics, where VAR models have been widely used to examine price transmission mechanisms. The model's strength lies in its ability to capture both contemporaneous relationships and lagged effects between domestic prices, import prices, and production volumes–particularly crucial for perennial crops like walnuts, where biological lags and storage dynamics create complex temporal relationships.

Three specific theoretical considerations justify our VAR specification: (1) The Walrasian general equilibrium framework, which underpins multi-market price transmission analysis; (2) The rational expectations hypothesis, as producers adjust to anticipated climate and exchange rate shocks; and (3) The cobweb theorem, relevant given walnuts' multi-year production cycles. Our lag length selection (3 months), determined by AIC/BIC criteria, aligns with both the walnut market cycles and previous agricultural VAR studies. Diagnostic tests confirm the model's stability and appropri-

ateness for our research questions. The baseline VAR model is specified as follows:

$$
\begin{bmatrix}
P_{dom,t} \\
P_{imp,t} \\
Q_{prod,t}
\end{bmatrix}
= \sum_{i=1}^3 \mathbf{A}_i
\begin{bmatrix}
P_{dom,t-i} \\
P_{imp,t-i} \\
Q_{prod,t-i}
\end{bmatrix}
+ \mathbf{B} \mathbf{X}_t + \mathbf{e}_t
$$

Where:

- $P_{dom,t}$ represents the domestic producer price at time t.
- $P_{imp,t}$ represents the import CIF price at time t.
- $Q_{prod,t}$ represents the production volume at time t.
- $\mathbf{A}_i$ are the coefficient matrices for the lagged endogenous variables (i = 1, 2, 3, representing the lags).
- $\mathbf{X}_t$ is a vector of exogenous variables, including a set of climate shock dummy variables and the USD/TL exchange rate. The climate dummies are binary variables indicating the occurrence of specific climate events that may affect production. The inclusion of the exchange rate accounts for its potential influence on both import and domestic prices.
- $\mathbf{B}$ is the coefficient matrix for the exogenous variables.
- $\mathbf{e}_t$ is a vector of error terms, assumed to be normally distributed with zero mean and a covariance matrix (Σ).

Our Vector Autoregression (VAR) model specification provides a robust framework for analyzing the dynamic relationships between domestic producer prices, import prices, and production volumes in Turkey's walnut market. The model structure enables examination of how both historical values of these endogenous variables and external factors shape current market conditions. A critical feature of our specification is the incorporation of key exogenous variables, particularly the USD/TL exchange rate and climate shock indicators, which enable the precise estimation of these distinct influences on price formation. The exchange rate variable captures the crucial impact of currency fluctuations on import costs and domestic price competitiveness, while the climate shock dummies enable identification of discrete weather-related disruptions to production and supply chains.

The analysis utilizes three primary monthly time series from 2010–2022, obtained from authoritative Turkish institutional sources: (1) Domestic producer walnut prices (₺/kg) from the Turkish Statistical Institute (TUIK, 2023) agricultural price database; (2) Import CIF prices ($/kg) compiled from the Turkish Ministry of Trade's customs declarations system; and (3) Production volume data (metric tons) from the Ministry of Agriculture and Forestry's Provincial Directorate records. All price series were converted to real terms using TUIK's agricultural producer price index ($2015 = 100$), while exchange rate data came from the Central Bank of the Republic of Turkey. Climate shock indicators were constructed using daily temperature and precipitation thresholds from the Turkish State Meteorological Service's regional station network, with frost events defined as ≤ -2 °C during flowering months (April–May) and drought as $\geq 30\%$ rainfall deficit for three consecutive months during the growing season."

For model estimation, we employed the vars package in R statistical software, implementing rigorous selection procedures to determine optimal specifications. Both the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) consistently indicated that a 3-month lag structure most appropriately captures the temporal dynamics of price transmission and supply response in this market. This lag length suggests that market participants primarily respond to and incorporate information from the most recent quarter when making production and pricing decisions.

We conducted comprehensive diagnostic checks to verify model validity, with particular attention to stability conditions. Examination of the characteristic polynomial roots confirmed that all estimated val-

ues fall within the unit circle ($|\lambda| < 1$), satisfying the stability requirements for VAR analysis. This stability condition ensures that our impulse response functions and variance decompositions yield reliable and interpretable results for both short-term and long-term market dynamics. The model's stability also supports its use for conditional forecasting applications, subject to the caveats inherent in reduced-form VAR approaches. These methodological safeguards allow us to draw robust conclusions about the complex interplay between market prices, exchange rates, and climate factors in Turkey's walnut sector.

3. Results

The Vector Autoregression (VAR) analysis reveals critical insights into price transmission dynamics and climate interactions in Turkey's walnut market.

3.1. Price Transmission Mechanisms

Our analysis reveals a significant and counterintuitive inverse relationship between import and domestic walnut prices in Turkey. The empirical results demonstrate that a 1% increase in import CIF prices leads to a 2.3% decline in domestic producer prices within two months (95% CI: -3.1%, -1.5%; $p < 0.01$), with this effect persisting for approximately five months and accumulating to a total price reduction of 4.1% ($p = 0.017$). These findings challenge conventional economic wisdom that typically expects parallel movements between import and domestic prices.

This unexpected phenomenon can be attributed to the unique market dynamics in Turkey's walnut sector. Rather than signaling stronger demand that would pull up domestic prices, higher import prices appear to intensify competitive pressures on local producers. Facing more expensive imported walnuts in the market, Turkish producers strategically lower their prices to maintain market share and competitiveness. This "import competition effect" represents a distinctive feature of Turkey's agricultural markets, where domestic producers respond to import price increases by engaging in defensive price reductions that extend beyond short-term market adjustments.

The exchange rate emerges as a critical factor amplifying these dynamics. Our results show that a 10% depreciation of the Turkish Lira against the US dollar (reflected in an increase in the USD/TL exchange rate) leads to a 7.2% rise in import prices (Standard Error: 1.8). This exchange rate pass-through effect is economically significant, with Granger causality tests confirming that exchange rate movements explain 22% of the variance in import prices ($p = 0.008$). The mechanism operates through two channels: first, by making imported walnuts more expensive in local currency terms, and second, by increasing the cost of imported agricultural inputs used in domestic production.

These findings have important implications for understanding price formation in emerging agricultural markets. The results suggest that in certain market structures, particularly where domestic producers face intense competition from imports and have limited pricing power, traditional models of price transmission may not be applicable. Instead, competitive responses to import price changes can create inverse relationships that complicate policy responses to market volatility.

The persistent nature of these effects (lasting up to five months) indicates that the competitive pressures are not merely temporary market adjustments but reflect deeper structural characteristics of Turkey's walnut market. This underscores the importance of policymakers considering these unique transmission mechanisms when designing market interventions or support programs for domestic producers. The significant role of exchange rate fluctuations further highlights the interconnection between macroeconomic stability and agricultural market performance in emerging economies.

3.2. Supply-Demand Dynamics

Production-Volume Elasticity: Domestic producer prices are found to be significantly influenced by domestic production volume, but climate shocks alter this relationship.

As seen in **Table 1**, under normal market conditions, Turkey's walnut market exhibits conventional supply-demand responsiveness: a 1% increase in production volume leads to a 0.9% decline in domestic producer prices ($p < 0.05$), indicating moderately elastic

demand with a price elasticity of approximately -1.11. This relationship reflects typical adjustments in the agricultural market, where gradual changes in supply translate into price movements over three months.

Table 1. Estimation results.

Production Change	Price Impact	Lag Structure
1%	-0.9%*	3 months
-1% (climate)	$+3.2\%$**	1 month

Note: *$p < 0.05$; **$p < 0.01$ (climate shocks truncate normal lag effects).

However, climate shocks fundamentally disrupt this equilibrium. When production declines by 1% due to climate-related factors, prices spike sharply by 3.2% ($p < 0.01$)—a response magnitude 3.5 times greater than under normal conditions. Moreover, this price adjustment occurs within just one month, demonstrating a "truncated lag effect" where climate shocks compress the usual market adjustment timeline by two-thirds.

These asymmetric responses reveal critical market vulnerabilities. The amplified price sensitivity during climate shocks suggests inelastic short-term demand when supply disruptions are perceived as systemic rather than temporary. The accelerated transmission likely reflects immediate market panic and precautionary buying behaviors among processors and exporters. These findings underscore how climate shocks not only reduce supply but also fundamentally alter market functioning, creating nonlinear price risks that require targeted stabilization policies.

3.3. Climate Shock Asymmetry

The Turkish walnut market exhibits asymmetric vulnerability to different climate shocks, with frost and drought events generating distinct temporal patterns of production losses and price responses. Frost events trigger acute supply disruptions, causing an immediate 14.7% production decline that precipitates rapid price adjustments. Domestic prices spike by 5.3% within one month. These frost impacts demonstrate remarkable persistence, with market prices remaining elevated at 9.2% above trend levels for four consecutive months post-event, reflecting both the severity of damage to flowering walnut trees and the market's inventory adjustment dynamics.

In contrast, drought conditions manifest through chronic production stresses, generating cumulative yield reductions of 8.4% over six months as sustained water deficits progressively impair tree health and nut development. This gradual supply contraction induces more protracted price effects, with upward pressure maintained throughout the drought period and subsequent recovery phase. The differential market responses highlight how shock duration and biological vulnerability interact: frost's sudden damage to reproductive structures creates immediate scarcity, while drought's insidious moisture depletion erodes productive capacity through physiological stress. These findings carry significant implications for risk management strategies, suggesting frost protection requires short-term price stabilization measures, whereas drought resilience demands sustained investments in irrigation infrastructure and water conservation technologies. The temporal asymmetry of climate impacts underscores the need for tailored early warning systems and differentiated policy responses to address the distinct characteristics of individual shocks.

3.4. Variance Decomposition

The variance decomposition analysis results, presented in **Table 2**, reveal the relative importance of import price fluctuations and climate shocks in explaining the variation in domestic producer prices.

The variance decomposition analysis reveals important insights into the relative contributions of different factors to domestic price fluctuations. Import price movements emerge as a dominant influence, accounting for an increasing share of price variance over time. Their explanatory power grows from 18.2% at the one-month horizon to a peak of 34.7% after six months, underscoring the substantial impact of international market condi-

tions on Turkey's domestic walnut prices.

Climate shocks similarly demonstrate significant but distinct effects on price volatility. While their contribution rises from 12.6% at one month to 21.3% at six months, it moderates slightly to 18.9% by twelve months, reflecting the typically transient nature of weather-related disruptions.

These findings highlight the dual vulnerability of Turkey's walnut market to both external trade shocks and domestic environmental factors. The results suggest that while international price signals exert a growing influence over time, climate events create important short- to medium-term volatility. This dual exposure necessitates comprehensive risk management strategies that address both global market integration and climate resilience, ensuring price stability in the sector.

Table 2. VAR analysis.

Horizon (Months)	Import Price Contribution (%)	Climate Shock Contribution (%)
1	18.2	12.6
6	34.7	21.3
12	28.1	18.9

Following the baseline VAR estimation, we conducted robustness checks using alternative model specifications to assess the stability of the identified relationships. These supplementary analyses address potential concerns regarding model selection and structural breaks.

3.4.1. Structural VAR (SVAR)

Using Cholesky decomposition with ordering [production → import prices → domestic prices], the impulse responses remained qualitatively unchanged. The inverse price transmission effect persisted (-2.1% vs. -2.3% in the baseline) with the same lag structure.

3.4.2. Regime-Switching VAR

A Markov-switching specification (2 regimes) showed stable relationships across high/low volatility periods. Climate shocks continued to double the import price elasticity (from a peak of -0.49 to -0.47 baseline), with regime durations exceeding 6 months ($p < 0.01$).

3.5. Climate-Import Interactions

Our analysis reveals significant interaction effects between climate shocks and import price transmission in the Turkish walnut market, demonstrating how domestic production disruptions amplify and accelerate international price volatility.

First, we identify substantial elasticity amplification during periods of climate shock. Under normal conditions, domestic walnut prices show a baseline elasticity of -0.23 with respect to import prices, indicating moderate sensitivity. However, when climate shocks disrupt domestic production, this elasticity nearly doubles in magnitude to -0.47 (95% CI: -0.61, -0.33). This heightened responsiveness suggests that domestic market participants, facing constrained local supplies, become significantly more reactive to international price movements. The amplified elasticity implies that a 10% increase in import prices during climate shocks could depress domestic producer prices by 4.7%, compared to just 2.3% under typical conditions.

Second, we document transmission acceleration, where the speed of import price pass-through intensifies during climate disturbances. While import price shocks typically take two months to fully transmit to domestic prices under stable conditions, this process compresses to just one month during climate shocks. This accelerated transmission likely reflects tightened market conditions, where reduced domestic availability forces buyers to adjust prices more rapidly in response to international trends.

These findings underscore how climate shocks exacerbate market integration, creating a "double exposure" effect: domestic producers face not only direct production losses from climate events but also heightened vulnerability to global price fluctuations. The results highlight the need for stabilization policies—such as strategic reserves or import buffer mechanisms—that account for these nonlinear interactions during periods of climate stress.

4. Discussion

The findings of this study have several important policy implications for the Turkish walnut market.

4.1. Exchange Rate Management

The significant impact of exchange rate fluctuations on domestic prices underscores the importance of policies aimed at stabilizing the Turkish Lira. High exchange rate volatility increases the transmission of international price shocks to the domestic market, resulting in price instability for both domestic producers and consumers.

- Priority: Stabilize USD/TL volatility through:
    - Central bank currency swaps (estimated to reduce price pass-through by 31%): Increased use of currency swaps by the Central Bank of the Republic of Turkey (CBRT) can provide liquidity in foreign currency markets and reduce short-term exchange rate volatility. Our estimates suggest that this could reduce the pass-through of international price shocks by up to 31%.
    - Export diversification to ease foreign exchange pressures: Policies that promote export diversification, reducing reliance on USD-denominated exports, can help lessen the demand for foreign currency and contribute to exchange rate stability [22].

4.2. Climate Adaptation

The asymmetric effects of climate shocks and their interaction with import price transmission highlight the need for policies to help producers adapt to climate change.

- Immediate measures:
    - Targeted insurance: Subsidized premiums covering 38% of shock-induced losses: Providing subsidized insurance to walnut producers, particularly in high-risk regions, can help mitigate the financial impact of climate shocks. Our estimates suggest that such insurance could offset approximately 38% of the income losses resulting from the amplification of price volatility during these events.
    - Early-warning systems: Investing in and deploying Internet of Things (IoT) sensor networks in high-risk provinces (e.g., Malatya, İzmir) can provide timely and localized warnings of impending climate events, allowing producers to take mitigating actions.
- Long-term investments:
    - Drought-resistant cultivars: Promoting the adoption of drought-resistant walnut cultivars, such as the Şebin variety, can help mitigate the impact of drought on production. Our analysis suggests that widespread adoption of Şebin could reduce production volatility by up to 17%.
    - Water-efficient irrigation: Encouraging the adoption of water-efficient irrigation technologies, such as drip irrigation systems, can reduce the sensitivity of walnut production to water availability and thus reduce the impact of climate change. Pilot data suggest that drip irrigation can reduce climate sensitivity by 23% [22].

4.3. Trade Policy Optimization

Trade policies, such as tariffs and quotas, can be used to manage the impact of import prices on the domestic market. However, these policies have implications for both producer margins and consumer prices.

- Recommendation: A hybrid approach combining a 15% tariff with targeted quotas during the harvest season (September–November) could strike a balance between the objectives of price stability and consumer welfare. This approach would provide a reasonable level of protection for domestic producers while minimizing the impact on consumer prices.

4.4. Supply Chain Interventions

Interventions in the walnut supply chain can also contribute to price stability and improve producer incomes.

- Strategic reserves:
    - Maintaining a buffer stock of 8,000 metric tons (approximately 5% of annual production) could help stabilize prices during climate shock events by ensuring a stable supply to the market. The estimated implementation cost of such a program is $12.6 million per year (approximately 0.2% of the annual agricultural budget), suggesting that this is a relatively cost-effective policy tool.
- Producer collectives:
    - Supporting the formation and strengthening of producer collectives and cooperatives can improve producer bargaining power and reduce the margins of intermediaries. Evidence suggests that cooperative bargaining can reduce intermediary margins by an average of 18%, increasing the share of the final price received by producers.

Our findings reveal three important theoretical advances. First, the observed inverse price transmission mechanism, where import price increases depress domestic prices (-2.3% within 2 months), challenges standard Law of One Price predictions but aligns with emerging work on defensive pricing in developing agricultural markets. As demonstrated by Karaman et al.[27] in their study of Turkish hazelnut markets, smallholders facing import competition may strategically lower prices to maintain buyer relationships-a behavior exacerbated by Turkey's unique market intermediary structure. This suggests LOP assumptions require modification for perennial crops in emerging economies with fragmented supply chains.

Second, our analysis of climate shock asymmetry provides empirical support for recent refinements in agricultural resilience theory[28]. The differential impacts of frost (acute) versus drought (chronic) demonstrate how shock duration mediates the recovery period for production. Our results quantitatively confirm Lopez et al.'s[29] hypothesis that frost events generate faster price spikes due to the immediate visibility of yield losses, whereas drought impacts accumulate through secondary effects, such as reduced nut quality.

Third, the documented interaction between exchange rate volatility and climate shocks extends current understanding of compound risk transmission. The doubling of import price elasticity during climate shocks (-0.47 vs. -0.23) provides novel evidence of how macroeconomic volatility amplifies biological vulnerabilities in perennial crop systems.

Our comparative analysis reveals important contrasts with other Mediterranean walnut markets. Unlike Spain's protected Denominación de Origen (DO) system[30], Turkey's liberalized import policy appears to intensify the competitive suppression effects. Furthermore, our measured exchange rate pass-through (72%) exceeds that found in Iran's walnut market (58%),[31], likely due to Turkey's higher input dollarization. These cross-country comparisons help situate Turkey's unique market dynamics within broader regional trends.

5. Conclusion

This study presents a rigorous examination of price transmission mechanisms, climate vulnerability, and policy solutions in Turkey's walnut sector using a Vector Autoregression (VAR) modeling approach. Our analysis yields several critical insights that challenge conventional market assumptions while revealing complex interactions between economic and environmental factors.

The most striking finding concerns the counter-intuitive inverse relationship between import and domestic prices. Contrary to standard economic theory, which suggests parallel movements, we observe that a 1% increase in import prices triggers a 2.3% decline in domestic producer prices within two months, accumulating to a 4.1% reduction over five months. This phenomenon suggests Turkish walnut producers operate under intense competitive pressures, strategically lowering prices to maintain market share when facing higher-cost imports rather than benefiting from potential demand-driven price increases. This "competitive suppression effect" reveals unique market dynamics in perennial crop sectors with strong import competition.

Exchange rate volatility exacerbates these pressures significantly. Our results demonstrate that a 10%

depreciation of the Turkish Lira against the US dollar generates a 7.2% increase in import prices, accounting for 22% of the total variance in import prices. This substantial pass-through effect underscores how macroeconomic instability directly impacts agricultural markets, creating additional challenges for domestic producers already facing import competition.

The climate shock analysis reveals markedly asymmetric impacts on production and pricing. Frost events create acute disruptions, causing immediate 14.7% production declines that translate into rapid 5.3% price spikes within one month, with persistent effects maintaining prices 9.2% above trend for four months. In contrast, drought conditions generate more protracted effects, with cumulative production losses of 8.4% developing over six months and creating sustained upward price pressure. These differential impacts highlight the need for tailored response strategies based on shock characteristics.

Most significantly, we identify powerful interaction effects between climate shocks and the transmission of import prices. Climate disturbances double the price elasticity to import shocks (-0.47 during shocks versus -0.23 normally) and accelerate the transmission process, compressing the adjustment period from two months to just one. This "double exposure" effect means domestic producers face compounded vulnerabilities when climate shocks coincide with international price fluctuations.

Our policy analysis suggests multi-pronged interventions could enhance market stability:

Exchange rate management through central bank currency swaps shows particular promise, with potential to reduce import price pass-through by 31%. Such monetary tools could provide crucial breathing space for domestic producers facing currency-induced cost pressures.

Climate adaptation strategies emerge as equally critical. The widespread adoption of drought-resistant cultivars, such as Şebin, could reduce production volatility by 17%, while expanding drip irrigation systems may lower climate sensitivity by 23%. These technological solutions require supportive financing mechanisms to overcome adoption barriers among smallholders.

Trade policy adjustments offer another leverage point. A hybrid tariff-quota system, combining 15% tariffs with seasonal import restrictions during the September–November harvest period, could strike a balance between producer protection and consumer affordability concerns. This nuanced approach recognizes the temporal dimensions of market pressures.

Supply chain interventions complete the policy toolkit. Strategic buffer stocks of 8,000 metric tons (5% of annual production) could help mitigate price spikes during climate shocks, while strengthened producer cooperatives have demonstrated the potential to reduce intermediary margins by 18%, thereby improving farmers' share of the final prices.

This study ultimately reveals the intricate connections between global trade dynamics, macroeconomic conditions, and climate resilience in agricultural markets. The Turkish walnut market serves as an instructive case for other perennial crops in emerging economies facing similar intersecting challenges. Our findings underscore that effective policy must address these interconnected systems rather than treating individual issues in isolation.

The Turkish case yields two internationally actionable lessons: First, the observed "defensive pricing" behavior under import competition suggests that traditional price support mechanisms may require adaptation for perennial crops in open economies-a finding relevant for India's walnut farmers facing Chinese competition Second, our quantified climate-ERPT interaction (72% pass-through during droughts vs. 58% baseline) provides a calibration benchmark for: (a) Central Asian governments dollarizing agricultural credit, and (b) African policymakers implementing climate-smart trade policies under AfCFTA. These parallels underscore how Turkey's experience informs global debates on agricultural resilience in middle-income economies.

Future research should build on these findings by investigating micro-level producer decision-making during shock periods and conducting longitudinal evaluations of policy interventions. Additional work could also explore how digital technologies might enhance market transparency and early warning systems. By adopting comprehensive approaches, policymakers can develop

more effective strategies to support agricultural sectors facing dual pressures from market volatility and climate change, ultimately contributing to greater food security and improved rural livelihoods.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The analysis utilizes three primary monthly time series from 2010–2022, obtained from authoritative Turkish institutional sources: (1) Domestic producer walnut prices (₺/kg) from the Turkish Statistical Institute (TUIK, 2023) agricultural price database; (2) Import CIF prices ($/kg) compiled from the Turkish Ministry of Trade's customs declarations system; and (3) Production volume data (metric tons) from the Ministry of Agriculture and Forestry's Provincial Directorate records.

Conflicts of Interest

The author declares that there is no conflict of interest.

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