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Economic Resilience of Pistachio Production under Water Scarcity A Panel Data Analysis of Iranian Production Hubs

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Abstract

Water scarcity has become a persistent structural constraint on agricultural production in many arid and semi-arid regions of Iran, with particularly significant implications for pistachio-producing areas where production systems depend heavily on groundwater resources. Although pistachio cultivation has considerable economic importance for rural livelihoods, regional employment, agricultural income, and export earnings, prolonged water stress can undermine production stability and reduce the capacity of production systems to absorb and recover from climatic and resource-related shocks. This study develops an economic resilience framework for assessing pistachio production under water scarcity across major Iranian production hubs. The study employs a panel-data approach to investigate the relationship between water scarcity and the economic stability of pistachio production over time and across geographically distinct production areas. The empirical framework integrates production performance, cultivated area, climatic conditions, precipitation variability, drought intensity, and indicators of water-resource pressure to identify differences in resilience among production hubs. The analysis distinguishes between short-term fluctuations in production and persistent structural effects associated with water scarcity, allowing the resilience of pistachio-producing systems to be evaluated beyond conventional measures of yield or water productivity. Panel econometric models are employed to estimate the magnitude and direction of the relationships between water stress and economic production outcomes while controlling for unobserved heterogeneity across production hubs and temporal effects. The results are expected to demonstrate substantial spatial and temporal heterogeneity in the economic response of pistachio production to water scarcity, indicating that exposure to similar water constraints does not necessarily generate equivalent economic consequences across production regions. The findings provide an empirical basis for identifying production hubs with greater vulnerability and those demonstrating comparatively stronger adaptive capacity. The study contributes to agricultural economics by connecting resource scarcity with regional economic resilience and offers an analytical foundation for designing differentiated water-management and agricultural policies aimed at sustaining pistachio production under increasing environmental and economic uncertainty.

Keywords: Pistachio production; Economic resilience; Water scarcity; Panel data; Agricultural economics

1- Introduction

Pistachio production occupies a distinctive position within Iran's agricultural economy because of its contribution to rural income, employment, export revenues, and the economic activity of production regions. However, the long-term sustainability of this production system is increasingly constrained by water scarcity. Major pistachio-producing areas are located in arid and semi-arid environments where agricultural production depends substantially on groundwater resources. Persistent groundwater depletion, recurrent droughts, and increasing climatic variability have consequently transformed water availability from a seasonal production constraint into a structural economic challenge for pistachio-producing regions [1,3,4].

The interaction between pistachio production and groundwater scarcity has received considerable attention in the Iranian agricultural literature. Previous research has demonstrated that the expansion and persistence of large-scale pistachio cultivation can intensify pressure on groundwater resources, particularly in major production areas such as Rafsanjan [1]. At the same time, empirical assessments of pistachio orchards in several

major producing provinces have revealed substantial differences in irrigation practices, water application, yield, and water productivity [2]. These differences suggest that the economic consequences of water scarcity are unlikely to be uniform across production regions.

Climate variability further complicates this relationship. Changes in temperature and precipitation can directly influence pistachio yields, while recurrent drought can amplify pressure on already-depleted water resources [4,6]. Groundwater depletion is particularly important because its effects may not appear immediately in annual production statistics. Producers may temporarily compensate for declining water availability through changes in irrigation practices, increased pumping, alterations in cultivated area, or other adaptive responses. Consequently, an assessment based solely on annual yield may underestimate the longer-term economic consequences of water scarcity.

Water management also has a direct relationship with production efficiency. Research conducted under different irrigation regimes has demonstrated that irrigation strategy can affect pistachio growth, yield, and water productivity [5]. Similarly, recent evidence from Iranian pistachio orchards indicates considerable variation in water productivity among production areas [13]. These findings are important from an agricultural economics perspective because the economic implications of water scarcity depend not only on the absolute quantity of available water but also on how efficiently producers transform water resources into agricultural output.

The concept of resilience provides a broader framework for examining these dynamics. Agricultural resilience concerns the capacity of production systems to withstand disturbances, adjust to changing conditions, and maintain their essential economic functions. Recent research on Iranian pistachio farmers has shown that resilience to climate change varies among farming communities and is influenced by socioeconomic and adaptive characteristics [7]. However, farmer-level resilience does not necessarily capture the economic resilience of an entire production hub. A regional production system may maintain relatively stable output despite declining water availability, whereas another region facing a comparable environmental pressure may experience substantial reductions in production and economic performance.

Recent agricultural economics literature has increasingly examined economic resilience using panel-data approaches. Such studies demonstrate that regional agricultural resilience can be influenced by financial, demographic, technological, and institutional factors and that considerable heterogeneity may exist across regions [8-10]. Nevertheless, these studies generally address agricultural resilience at an aggregate level rather than focusing on a specific high-value, water-dependent crop such as pistachio. The economic resilience of pistachio production under persistent water scarcity therefore remains insufficiently examined through a comparative regional framework.

This gap is particularly important for Iran because pistachio production is geographically concentrated. Differences in groundwater conditions, climatic exposure, irrigation practices, and production structures mean that a common national response to water scarcity may produce unequal economic outcomes across production hubs. Moreover, evidence concerning the economic welfare effects of agricultural water losses indicates that inefficient water use can generate consequences extending beyond individual farms to broader market and welfare outcomes [12]. Recent research on drought and salinity resilience in pistachio production further indicates that production performance can be affected by the interaction of environmental stresses rather than by a single climatic factor [11].

Against this background, the present study investigates the economic resilience of pistachio production under water scarcity across major Iranian production hubs using a panel-data framework. Rather than examining water scarcity solely through its effect on yield or water productivity, the study focuses on the capacity of production systems to maintain economic production performance under persistent resource pressure. The analysis considers temporal changes and differences among production hubs to identify heterogeneous responses to water scarcity and climatic stress.

The study addresses three central questions. First, to what extent does water scarcity affect the economic performance of pistachio production across major Iranian production hubs? Second, do pistachio-producing regions exhibit statistically different levels of economic resilience under comparable water and climatic pressures? Third, which production and environmental characteristics are associated with stronger resilience?

Answering these questions can contribute to agricultural economics in two ways. Conceptually, the study extends the application of economic resilience from general regional agriculture to a specialized, water-intensive perennial crop. Empirically, it provides a comparative framework for examining how persistent water constraints translate into heterogeneous production outcomes across Iranian pistachio-producing regions. The

findings can consequently support more differentiated agricultural and water-management policies rather than uniform interventions across all production areas

2- Problem Statement

The central economic problem facing Iranian pistachio production is not simply a decline in water availability, but the increasing difficulty of maintaining stable production performance when water constraints persist over time. Pistachio orchards are perennial production systems, meaning that producers cannot respond to water shortages in the same way as annual-crop farmers who can rapidly change their cultivated area or crop choice. Persistent reductions in water availability can therefore affect orchard productivity, production continuity, investment decisions, and the economic viability of production over several years.

This problem becomes more complex because water scarcity is spatially heterogeneous. Iranian pistachio production is concentrated in regions with different groundwater conditions, climatic characteristics, irrigation systems, and production structures. Consequently, identical reductions in water availability may generate substantially different economic outcomes across production hubs. A region with relatively efficient water use and stronger production capacity may preserve a greater proportion of its output under water stress, whereas another region may experience a sharper decline. Existing evidence on water productivity and irrigation practices confirms considerable differences among Iranian pistachio-producing areas [2,13].

A further difficulty arises from the cumulative nature of groundwater depletion. Groundwater stress may not immediately translate into proportional reductions in annual pistachio production because producers can initially respond through deeper pumping, changes in irrigation practices, or adjustments in orchard management. Such responses can temporarily stabilize production while simultaneously increasing production costs and intensifying pressure on water resources [1,3]. Therefore, observing relatively stable production in a particular year does not necessarily indicate that the underlying production system is economically resilient.

Climate variability adds another dimension to the problem. Changes in temperature, precipitation, and drought conditions can affect pistachio productivity and interact with water scarcity rather than operating independently [4,6]. The resulting combination of environmental pressures creates uncertainty regarding the ability of production hubs to maintain stable economic performance. Research on pistachio farmers has already demonstrated differences in their capacity to cope with climate-related disturbances [7], but this evidence does not fully explain whether such differences translate into measurable variations in the economic resilience of regional production systems.

The research problem, therefore, concerns the absence of a sufficiently integrated empirical framework for determining how persistent water scarcity affects the economic resilience of geographically distinct pistachio production hubs. Conventional measures such as yield per hectare or water productivity provide important information but do not fully capture the capacity of a production system to absorb shocks, maintain performance, and adjust over time. A production hub may have relatively high water productivity but remain economically vulnerable to prolonged water scarcity, while another may exhibit lower initial productivity but greater capacity to maintain production during adverse conditions.

This distinction creates a methodological requirement for examining both spatial and temporal variation. A panel-data framework is particularly appropriate because it allows changes within production hubs to be examined simultaneously with differences between them. Such an approach can control for persistent characteristics of individual production areas and distinguish temporary fluctuations from more systematic effects associated with water scarcity. Recent research on agricultural economic resilience has demonstrated the usefulness of panel-data methods for identifying regional differences and evaluating factors associated with resilience [8-10].

Accordingly, the present study defines the research problem around a specific empirical question: how does persistent water scarcity influence the capacity of major Iranian pistachio production hubs to maintain stable economic production performance over time? Addressing this question requires moving beyond a simple water–yield relationship and examining the combined effects of water-resource pressure, climatic variability, and production characteristics. This perspective is particularly relevant given evidence that inefficient agricultural water use can generate wider economic and welfare losses [12] and that production resilience can be affected by interacting environmental stresses [11].

The study consequently seeks to identify whether economic resilience differs significantly among Iranian pistachio production hubs and whether variations in water scarcity and climatic conditions help explain these

differences. The resulting evidence can provide a more precise basis for distinguishing between regions requiring immediate adaptation measures and those possessing comparatively stronger capacity to sustain production under continuing water constraints

3- Research Methodology

3.1. Research Design

This study employs a quantitative, longitudinal research design based on panel-data econometrics to examine the economic resilience of pistachio production under water scarcity across major Iranian production hubs. The methodological framework is designed to capture both temporal changes within production areas and structural differences between them. This approach is particularly appropriate because water scarcity, climatic variability, and agricultural production do not operate as isolated annual events but evolve over successive production periods.

The analytical unit is defined as a pistachio production hub observed repeatedly over time. The resulting dataset has two dimensions: the cross-sectional dimension represented by production hubs and the time dimension represented by annual observations. This structure makes it possible to distinguish persistent regional characteristics from year-specific shocks.

The empirical framework is organized around three components: measurement of economic production performance, measurement of water and climatic stress, and estimation of the relationship between these factors through panel-data models.

3.2. Study Area and Production Hubs

The study focuses on the principal pistachio-producing areas of Iran. The selection of production hubs is based on their importance in national pistachio production and the availability of consistent information on production, cultivated area, climatic conditions, and water-related indicators.

The geographical concentration of pistachio cultivation is analytically advantageous because it permits comparison between production systems exposed to different levels of water and climatic pressure. Previous empirical research has documented substantial differences in irrigation water application and water productivity among major pistachio-producing provinces, including Kerman, Khorasan Razavi, Yazd, and Semnan [2]. These areas therefore provide an appropriate basis for comparative analysis.

The geographical framework is complemented by information on groundwater conditions and drought exposure. Groundwater depletion constitutes a particularly important indicator because pistachio production in several major production regions depends substantially on groundwater abstraction. Evidence from Iranian catchments indicates persistent groundwater depletion over extended periods [3]. In parallel, drought conditions in southeastern Iran provide an important measure of climatic pressure affecting water availability [4].

3.3. Data Structure and Variables

The empirical dataset is constructed as a balanced or near-balanced panel according to the availability and consistency of annual observations for the selected production hubs. The principal dependent variable represents the economic performance of pistachio production, while explanatory variables capture water scarcity, climatic stress, and production characteristics.

The principal variables are defined as follows.

Variable	Symbol	Measurement
Pistachio production	PROD	Annual pistachio output
Harvested area	AREA	Annual harvested pistachio area
Yield	YIELD	Production per unit of harvested area
Water scarcity	WS	Composite indicator of water-resource pressure
Precipitation	PREC	Annual precipitation
Temperature	TEMP	Annual or growing-season temperature
Drought intensity	DROUGHT	Standardized drought indicator

Groundwater pressure	GW	Indicator of groundwater depletion or stress
Production stability	STAB	Measure of persistence of production performance

Production and cultivated-area variables provide the agricultural production dimension of the model. Water scarcity is represented through indicators reflecting the availability and pressure on water resources. Climatic variables are included to distinguish water-related effects from broader climatic disturbances.

The selection of these variables is consistent with previous empirical research showing that irrigation conditions, water productivity, climatic factors, and groundwater conditions can materially affect pistachio production [2,3,5,6,13].

3.4. Measurement of Economic Resilience

A central methodological issue is the operationalization of economic resilience. In this study, resilience is not treated as a simple level of production. Instead, it represents the capacity of a pistachio production hub to maintain its production performance when exposed to water and climatic stress.

A resilience indicator can be constructed from deviations of observed production performance from the hub-specific expected or trend level. One suitable formulation is:

$$\text{Economic Resilience}_{it} = 1 - |Y_{it} - \hat{Y}_{it}| / \hat{Y}_{it}$$

where:

Y_{it} represents observed economic production performance of production hub i in year t, and $\hat{Y}_{it}$ represents the expected production performance based on the hub-specific trend and structural characteristics.

Higher values indicate that observed performance remains closer to the expected level despite environmental disturbances, whereas lower values indicate greater deviation and consequently weaker resilience.

Because economic resilience can be sensitive to the scale of production, the principal analysis will rely on normalized production-performance measures rather than raw output alone. Yield and production stability can therefore be incorporated as complementary indicators.

The conceptual distinction between agricultural resilience and economic resilience is important. Previous research on pistachio farmers has primarily examined resilience as the ability of agricultural households to cope with climate change [7]. The present study instead focuses on the persistence of production performance at the production-hub level.

3.5. Water Scarcity Indicator

Water scarcity is treated as a multidimensional condition rather than a single physical measurement. This is necessary because the economic consequences of water scarcity can emerge through several mechanisms, including reduced water availability, declining groundwater reserves, drought, and increasing pressure on irrigation systems.

A composite Water Scarcity Index can therefore be constructed after standardizing the principal water-related variables:

$$WSI_{it} = w1\, Z(GW_{it}) + w2\, Z(DROUGHT_{it}) + w3\, Z(WD_{it})$$

where:

WSI_{it} = Water Scarcity Index for production hub i in year t

Z = standardized value of each component

GW = groundwater pressure

DROUGHT = drought intensity

WD = water-demand or water-availability pressure

w1, w2, and w3 = weights assigned to the standardized components.

Where data permit, equal weighting will be used as the baseline specification to avoid imposing subjective economic weights. Alternative weighting specifications can be examined through robustness analysis.

This approach reflects the fact that groundwater depletion and drought can jointly influence agricultural water availability. Previous research has demonstrated the importance of both long-term groundwater depletion and drought conditions in Iran [3,4].

3.6. Econometric Model

The primary econometric specification is a fixed-effects panel model:

$$ER_{it} = \beta_0 + \beta_1 WSI_{it} + \beta_2 PREC_{it} + \beta_3 TEMP_{it} + \beta_4 AREA_{it} + \beta_5 YIELD_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where:

ER_{it} = economic resilience of pistachio production hub i in year t

WSI_{it} = water scarcity index

$PREC_{it}$ = precipitation

$TEMP_{it}$ = temperature

$AREA_{it}$ = harvested area

$YIELD_{it}$ = pistachio yield

μ_i = production-hub fixed effect

λ_t = year fixed effect

ε_{it} = idiosyncratic error term.

The coefficient β_1 is the principal parameter of interest. A statistically significant negative coefficient would indicate that greater water scarcity is associated with weaker economic resilience in pistachio production.

The production-hub fixed effects control for time-invariant characteristics such as geographical conditions, historical production structure, soil characteristics, and persistent institutional differences. Year fixed effects control for national-level shocks that affect all production hubs simultaneously.

3.7. Dynamic Specification

Because pistachio is a perennial crop and the consequences of water stress may persist beyond a single production year, a dynamic specification is also considered:

$$ER_{it} = \alpha + \rho ER_{i,t-1} + \beta_1 WSI_{it} + \beta_2 PREC_{it} + \beta_3 TEMP_{it} + \beta_4 AREA_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

The lagged dependent variable captures persistence in economic performance. The parameter ρ indicates the extent to which the previous year's resilience affects current resilience.

A relatively high value of ρ would indicate strong persistence in production performance, while a lower value would suggest greater sensitivity to current shocks.

This dynamic perspective is particularly relevant because adjustments in pistachio orchards can take place over several production cycles rather than within a single year.

3.8. Estimation Strategy and Diagnostic Tests

The empirical analysis proceeds in several stages. First, descriptive statistics are calculated for all variables, including means, standard deviations, minimum and maximum values. Second, temporal and cross-sectional variation is examined. Third, correlations among the explanatory variables are assessed to identify potential multicollinearity.

The selection between pooled ordinary least squares, fixed-effects, and random-effects specifications is determined through standard panel-data diagnostic procedures. The Hausman specification test is used to assess whether the fixed-effects or random-effects estimator is more appropriate.

Additional diagnostic procedures include tests for heteroskedasticity, serial correlation, and cross-sectional dependence. Where necessary, heteroskedasticity- and autocorrelation-robust standard errors are employed.

The robustness of the principal findings is evaluated by estimating alternative specifications using individual water-related variables instead of the composite Water Scarcity Index. This makes it possible to determine whether the estimated relationship is driven primarily by groundwater pressure, drought conditions, or their combined effect.

3.9. Empirical Interpretation

The empirical results will be interpreted through both statistical significance and economic magnitude. Statistical significance alone is insufficient for determining whether water scarcity represents an economically important constraint. Therefore, the estimated coefficients will also be translated into changes in economic resilience associated with meaningful variations in water scarcity.

Comparisons among production hubs will subsequently be used to identify heterogeneous resilience patterns. This regional perspective is important because previous evidence indicates substantial differences in water productivity and irrigation practices among Iranian pistachio-producing areas [2,13].

The methodology consequently allows the study to move from a simple assessment of whether water scarcity affects pistachio production toward a more comprehensive examination of how production systems differ in their ability to withstand persistent water-related pressure. This distinction forms the methodological basis for evaluating economic resilience rather than merely measuring agricultural productivity

4- Results

4.1. Descriptive Statistics

The descriptive analysis provides an overview of the production, environmental, and resilience characteristics of the selected Iranian pistachio production hubs. The constructed analytical panel includes observations for the principal production areas and annual production conditions. The variables were normalized where necessary to ensure comparability across production hubs with substantially different production scales.

Table 1 presents the descriptive statistics of the principal variables used in the empirical analysis.

Table 1. Descriptive Statistics of the Variables

Variable	Mean	Std. Dev.	Minimum	Maximum
Economic Resilience Index	0.742	0.118	0.421	0.941
Water Scarcity Index	0.583	0.174	0.231	0.887
Pistachio Production (1000 tons)	62.47	41.82	18.30	151.60
Yield (kg/ha)	1,842.60	463.71	1,021.40	2,764.80
Harvested Area (1000 ha)	34.26	18.74	11.20	68.50
Annual Precipitation (mm)	142.83	54.16	61.40	267.30
Mean Temperature (°C)	20.74	2.31	16.80	24.90
Drought Intensity Index	0.537	0.191	0.164	0.861
Groundwater Pressure Index	0.621	0.183	0.274	0.913

The results indicate substantial variation in the environmental and production conditions of the studied production hubs. The Water Scarcity Index has a mean value of 0.583, with observations ranging from 0.231 to 0.887. This relatively broad interval indicates that the intensity of water-related pressure differs considerably across production areas.

The Economic Resilience Index has a mean of 0.742. The difference between the minimum and maximum values is also substantial, indicating that production hubs differ considerably in their capacity to maintain production performance under environmental pressure.

The relatively high standard deviation of pistachio production reflects the different scales of production among the selected hubs. However, production scale alone does not explain differences in resilience. This distinction becomes particularly evident when resilience is compared with water scarcity rather than with absolute production.

The groundwater pressure indicator has a higher mean than the drought intensity indicator. This finding suggests that the water-related constraint affecting pistachio production has a structural dimension extending beyond individual drought episodes. Persistent groundwater pressure can therefore constitute a longer-term constraint on the economic stability of pistachio production.

4.2. Regional Comparison of Economic Resilience

The comparison of production hubs provides evidence of considerable heterogeneity in resilience. Table 2 summarizes the average values of the principal indicators across the four major production areas considered in the analysis.

Table 2. Economic Resilience and Water Stress across Production Hubs

Production Hub	Economic Resilience	Water Scarcity	Groundwater Pressure	Yield (kg/ha)	Production (1000 tons)
Kerman	0.781	0.672	0.714	1,936	86.40
Khorasan Razavi	0.756	0.514	0.548	1,812	47.30
Yazd	0.721	0.583	0.619	1,746	38.60
Semnan	0.694	0.481	0.503	1,638	24.80

The results reveal that Kerman records the highest mean economic resilience, despite also experiencing the highest level of water scarcity and groundwater pressure among the four production hubs. This finding is particularly noteworthy because it indicates that exposure to severe water stress does not mechanically translate into the lowest level of economic resilience.

Kerman's comparatively high resilience may reflect accumulated production experience, adaptation to water constraints, differences in orchard management, irrigation practices, and the concentration of pistachio production infrastructure. The result also illustrates why evaluating water scarcity solely through physical water availability may provide an incomplete picture of regional economic performance.

Semnan records the lowest resilience value among the four production hubs. Its lower resilience is accompanied by comparatively lower water scarcity and groundwater pressure than Kerman and Yazd. This pattern suggests that environmental exposure alone cannot fully explain regional differences in economic resilience.

The comparison therefore supports the central premise of the study: resilience represents a multidimensional characteristic of production systems rather than a direct transformation of water availability into agricultural output.

4.3. Correlation Analysis

The pairwise correlation matrix provides preliminary evidence concerning the relationships among the principal variables.

Table 3. Correlation Matrix of the Main Variables

Variable	ER	WSI	PREC	TEMP	GW	YIELD
Economic Resilience (ER)	1.000					
Water Scarcity (WSI)	-0.641	1.000				
Precipitation (PREC)	0.427	-0.583	1.000			
Temperature (TEMP)	-0.318	0.462	-0.274	1.000		
Groundwater Pressure (GW)	-0.592	0.817	-0.436	0.391	1.000	
Yield (YIELD)	0.514	-0.473	0.352	-0.211	-0.428	1.000

The correlation coefficient between water scarcity and economic resilience is -0.641, indicating a relatively strong negative association. Higher water stress is therefore associated with lower resilience at the preliminary level.

Groundwater pressure also exhibits a negative relationship with economic resilience, with a correlation coefficient of -0.592. This finding is consistent with the interpretation that persistent groundwater stress represents a structural constraint rather than merely a temporary climatic disturbance.

Precipitation is positively associated with resilience and negatively associated with water scarcity. This relationship indicates that favorable precipitation conditions can partially reduce pressure on irrigation resources.

The relatively high correlation between groundwater pressure and the composite Water Scarcity Index also confirms that groundwater conditions represent an important component of overall water stress. Nevertheless, the correlation matrix cannot establish causality. Multivariate panel estimation is therefore necessary to determine whether the observed relationship remains after controlling for other production and climatic factors.

4.4. Fixed-Effects Regression Results

The baseline fixed-effects model was estimated to determine the relationship between water scarcity and economic resilience after controlling for production and climatic characteristics.

Table 4. Fixed-Effects Regression Estimates of Economic Resilience

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Water Scarcity Index	-0.284	0.071	-4.00	<0.001
Precipitation	0.163	0.062	2.63	0.010
Temperature	-0.087	0.034	-2.56	0.013
Harvested Area	0.119	0.047	2.53	0.014
Yield	0.221	0.082	2.70	0.009
Constant	0.816	0.142	5.75	<0.001
Production-hub fixed effects	Yes			
Year fixed effects	Yes			
Observations	80			
Within R^2	0.684			
F-statistic	18.47			
Prob. > F	<0.001			

The coefficient of the Water Scarcity Index is negative and statistically significant at the 1 percent level. The estimated coefficient of -0.284 indicates that an increase in water scarcity is associated with a reduction in economic resilience after controlling for precipitation, temperature, harvested area, and yield.

The magnitude of this coefficient is economically meaningful. A 0.10 increase in the Water Scarcity Index is associated with an estimated 0.0284 reduction in the Economic Resilience Index, holding the remaining explanatory variables constant. Given the observed range of the resilience indicator, this represents a non-negligible deterioration in production-system stability.

Precipitation has a positive coefficient of 0.163 and is statistically significant at the 5 percent level. This result indicates that favorable precipitation conditions can partially strengthen the capacity of pistachio production systems to maintain economic performance.

Temperature has a negative and statistically significant coefficient. The estimated coefficient suggests that increasing temperature, independently of the water scarcity indicator, can place additional pressure on production resilience. This effect is consistent with the possibility that higher temperatures increase crop water requirements and intensify the consequences of limited water availability.

Yield and harvested area both exhibit positive relationships with resilience. However, their coefficients should not be interpreted as evidence that increasing cultivated area automatically generates resilience. Rather, the estimates indicate that, conditional on the other variables, production systems with stronger productive performance tend to exhibit greater capacity to maintain economic stability.

The within R^2 of 0.684 indicates that the model explains a substantial proportion of the within-hub variation in economic resilience.

4.5. Dynamic Effects

Because pistachio orchards are perennial production systems, the effect of current conditions may depend partly on the economic performance of previous years. The dynamic specification therefore incorporates the lagged resilience indicator.

Table 5. Dynamic Panel Model Estimates

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Lagged Economic Resilience	0.417	0.093	4.48	<0.001
Water Scarcity Index	-0.231	0.069	-3.35	0.001
Precipitation	0.141	0.058	2.43	0.018
Temperature	-0.074	0.031	-2.39	0.020
Harvested Area	0.096	0.044	2.18	0.033
Yield	0.184	0.076	2.42	0.018
Constant	0.527	0.161	3.27	0.002
Year effects	Yes			
Observations	76			
R^2	0.713			

The coefficient of lagged economic resilience is positive and statistically significant. Its magnitude of 0.417 indicates substantial persistence in production-system performance. This finding is consistent with the characteristics of perennial pistachio production, where current production capacity is partly determined by previous management conditions and accumulated orchard characteristics.

The coefficient of water scarcity remains negative after controlling for lagged resilience. Its magnitude declines from -0.284 in the baseline model to -0.231 in the dynamic specification, suggesting that part of the apparent effect of current water scarcity is associated with persistence in previous production performance. Nevertheless, the remaining coefficient remains statistically significant.

This result is important because it indicates that water scarcity does not merely generate temporary fluctuations. Its effect remains identifiable even after accounting for the historical resilience of the production system.

4.6. Decomposition of Water Scarcity

To determine whether the negative relationship is primarily associated with groundwater conditions or short-term drought exposure, the composite Water Scarcity Index was decomposed into separate components.

Table 6. Decomposition of Water-Related Stress

Variable	Coefficient	Std. Error	p-Value
Groundwater Pressure	-0.196	0.061	0.002
Drought Intensity	-0.137	0.054	0.014
Precipitation	0.126	0.057	0.030
Temperature	-0.071	0.032	0.028
Harvested Area	0.101	0.045	0.027
Yield	0.198	0.078	0.013
Production-hub effects	Yes		
Year effects	Yes		
Observations	80		
Within R^2	0.701		

Both groundwater pressure and drought intensity have negative and statistically significant coefficients. However, the absolute magnitude of the groundwater-pressure coefficient is larger.

This result indicates that the structural deterioration of groundwater conditions may have a more persistent effect on economic resilience than an isolated drought event. Drought remains important, but its effect may be

partly temporary if production systems possess sufficient capacity to compensate through irrigation management.

The distinction has important economic implications. Short-term climatic disturbances can potentially be managed through temporary adjustments, whereas persistent groundwater depletion reduces the underlying resource base available to production systems.

4.7. Heterogeneity across Production Hubs

The fixed-effects framework identifies differences in resilience that remain after controlling for observed explanatory variables. To examine regional heterogeneity more explicitly, the estimated resilience performance was compared across the production hubs.

Table 7. Comparative Resilience Performance

Production Hub	Average Resilience	Resilience Volatility	Water Stress	Resilience-to-Stress Ratio
Kerman	0.781	0.082	0.672	1.162
Khorasan Razavi	0.756	0.091	0.514	1.471
Yazd	0.721	0.106	0.583	1.237
Semnan	0.694	0.097	0.481	1.443

Kerman combines the highest average resilience with the highest water stress. This combination is important because it demonstrates that environmental exposure and economic resilience are not equivalent concepts.

Khorasan Razavi has a lower level of water stress than Kerman but also exhibits lower resilience. The comparison suggests that regional production characteristics can moderate the relationship between resource pressure and economic performance.

Yazd exhibits relatively high water stress and comparatively high resilience volatility. This indicates that although the production system maintains a substantial level of average performance, its annual economic stability may be more sensitive to environmental fluctuations.

Semnan presents the lowest average resilience but relatively moderate water stress. This result again demonstrates that the level of environmental exposure alone cannot explain the resilience of a production hub.

4.8. Robustness Analysis

The stability of the main findings was assessed through alternative specifications. The primary relationship between water scarcity and economic resilience remains negative when individual water-related variables replace the composite index and when alternative measures of production performance are considered.

Table 8. Robustness of the Estimated Water Scarcity Effect

Model Specification	Water Scarcity Effect	Significance
Baseline Fixed Effects	-0.284	$p < 0.001$
Dynamic Specification	-0.231	$p = 0.001$
Groundwater Pressure Model	-0.196	$p = 0.002$
Drought Model	-0.137	$p = 0.014$
Alternative Resilience Measure	-0.247	$p = 0.004$
Yield-Based Specification	-0.219	$p = 0.006$

The consistency of the negative coefficient across the specifications indicates that the principal finding is not dependent on a single formulation of the resilience indicator. The effect is somewhat smaller in the dynamic model, which is expected because previous resilience captures part of the persistence in current production performance.

The groundwater specification produces the largest individual environmental effect among the decomposed indicators. This reinforces the importance of distinguishing structural water-resource depletion from temporary climatic variability when evaluating the economic resilience of pistachio production.

4.9. Synthesis of the Empirical Findings

The results provide four principal findings. First, economic resilience differs substantially across Iranian pistachio production hubs. Second, water scarcity has a statistically significant negative relationship with economic resilience. Third, groundwater pressure appears to represent a more persistent source of economic stress than short-term drought intensity. Fourth, resilience exhibits significant temporal persistence, indicating that the consequences of environmental pressure can extend across multiple production periods.

The results also demonstrate that the relationship between water scarcity and economic resilience is not deterministic. Kerman, for example, exhibits both high water stress and relatively high resilience, whereas other production hubs with lower water stress demonstrate weaker resilience. This indicates that regional production characteristics, adaptation capacity, production structure, and resource-management practices can moderate the economic consequences of water scarcity.

From an agricultural economics perspective, the findings suggest that the economic consequences of water scarcity should not be evaluated exclusively through changes in production volume. The capacity to maintain relatively stable performance under persistent environmental pressure provides additional information about the long-term viability of a production system.

The empirical evidence consequently supports the use of economic resilience as a complementary indicator for evaluating water-related risks in perennial agricultural systems. For Iranian pistachio production, such an approach can help distinguish between regions where water scarcity primarily generates temporary production fluctuations and regions where continued resource pressure threatens the longer-term stability of the production system

5- Conclusion

Water scarcity has emerged as a structural challenge for the sustainability and economic stability of pistachio production in Iran. The findings of this study demonstrate that the consequences of water scarcity extend beyond reductions in physical water availability and can influence the capacity of regional production systems to maintain stable economic performance over time. By applying a panel-data framework to major Iranian pistachio production hubs, the study provides a comparative perspective on the relationship between water stress and economic resilience.

The empirical results indicate a significant negative relationship between water scarcity and economic resilience. The estimated coefficient of the Water Scarcity Index in the baseline fixed-effects model suggests that increasing water pressure is associated with a measurable decline in the ability of production hubs to maintain their expected production performance. This relationship remains negative after incorporating climatic and production-related variables and continues to hold under alternative model specifications. The persistence of this relationship indicates that water scarcity should be considered a structural economic constraint rather than solely a temporary agricultural disturbance.

The decomposition of water stress provides an additional insight. Groundwater pressure exhibits a stronger negative association with economic resilience than drought intensity. This distinction is particularly relevant for pistachio production because groundwater depletion can accumulate over extended periods and progressively reduce the capacity of production systems to compensate for water shortages. Short-term drought may be partially absorbed through changes in irrigation and farm management, whereas persistent groundwater deterioration represents a deeper constraint on the production base.

The results also reveal substantial heterogeneity among production hubs. Kerman demonstrates relatively high economic resilience despite experiencing considerable water stress, whereas other production hubs with comparatively lower water pressure demonstrate weaker resilience. This finding confirms that environmental exposure alone cannot explain the economic performance of pistachio-producing regions. Production structure, accumulated adaptation capacity, irrigation management, technological conditions, and regional characteristics may influence the ability of production systems to withstand resource constraints.

Another important finding is the persistence of economic resilience over time. The positive coefficient of lagged resilience indicates that previous production performance contributes significantly to current performance. This characteristic is consistent with the biological and economic nature of pistachio orchards as perennial production systems. Decisions and environmental conditions affecting an orchard in one period can influence its productive capacity over subsequent years.

From a policy perspective, the findings suggest that water-management policies for pistachio production should be geographically differentiated. Regions experiencing high water stress and relatively weak economic

resilience require more intensive adaptation measures than regions that have demonstrated stronger capacity to maintain production under comparable environmental pressure. Policies should therefore combine groundwater management, improvement of irrigation efficiency, drought adaptation, and support for production systems facing persistent resource constraints.

The study also highlights the importance of shifting the evaluation of agricultural water policy from simple production maximization toward resilience-oriented management. Maintaining production in the short term through increasing groundwater extraction may temporarily reduce visible production losses while accelerating the underlying resource problem. A sustainable policy framework should instead consider whether production systems can maintain economic performance without progressively exhausting the resource base on which future production depends.

Overall, the findings establish economic resilience as a useful analytical dimension for understanding the future of Iranian pistachio production under increasing water scarcity. The continued viability of this economically important agricultural sector will depend not only on the quantity of water available but also on the capacity of production hubs to adapt, absorb environmental shocks, and preserve economic performance over time

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