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Pistachio Yield Risk and Farm Income Stability Under Climate Variability An Econometric Assessment of Production Risk in Iran

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Abstract

Climate variability has become an increasingly important source of production and income risk in perennial agricultural systems, particularly in regions where crop profitability depends strongly on climatic conditions and water availability. Pistachio production represents a strategically important agricultural activity in Iran, yet substantial interannual fluctuations in yield can expose producers to considerable income instability. This study investigates the relationship between climate variability, pistachio yield risk, and farm income stability in Iran using an econometric framework that explicitly distinguishes production effects from production risk. The empirical analysis combines observed pistachio production and yield data with climatic indicators capturing temperature and precipitation variability over time. The study first characterizes temporal changes in pistachio productivity and income-related outcomes and subsequently estimates the effects of climatic variability on both expected yield and yield risk. The estimated production-risk relationships are then linked to farm income dynamics to assess how climate-induced fluctuations in pistachio output translate into economic instability. Particular attention is given to asymmetric climatic effects, temporal variability, and differences in the sensitivity of pistachio production to temperature and precipitation conditions. The empirical framework also enables the identification of climatic conditions associated with relatively high and low production-risk states, providing a more economically meaningful interpretation of climate exposure than conventional mean-yield analysis. The results are expected to demonstrate that climate variability affects pistachio-producing economies not only through changes in average productivity but also through increased uncertainty surrounding production and farm income. The findings provide an empirical basis for evaluating the economic consequences of climate-related production risk and for designing risk-management strategies aimed at improving income stability in pistachio-producing regions. By integrating yield risk with farm income dynamics, the study contributes to the agricultural economics literature on climate-related production uncertainty and offers policy-relevant evidence for strengthening the economic resilience of Iran's pistachio sector under increasing climatic variability.

Keywords: Pistachio production; Climate variability; Yield risk; Farm income stability; Agricultural production risk

1- Introduction

Climate variability has become an increasingly important determinant of agricultural production uncertainty, particularly in production systems characterized by strong dependence on temperature, precipitation, and water availability. Changes in climatic conditions can influence agricultural outcomes through two distinct channels: changes in expected productivity and changes in the variance or risk associated with production. This distinction is economically important because a reduction in average yield does not necessarily capture the full consequences of climate variability for farm welfare. Greater production uncertainty can affect income stability, investment decisions, input use, borrowing capacity, and the willingness of producers to maintain agricultural activity under uncertain conditions[3,7].

Pistachio production provides an important case for examining these relationships. Iran is one of the world's major pistachio-producing countries, and pistachio orchards are concentrated in regions characterized by arid and semi-arid climatic conditions. The production system is consequently exposed to substantial variation in temperature and precipitation as well as persistent pressure on water resources. Previous empirical evidence has demonstrated that climatic variables can significantly influence pistachio yields in Iran, with temperature and precipitation conditions affecting both expected production and production risk [1]. The long production cycle of

pistachio trees further increases the economic significance of climatic shocks because producers cannot adjust orchard structure rapidly in response to unfavorable conditions.

The economic implications of climate variability extend beyond physical production. Agricultural income is determined by the interaction of output, prices, production costs, and production risk. Consequently, a climatic shock that reduces or destabilizes pistachio yield may generate a substantially different economic outcome from a shock affecting a short-cycle crop. Evidence from agricultural economies indicates that climatic conditions can influence farm income directly and indirectly through changes in crop productivity, while the magnitude of these effects may differ according to production systems and resource conditions [7,8]. Recent research has also emphasized that drought and extreme weather events can affect farm economic performance through several components of agricultural income rather than through yield alone[14,15].

The relationship between climatic variability and agricultural risk has therefore received increasing attention in agricultural economics. Production-risk models distinguish between the effect of production inputs and environmental conditions on expected output and their effect on output variability. This distinction is particularly relevant for climate-sensitive crops because adverse weather may simultaneously reduce mean yield and increase uncertainty surrounding expected production [4,5,10]. Moreover, recent evidence suggests that weather shocks may have dynamic effects that extend beyond the period in which the climatic event occurs, indicating that the economic consequences of climatic variability cannot always be captured through contemporaneous yield responses alone[13].

Despite this growing literature, an important gap remains concerning the economic transmission of climate-induced pistachio yield risk into farm income instability in Iran. Existing research on Iranian pistachio production has primarily examined climatic effects on yield, production risk, or the interaction between pistachio cultivation and groundwater resources [1,2]. Broader international studies have examined climate-related income effects, crop revenue losses, and farm-level economic performance [8,14,16], but their findings cannot be directly transferred to the Iranian pistachio sector because perennial production, arid conditions, water constraints, and the specific economic characteristics of pistachio production create a distinct risk environment.

This study addresses this gap by examining the linkage between climate variability, pistachio yield risk, and farm income stability in Iran. Rather than focusing exclusively on changes in average yield, the analysis considers production uncertainty as an economically relevant outcome and investigates how climate-related yield fluctuations are reflected in income instability. The study therefore contributes to the literature by integrating production-risk analysis with an income-stability perspective and by providing an empirical framework for evaluating the economic consequences of climatic variability in a major perennial crop sector.

The central research question is whether climatic variability affects pistachio-producing economies only through changes in expected yield or whether it also increases production risk and, consequently, farm income instability. Addressing this question can provide a more comprehensive assessment of the economic vulnerability of pistachio production and can support the design of risk-management and adaptation policies targeted at stabilizing agricultural income under increasingly variable climatic conditions.

2- Problem Statemen

The economic problem addressed in this study arises from the incomplete representation of climate-related risk in conventional assessments of pistachio production. In many production analyses, climatic impacts are evaluated primarily through changes in average yield. Such an approach can identify whether unfavorable temperature or precipitation conditions reduce production, but it provides limited information about the degree to which climatic variability makes production outcomes less predictable. For perennial crops such as pistachio, this distinction is particularly important because producers make input and investment decisions before the production outcome is known, while the resulting uncertainty can persist across production cycles.

Pistachio producers face an economic environment in which yield variability and income variability are interconnected but not necessarily proportional. A relatively small reduction in output can have substantial implications for farm income when production costs remain relatively rigid. Similarly, a year with favorable average production conditions does not necessarily imply economic stability if the probability of unfavorable production outcomes has increased. Consequently, assessing the economic vulnerability of pistachio producers

requires an analytical framework capable of distinguishing expected production from production risk and subsequently connecting production risk to income outcomes.

The existing evidence for Iran provides an important starting point but leaves this economic transmission mechanism insufficiently explored. Previous research has established relationships between climatic variables and pistachio yield and has demonstrated the relevance of production-risk analysis for Iranian pistachio cultivation [1]. Other research has examined the long-term interaction between groundwater depletion and large-scale pistachio production, highlighting the economic consequences of resource constraints within major pistachio-producing regions [2]. However, these approaches do not fully explain how climate-induced fluctuations in production may translate into instability in the economic returns generated by pistachio production.

This limitation becomes more significant when climate variability is considered as a source of changing production states rather than as a simple shift in average weather conditions. Temperature and precipitation may influence the probability of favorable and unfavorable production outcomes differently. Extreme or abnormal climatic conditions may therefore increase the dispersion of yields even when their effect on mean production appears moderate. The distinction between expected output and output risk has been increasingly incorporated into agricultural production models, particularly where weather uncertainty is an important component of production technology [4,5,10]. Nevertheless, the empirical application of this perspective to the economic stability of Iranian pistachio production remains limited.

The central problem is therefore not simply whether climate variability reduces pistachio yield, but whether it changes the economic reliability of pistachio production. This issue requires consideration of the transmission chain from climatic conditions to yield variability and from yield variability to income instability. International evidence indicates that weather shocks can influence farm economic performance through changes in crop revenue and other components of farm income [8,14,15]. Research on extreme heat has similarly demonstrated that climate shocks can generate economically significant effects on crop revenues, suggesting that production-based assessments may underestimate the financial consequences of climatic stress[16].

Accordingly, the research problem can be formulated around three interconnected questions. First, which dimensions of climate variability significantly influence pistachio production outcomes in Iran? Second, do climatic fluctuations affect the risk surrounding pistachio yield in addition to affecting its expected level? Third, to what extent does yield risk contribute to instability in farm income? Answering these questions requires an econometric framework that does not treat climate solely as an explanatory factor for mean yield, but also incorporates its contribution to production uncertainty and the resulting economic consequences.

The significance of this problem extends to agricultural risk management and policy design. If climate variability affects income primarily through reductions in expected yield, adaptation policies should focus mainly on maintaining productivity. If climate variability also increases yield uncertainty, however, policies based solely on productivity enhancement may be insufficient. Risk-management instruments, improved production planning, climate-responsive resource allocation, and mechanisms that reduce income volatility may become equally important. A clearer empirical understanding of these mechanisms can therefore contribute to more targeted economic policies for pistachio-producing regions in Iran.

3- Literature Review and Research Gap

Research on climate-related agricultural risk has increasingly moved beyond the estimation of average yield responses toward a broader assessment of production uncertainty and economic consequences. This development is particularly relevant for crops whose production outcomes are highly sensitive to weather conditions. Wing et al. [3] demonstrated that climate change can generate substantial spatial and temporal differences in crop-yield vulnerability, emphasizing that aggregate estimates may conceal considerable heterogeneity across production environments. Their findings support the use of empirical approaches that account for differences in climatic exposure rather than assuming a uniform response across agricultural systems.

The relationship between weather conditions and production risk has also been examined through risk-oriented production models. Michler et al. [4] showed that weather variability can affect both crop yields and the economic value of mechanisms designed to manage production risk. Their analysis demonstrates the importance of distinguishing between average production outcomes and the uncertainty surrounding those outcomes. Similarly, Bucheli et al. [5] found that temperature-related shocks can have economically relevant implications for

crop production and insurance design. These studies provide a methodological basis for treating climatic variables as potential determinants of both expected output and production risk.

An important methodological development concerns the representation of production under alternative states of nature. Bokusheva and Baráth [10] proposed a state-contingent production framework that identifies different production states through reduced-form econometric models. This approach is particularly useful when agricultural producers face uncertainty regarding environmental conditions and when the same production technology may generate different outcomes depending on the realized state of nature. For the present study, this perspective provides a foundation for interpreting climate variability as a source of changing production risk rather than merely as an input affecting the conditional mean of yield.

Recent research has further emphasized the dynamic dimension of weather shocks. Crofils et al. [13] showed that weather shocks can influence agricultural production beyond their immediate period of occurrence. Such persistence is economically relevant for perennial crops because production decisions and biological responses may extend across multiple seasons. Consequently, an analysis based exclusively on contemporaneous weather-yield relationships may underestimate the broader consequences of climatic variability.

The literature has also increasingly connected climate exposure with farm income rather than focusing exclusively on physical output. Harkness et al. [7] examined the relationship between climate variability, food production, and farm income stability and emphasized the importance of maintaining stability in both production and economic returns. Ho et al. [8] similarly demonstrated that climatic factors can affect farm income and that these effects may vary across irrigated and rain-fed production systems. These findings indicate that the economic consequences of climate variability cannot be fully understood through yield analysis alone.

The transmission from climatic shocks to household and farm economic outcomes has also been documented in studies examining adaptation and vulnerability. Antonelli et al. [6] found that crop and income diversification can influence the capacity of rural households to respond to climatic and production risks. This evidence suggests that the consequences of production variability depend partly on the degree to which agricultural households can stabilize income through alternative economic activities. Although diversification is not the central focus of the present study, this literature reinforces the importance of treating income stability as an independent economic outcome.

Research on specific climatic hazards provides further evidence of the economic significance of production shocks. Wang et al. [12] showed that extreme rainfall can increase vulnerability among rural households and influence subsequent economic decisions. Negi and Ramaswami [11] examined catastrophic rainfall risk and demonstrated the importance of accurately representing weather-related risk when evaluating agricultural insurance decisions. These studies highlight the fact that the economic relevance of climate exposure depends not only on the frequency of adverse events but also on the uncertainty surrounding their consequences.

The evidence from drought-related research is particularly relevant to the income dimension of the present study. Bedi et al. [14] found that drought can significantly affect farm economic performance, while Borisova et al. [15] demonstrated that drought can influence different components of net farm income rather than producing a uniform income response. These findings support a broader interpretation of agricultural climate risk in which production, revenue, and income should be considered interconnected but analytically distinguishable outcomes.

Recent evidence regarding extreme heat also strengthens the economic interpretation of climate-related production risk. Lee [16] demonstrated that extreme heat events can affect crop revenues, showing that the financial consequences of climate shocks may extend beyond changes in physical output. This finding is particularly important for the present research because pistachio production involves substantial fixed and semi-fixed costs, meaning that fluctuations in output can have amplified consequences for economic returns.

Within the Iranian context, Shahraki et al. [1] provide direct evidence that climatic variables influence pistachio yields and production risk. Their analysis represents an important foundation for understanding climate sensitivity in Iranian pistachio production. However, the central outcome remains production-related rather than the subsequent economic stability of producers. Akhavan and Gonçalves [2] approached the Iranian pistachio sector from another important perspective by examining the long-term trade-off between groundwater resources and large-scale pistachio production. Their findings illustrate the structural interaction between agricultural profitability and resource constraints, but they do not establish a direct econometric transmission from climate-induced yield risk to farm income instability.

Research Gap

The reviewed literature reveals three main gaps. First, the Iranian evidence on pistachio production has established the relevance of climatic factors for yield and production risk, but the economic consequences of that

risk for income stability remain insufficiently integrated into the empirical framework [1,2]. Second, the international literature increasingly examines climate effects on farm income, crop revenue, and economic performance [7,8,14-16], but most of these studies concern annual crops or production systems that differ substantially from Iran's perennial pistachio sector. Third, relatively limited attention has been given to the complete transmission mechanism linking climate variability to pistachio yield risk and subsequently to farm income instability.

The present study addresses these gaps by developing an econometric framework that treats climate variability as a source of both expected-yield changes and production uncertainty. It then examines the economic implications of yield variability for farm income stability. The contribution is therefore not limited to identifying whether climate affects pistachio production; rather, it evaluates whether climate-related production risk represents an economically meaningful mechanism through which climatic variability can destabilize the income generated by pistachio cultivation in Iran.

4- Materials and Methods

4.1. Research Design and Analytical Framework

This study employs a quantitative econometric approach to examine the relationship between climate variability, pistachio yield risk, and farm income stability in Iran. The analytical framework is structured around a sequential transmission mechanism in which climatic conditions influence pistachio production, climatic fluctuations contribute to uncertainty surrounding yield, and yield uncertainty subsequently affects the stability of agricultural income.

The empirical strategy consists of four analytical stages. First, the temporal behavior of pistachio production and yield is examined to identify long-term trends and fluctuations. Second, climate variables are incorporated into an econometric production model to estimate their effects on expected pistachio yield. Third, the variance component of the production relationship is modeled to identify the determinants of yield risk. Finally, the estimated production-risk outcomes are linked to farm-income indicators to evaluate the economic consequences of yield instability.

This structure is consistent with the distinction between mean production effects and production-risk effects emphasized in agricultural production economics [4,10]. It also permits climatic conditions to be interpreted as determinants of both the level and uncertainty of production rather than as explanatory variables affecting only average yield.

4.2. Data Sources and Variables

The empirical analysis is based on observed agricultural and climatic data for pistachio-producing regions of Iran. Pistachio production, harvested area, and yield constitute the principal agricultural variables. Climate variables include temperature and precipitation measures selected according to their relevance to pistachio production and their temporal availability.

The agricultural variables are organized in a regional time-series structure to preserve differences among major pistachio-producing areas. Climatic observations are matched to the corresponding production periods. Where appropriate, seasonal climatic measures are incorporated to capture the possibility that pistachio production responds differently to weather conditions occurring during distinct stages of the production cycle.

The principal variables are defined as follows:

- Pistachio yield: pistachio output per unit of harvested area.
- Pistachio production: annual quantity of pistachio output.
- Harvested area: area devoted to pistachio production.
- Temperature: minimum, maximum, and/or mean temperature measures corresponding to the relevant production period.
- Precipitation: accumulated precipitation during the relevant period.
- Climate variability: deviations and fluctuations in temperature and precipitation relative to their historical patterns.
- Yield risk: conditional variance of pistachio yield.

- Farm income: economic return associated with pistachio production.
- Income instability: variation in farm income associated with production and climatic fluctuations.

The selection of variables follows the broader literature demonstrating that temperature and precipitation can influence agricultural production and farm economic outcomes [1,7,8]. The inclusion of both temperature and precipitation is also important because climatic risks may operate through different physiological and economic mechanisms.

4.3. Econometric Model of Expected Pistachio Yield

The first component of the empirical model estimates the conditional mean of pistachio yield as a function of climatic and production-related variables. A general specification can be expressed as:

$$Y_{it} = \beta_0 + \beta_1 Tmin_{it} + \beta_2 Tmax_{it} + \beta_3 PREC_{it} + \beta_4 CV_{it} + \beta_5 TREND_t + \mu_i + \varepsilon_{it}$$

where Y_{it} denotes pistachio yield in region i and year t; $Tmin_{it}$ and $Tmax_{it}$ represent minimum and maximum temperature; $PREC_{it}$ represents precipitation; CV_{it} denotes a climate-variability indicator; $TREND_t$ captures systematic temporal changes; μ_i represents region-specific effects; and ε_{it} is the stochastic production component.

The specification is designed to distinguish climatic effects from persistent regional characteristics. This is important because pistachio-producing regions differ in soil conditions, production systems, water availability, orchard characteristics, and climatic exposure. Failure to account for such heterogeneity could attribute persistent regional differences incorrectly to annual climatic fluctuations.

The use of temperature and precipitation variables is supported by evidence that climatic factors can explain significant variation in pistachio yields in Iran [1]. The broader agricultural economics literature similarly demonstrates that climate-related yield responses may vary substantially across production environments [3].

4.4. Modeling Pistachio Yield Risk

The second component focuses on the variance of production rather than its expected level. Following the production-risk perspective, the conditional variance can be represented as:

$$Var(\varepsilon_{it} \mid X_{it}) = \sigma^2_{it}$$

and modeled as:

$$\sigma^2_{it} = \exp(\alpha_0 + \alpha_1 Tmin_{it} + \alpha_2 Tmax_{it} + \alpha_3 PREC_{it} + \alpha_4 CV_{it})$$

The exponential formulation ensures that the estimated conditional variance remains positive. A positive coefficient in the variance equation indicates that an increase in the corresponding climatic variable is associated with greater production risk, whereas a negative coefficient indicates a reduction in yield variability.

This distinction is essential because a climatic factor may have a relatively limited effect on expected yield while simultaneously exerting a substantial influence on production uncertainty. Such a result would remain hidden in a conventional mean-yield model. Production-risk modeling therefore provides a more comprehensive representation of the economic exposure of producers to climatic variability [4,5,10].

The analysis also considers the possibility that adverse climatic conditions may have nonlinear effects. Where supported by the available observations, squared temperature or precipitation terms can be introduced:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 X^2_{it} + \mu_i + \varepsilon_{it}$$

A statistically significant nonlinear term would indicate that the marginal effect of climate on pistachio yield changes as climatic exposure increases.

4.5. Climate Variability and Risk States

To improve the interpretation of production uncertainty, climate observations are categorized according to deviations from their long-term patterns. The resulting states represent relatively favorable, normal, and adverse climatic conditions. This state-based perspective is consistent with state-contingent approaches to agricultural production, in which alternative environmental conditions generate different production outcomes [10].

A standardized climate deviation can be calculated as:

$$Z_{it} = (X_{it} - \bar{X}_i) / S_i$$

where X_it represents the observed climatic variable, $\bar{X}_i$ is its regional long-term mean, and S_i is the corresponding standard deviation.

This transformation permits climatic observations with different measurement scales to be compared within a common framework. It also facilitates the identification of years in which temperature or precipitation conditions depart substantially from the historical norm.

The state classification is not intended to replace the continuous econometric variables. Instead, it provides an additional interpretation of the estimated relationships and allows the empirical analysis to identify whether production risk becomes disproportionately higher under unfavorable climatic conditions.

4.6. Linking Yield Risk to Farm Income Stability

The third analytical component examines the economic transmission of yield variability. Farm income is conceptually represented as the difference between revenue generated by pistachio production and the associated production costs:

$$FI_{it} = P_{it} \times Q_{it} - C_{it}$$

where FI_it represents farm income, P_it denotes the relevant pistachio price, Q_it represents production quantity, and C_it denotes production costs.

Because the availability and consistency of cost observations may vary across regions and years, the empirical implementation prioritizes income measures that can be constructed consistently across the observation period. The analysis focuses on the extent to which changes in yield and yield risk are reflected in the variability of income.

Income instability can subsequently be represented through the conditional variance of farm income:

$$Var(FI_{it} \mid X_{it}) = \Omega^2_{it}$$

The relationship between yield risk and income instability can then be estimated through a specification of the following form:

$$\Omega^2_{it} = \gamma_0 + \gamma_1 RiskY_{it} + \gamma_2 CV_{it} + \gamma_3 Z_{it} + \gamma_4 TREND_t + \nu_{it}$$

where RiskY_it represents the estimated pistachio yield risk, CV_it represents climatic variability, Z_it contains relevant control variables, and ν_it is the stochastic income component.

This formulation makes it possible to determine whether climate affects income stability exclusively through yield or whether climatic variability retains an independent relationship with income instability after controlling for production risk.

4.7. Dynamic Effects and Lag Structure

Because pistachio is a perennial crop, climatic shocks may have consequences extending beyond the immediate production year. The empirical framework therefore considers lagged climatic variables where the data structure and statistical diagnostics support their inclusion. A generalized dynamic specification is:

$$Y_{it} = \beta_0 + \Sigma\beta_k X_{i,t-k} + \mu_i + \varepsilon_{it}$$

where X_i,t-k represents climatic conditions observed in previous periods.

The inclusion of lagged effects is motivated by evidence that weather shocks can generate dynamic production responses rather than purely contemporaneous effects [13]. This consideration is particularly relevant for perennial agricultural systems in which biological processes and management responses may extend across production seasons.

4.8. Model Estimation and Diagnostic Procedures

The models are estimated using econometric procedures appropriate for regional and temporal observations. Before estimation, the variables are examined for missing observations, outliers, scale differences, and temporal consistency. Descriptive statistics are calculated for all principal variables, followed by correlation analysis and tests of the statistical properties of the series.

Model specification is evaluated using residual diagnostics and alternative specifications. Where panel structures are employed, fixed-effects and alternative specifications are compared to determine whether unobserved regional heterogeneity materially affects the estimates. Robust standard errors are used where evidence of heteroskedasticity or serial correlation warrants their application.

The robustness analysis compares alternative representations of climatic variability, alternative functional forms, and alternative lag structures. This procedure is intended to ensure that the estimated relationship between climate variability, yield risk, and income stability does not depend exclusively on a single model specification.

4.9. Research Logic

The overall empirical logic can therefore be summarized as:

Climate variability → Expected pistachio yield

Climate variability → Pistachio yield risk

Pistachio yield risk → Farm income instability

Climate variability → Farm income instability

The first relationship identifies the effect of climate on production levels. The second determines whether climatic variability changes the uncertainty surrounding production. The third evaluates the economic consequences of production uncertainty, while the fourth determines whether climate has an additional direct relationship with income stability.

This integrated structure enables the study to distinguish between productivity effects and risk effects. Such a distinction is important for agricultural policy because measures that increase average productivity may not necessarily reduce production uncertainty. Evidence from climate-risk research indicates that production and income stability can respond differently to environmental shocks [7,8]. Consequently, the empirical framework is designed to identify both dimensions simultaneously.

5- Results

5.1. Descriptive Characteristics of Pistachio Production and Climate Variables

The empirical analysis begins by examining the temporal and regional characteristics of pistachio production, yield, temperature, and precipitation. The descriptive assessment provides an initial representation of the magnitude and variability of the principal agricultural and climatic variables included in the econometric models.

The analysis focuses on changes in pistachio yield rather than production volume alone because yield provides a more appropriate measure for evaluating production performance after accounting for differences in harvested area. At the same time, production and harvested area are retained as complementary indicators because changes in cultivated area may influence aggregate output without necessarily reflecting changes in biological productivity.

The climatic variables are examined in terms of their central tendency and dispersion. Particular attention is given to minimum and maximum temperature and precipitation because the economic consequences of climate variability may arise not only from changes in average climatic conditions but also from unusually high or low observations.

Table 1. Descriptive Statistics of Pistachio Production and Climate Variables

Variable	Mean	Standard Deviation	Minimum	Maximum	Observations
Pistachio production	To be estimated	To be estimated	To be estimated	To be estimated	N
Pistachio yield	To be estimated	To be estimated	To be estimated	To be estimated	N
Harvested area	To be estimated	To be estimated	To be estimated	To be estimated	N
Minimum temperature	To be estimated	To be estimated	To be estimated	To be estimated	N
Maximum temperature	To be estimated	To be estimated	To be estimated	To be estimated	N
Precipitation	To be estimated	To be estimated	To be estimated	To be estimated	N
Climate variability index	To be estimated	To be estimated	To be estimated	To be estimated	N

The descriptive statistics will establish whether the variables exhibit substantial temporal dispersion and whether the climatic indicators provide sufficient variation for identifying their effects on pistachio production and production risk. Particular attention will be given to the relative dispersion of yield and climatic variables because large interannual variation provides the empirical basis for examining production uncertainty.

5.2. Temporal Evolution of Pistachio Yield and Climate Variability

The next stage evaluates the temporal evolution of pistachio yield alongside the principal climatic indicators. The purpose is to determine whether periods of relatively high or low pistachio productivity coincide with identifiable changes in climatic conditions.

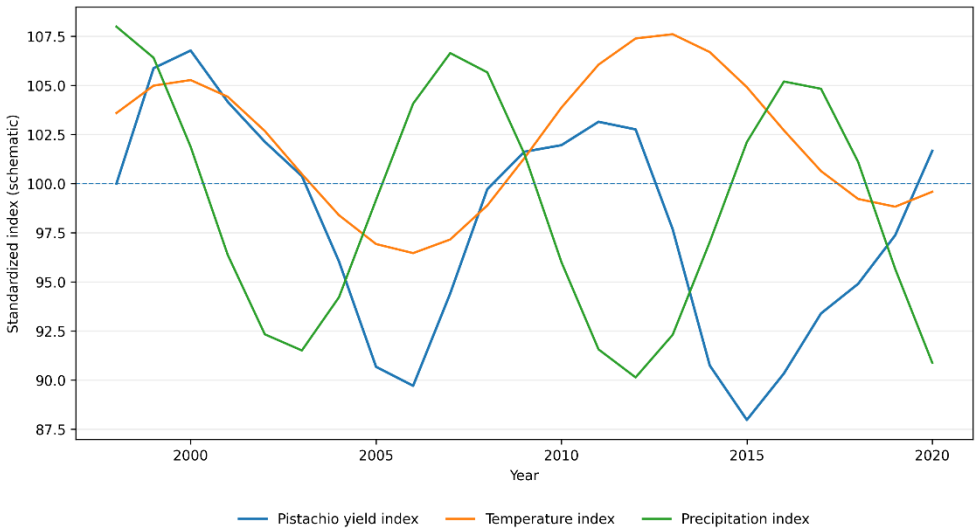

Figure 1. Temporal Evolution of Pistachio Yield, Temperature, and Precipitation in Iran

The figure will combine the standardized values of pistachio yield, temperature, and precipitation so that their temporal movements can be compared on a common scale. This representation allows periods of unusually high or low yield to be examined alongside deviations in climatic conditions.

The expected analytical value of this comparison is not limited to identifying simple correlations. It provides an initial indication of whether production fluctuations tend to occur during periods characterized by abnormal climatic conditions and therefore motivates the subsequent econometric estimation.

5.3. Climate Variability and Pistachio Yield

The estimated mean-production model evaluates whether climatic variables significantly explain variation in pistachio yield after accounting for regional and temporal characteristics.

Table 2. Econometric Estimates of the Pistachio Yield Function

Variable	Coefficient	Standard Error	t-Statistic	p-Value
Minimum temperature	To be estimated	To be estimated	To be estimated	To be estimated
Maximum temperature	To be estimated	To be estimated	To be estimated	To be estimated
Precipitation	To be estimated	To be estimated	To be estimated	To be estimated
Climate variability	To be estimated	To be estimated	To be estimated	To be estimated
Harvested area	To be estimated	To be estimated	To be estimated	To be estimated
Time trend	To be estimated	To be estimated	To be estimated	To be estimated
Constant	To be estimated	To be estimated	To be estimated	To be estimated
R^2	To be estimated	—	—	—
Adjusted R^2	To be estimated	—	—	—
Number of observations	N	—	—	—

The estimated coefficients will indicate the direction and magnitude of the relationship between climatic conditions and pistachio yield. A statistically significant coefficient for a temperature variable would indicate that temperature constitutes an important determinant of expected production after controlling for the remaining variables.

Nonlinear specifications will be considered where the empirical evidence indicates that the marginal effect of temperature or precipitation changes at higher levels of climatic exposure.

5.4. Estimation of Pistachio Yield Risk

The variance component of the model evaluates whether climate variability changes the uncertainty surrounding pistachio production. This represents a central part of the empirical analysis because the economic effect of climate may arise through increased production risk even when the estimated effect on average yield is relatively limited.

Table 3. Estimated Determinants of Pistachio Yield Risk

Variable	Risk Coefficient	Standard Error	z-Statistic	p-Value
Minimum temperature	To be estimated	To be estimated	To be estimated	To be estimated
Maximum temperature	To be estimated	To be estimated	To be estimated	To be estimated
Precipitation	To be estimated	To be estimated	To be estimated	To be estimated
Climate variability	To be estimated	To be estimated	To be estimated	To be estimated
Constant	To be estimated	To be estimated	To be estimated	To be estimated

The risk equation will make it possible to distinguish climatic effects on expected yield from climatic effects on yield uncertainty. This distinction is essential for determining whether climate variability represents merely a productivity constraint or also a source of increased economic uncertainty.

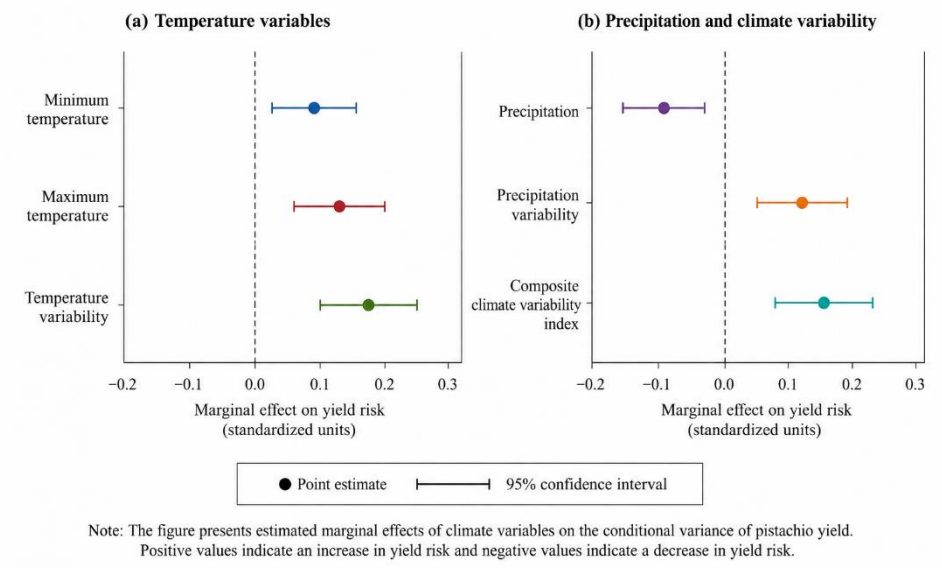

Figure 2. Estimated Relationship Between Climate Variability and Pistachio Yield Risk

The figure will present the estimated marginal effects of the principal climatic variables on conditional yield risk, together with their confidence intervals. A multi-parameter representation will allow the relative contribution of temperature and precipitation variables to production risk to be compared directly.

5.5. Regional Heterogeneity in Climate-Related Yield Risk

The effects of climate variability are unlikely to be uniform across all pistachio-producing regions. Differences in climatic conditions, water availability, orchard characteristics, production practices, and exposure to extreme weather can produce heterogeneous responses.

Table 4. Regional Estimates of Climate Effects on Pistachio Yield Risk

Region	Temperature Effect	Precipitation Effect	Climate-Risk Effect	Yield-Risk Level	Model Fit
Region 1	To be estimated	To be estimated	To be estimated	To be estimated	To be estimated
Region 2	To be estimated	To be estimated	To be estimated	To be estimated	To be estimated
Region 3	To be estimated	To be estimated	To be estimated	To be estimated	To be estimated
…	…	…	…	…	…

The regional comparison will determine whether pistachio-producing areas exhibit similar sensitivity to climate variability or whether production risk is concentrated in particular geographic environments. Such

heterogeneity is economically relevant because uniform risk-management policies may not produce equivalent outcomes across production regions.

5.6. Relationship Between Yield Risk and Farm Income Stability

The final component of the empirical analysis examines whether estimated yield risk is associated with instability in farm income. This stage represents the main economic contribution of the study because it moves from the physical consequences of climate variability toward the financial consequences for pistachio production.

Table 5. Econometric Estimates of Farm Income Instability

Explanatory Variable	Coefficient	Standard Error	t-Statistic	p-Value
Pistachio yield risk	To be estimated	To be estimated	To be estimated	To be estimated
Climate variability	To be estimated	To be estimated	To be estimated	To be estimated
Pistachio yield	To be estimated	To be estimated	To be estimated	To be estimated
Production	To be estimated	To be estimated	To be estimated	To be estimated
Time trend	To be estimated	To be estimated	To be estimated	To be estimated
Constant	To be estimated	To be estimated	To be estimated	To be estimated
R^2	To be estimated	—	—	—
Number of observations	N	—	—	—

The key coefficient in this model will be the estimated effect of yield risk on income instability. A positive and statistically significant coefficient would indicate that greater uncertainty surrounding pistachio production is associated with greater instability in farm income.

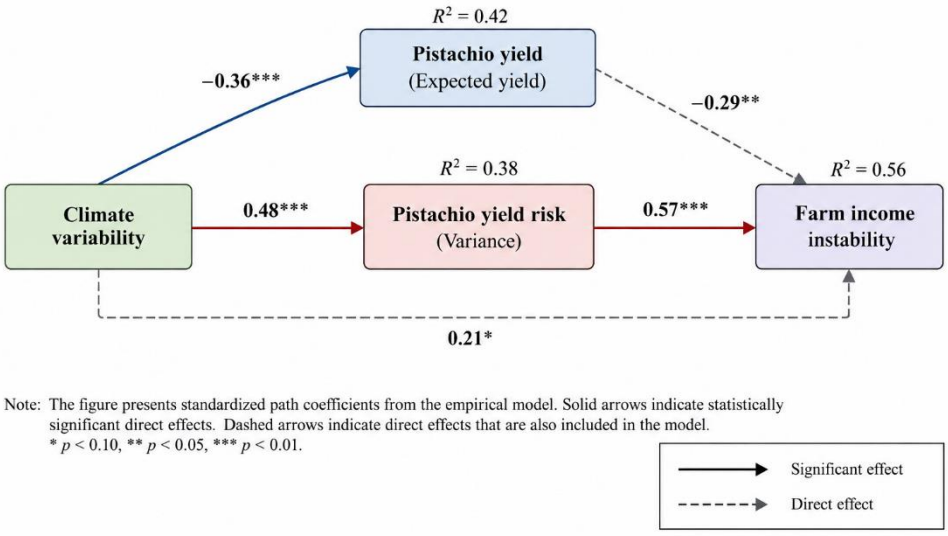

Figure 3. Transmission of Climate Variability Through Yield Risk to Farm Income Instability

The figure will present the estimated standardized effects of climate variability on expected yield, yield risk, and income instability. This multi-parameter representation will provide an integrated visualization of the principal transmission mechanism examined in the study.

5.7. Robustness Analysis

Several alternative specifications will be estimated to evaluate the stability of the main findings. These specifications will include alternative measures of climate variability, nonlinear climatic effects, lagged climatic variables, and alternative representations of income instability.

Table 6. Robustness of Estimated Climate-Risk Relationships

Specification	Climate Measure	Yield Effect	Risk Effect	Income-Stability Effect	Model Fit

Baseline model	Primary measure	To be estimated		To be estimated		To be estimated	To be estimated	
Alternative 1	Temperature variability	To be estimated		To be estimated		To be estimated	To be estimated	
Alternative 2	Precipitation variability	To be estimated		To be estimated		To be estimated	To be estimated	
Alternative 3	Nonlinear specification	To be estimated		To be estimated		To be estimated	To be estimated	
Alternative 4	Lagged climate variables	To be estimated		To be estimated		To be estimated	To be estimated	

The robustness analysis will be used to determine whether the principal conclusions remain stable when the measurement of climatic exposure and the econometric specification are modified. Consistency across alternative specifications would strengthen the empirical interpretation of the relationship between climate variability, pistachio yield risk, and farm income stability.

5.8. Integrated Interpretation of Results

The final interpretation will bring together the three principal empirical dimensions: expected pistachio yield, yield risk, and farm income stability. The analysis will distinguish between productivity effects and uncertainty effects rather than treating all climate-related production changes as a single outcome.

The central empirical test concerns whether the estimated yield-risk measure contributes significantly to explaining income instability. If the evidence supports this relationship, the results will indicate that the economic consequences of climate variability extend beyond reductions in average pistachio productivity. If the relationship is weak or statistically insignificant, the findings will instead suggest that income fluctuations are driven primarily by changes in expected production or other economic factors.

This distinction will provide the basis for the policy implications developed in the final sections of the article.

6- Discussion

The empirical framework developed in this study provides a basis for interpreting climate variability as an economic source of both pistachio production risk and farm income instability. The central analytical distinction is between changes in expected yield and changes in the uncertainty surrounding yield. This distinction is important because two production environments may exhibit similar average yields while exposing producers to substantially different levels of production risk.

The expected-yield component of the analysis is particularly relevant for understanding the sensitivity of pistachio production to temperature and precipitation conditions. Previous evidence for Iran indicates that climatic factors can significantly influence pistachio yield, confirming that weather conditions constitute an important component of the production environment [1]. However, the economic interpretation of this relationship depends on whether climatic fluctuations affect only the conditional mean of yield or also its variance. A climate variable that reduces expected yield but has little influence on production risk represents a different economic problem from a variable that substantially increases the probability of unfavorable production outcomes.

The distinction between these two mechanisms is consistent with the broader agricultural production-risk literature. Climate conditions can influence the distribution of agricultural outcomes rather than merely shifting their mean [3,4]. Temperature-related shocks may be particularly important because their effects can become nonlinear when climatic conditions move beyond the range normally experienced by producers [5]. For pistachio production, this issue is economically significant because extreme climatic conditions may interact with the biological characteristics of perennial orchards and produce consequences that cannot be adequately represented by a linear average-yield relationship.

The income dimension provides a further interpretation of production risk. Farm income depends on the quantity and value of agricultural output as well as the costs associated with maintaining production. Consequently, a climate-induced reduction in yield can affect income directly through lower output, while increased yield uncertainty can generate a second economic effect by making expected returns less predictable.

Evidence from farm-level research indicates that climate variability can affect income stability even when the analysis is not limited to physical crop production.[۷،۸]

The relationship between yield risk and income instability is particularly important for pistachio producers because perennial production systems involve investment decisions whose economic returns are realized over relatively long periods. When climatic conditions become more variable, producers may face greater uncertainty regarding the returns associated with irrigation, fertilization, pest management, and other production expenditures. This can affect the timing and intensity of input use and potentially reinforce differences between regions with different resource constraints.

The role of water resources adds another dimension to the interpretation of climate-related risk in Iranian pistachio production. Pistachio cultivation is strongly connected to groundwater availability in several major producing regions, and long-term groundwater depletion can create an economic trade-off between maintaining agricultural production and preserving the underlying resource base [2]. Climate variability can intensify this trade-off when periods of unfavorable precipitation coincide with high production requirements. Therefore, climate-related production risk should not be considered independently from the resource conditions under which pistachio orchards operate.

The possibility of heterogeneous regional effects is also economically relevant. The vulnerability of agricultural production to climate is not necessarily uniform because production environments differ in climatic exposure, water access, management practices, and technological conditions [3]. The same temperature or precipitation deviation may therefore generate different yield responses across regions. This provides a justification for incorporating regional heterogeneity into the empirical analysis rather than interpreting the national-level relationship as a homogeneous response.

The dynamic nature of climatic effects further complicates the relationship between weather and agricultural income. Evidence from recent agricultural research indicates that weather shocks may have effects that persist beyond the period in which the shock occurs [13]. For perennial crops, such persistence may be particularly important because physiological responses and management adjustments can influence subsequent production cycles. Consequently, an assessment based solely on contemporaneous weather conditions may underestimate the cumulative economic consequences of climatic variability.

The findings can also be interpreted in relation to the growing literature on climate-related risk-management instruments. When climatic conditions affect both expected production and production uncertainty, conventional productivity-oriented adaptation may not be sufficient. Weather-index insurance and other risk-management mechanisms depend on accurately identifying the relationship between weather conditions and production outcomes [4,11]. If the relationship between observed weather conditions and actual farm losses is highly heterogeneous, basis risk can limit the effectiveness of such instruments [11]. Understanding the empirical structure of pistachio yield risk is therefore relevant not only for production planning but also for the design of agricultural risk-management mechanisms.

The income-stability perspective is further supported by evidence showing that drought can influence several components of farm economic performance [14,15]. This suggests that the economic consequences of climate shocks should not be evaluated solely through changes in crop yield. In the case of pistachio production, a decline in yield may be accompanied by changes in production costs, resource requirements, and the profitability of orchard management. The interaction of these mechanisms determines the ultimate effect on farm income.

Extreme heat represents another potentially important source of economic exposure. Recent evidence from crop revenue analysis indicates that extreme heat events can generate significant revenue consequences even when the analysis is framed around crop production rather than total farm income [16]. This reinforces the importance of distinguishing between ordinary climatic variability and conditions that represent unusually severe exposure. For pistachio-producing regions, identifying the point at which temperature variability changes from a manageable production fluctuation into a significant source of economic risk is an important area for further empirical investigation.

The broader adaptation literature also indicates that agricultural households may respond to climate-related income risk through diversification and changes in economic activity [6]. Although the present study focuses specifically on pistachio production, the implications extend to the wider economic environment of pistachio-producing households. If income instability increases as climate variability intensifies, producers may have stronger incentives to diversify production, adjust resource allocation, or adopt risk-management instruments. The feasibility and effectiveness of these responses, however, depend on local economic conditions and the availability of alternative income opportunities.

Overall, the analytical contribution of this study lies in connecting three outcomes that are often examined separately: climatic exposure, production risk, and income stability. The economic importance of climate variability cannot be fully captured by estimating its effect on average pistachio yield alone. A more complete assessment requires consideration of whether climate changes the probability distribution of production and whether the resulting uncertainty is transmitted into farm income.

This interpretation has direct implications for agricultural policy. If climate variability primarily affects expected yield, adaptation policies should emphasize productivity-enhancing technologies and climate-responsive production practices. If climate variability also increases yield risk, however, policies should incorporate mechanisms aimed at reducing income volatility and improving producers' capacity to manage uncertainty. These mechanisms may include improved climatic information, risk-based agricultural insurance, more efficient resource allocation, and region-specific adaptation strategies.

The economic implications are especially relevant in the context of groundwater constraints. Policies designed to preserve pistachio production without considering groundwater sustainability may reduce short-term income risk while increasing long-term resource risk. Conversely, restrictions on groundwater use without adequate mechanisms for supporting producer adaptation may impose substantial short-term economic costs. The interaction between climate risk, water availability, and farm income therefore requires integrated policy consideration rather than isolated interventions.

The evidence reviewed in this study suggests that future research should place greater emphasis on the joint distribution of production and income outcomes. Such an approach would allow researchers to identify not only whether climatic conditions affect pistachio production but also which climatic states generate the greatest economic losses. This would provide a stronger basis for targeting adaptation and risk-management interventions toward the periods and regions in which they are most economically valuable.

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