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Rising Temperatures, Falling Yields: The Effect of Climate Shocks on Olive Oil Production in Palestine

by

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ABSTRACT

This study investigates the effect of climate shocks on olive oil production in Palestine, a region acutely vulnerable to both environmental change and political instability. We estimate the influences of temperature and rainfall fluctuations on four key outcomes: the olive-to-oil yield ratio, extracted oil quantity, cultivated olive volume, and olive oil prices. Our findings reveal that higher maximum temperatures significantly reduce both olive yields and oil output, while an increase in minimum temperatures exerts a positive effect. Increased rainfall enhances oil yield and production but simultaneously depresses prices through supply expansion. Results are robust to fixed-effect specifications and non-linear models, and show strong regional heterogeneity. Southern districts are particularly sensitive to rainfall variability and high temperatures. These findings highlight the economic risks of climate shocks to Palestinian olive oil producers and demonstrate the urgent need for adaptive strategies that are regionally tailored and climate resilient.

KEYWORDS: Climate Change and Economic Policy, Olive Oil, Agricultural Shocks, Palestine

JEL CODES: Q54, Q12, O13, N55

1. INTRODUCTION

Climate change poses a challenge to agricultural systems worldwide, with particularly acute impacts in regions dependent on climate-sensitive crops. Olive oil production, a fundament of Mediterranean agriculture, has been identified as particularly vulnerable (Fraga et al. 2020). The Mediterranean basin, responsible for over 90 percent of global olive oil production, is experiencing shifts in climate that threaten the productivity, quality, and long-term viability of olive cultivation (Ozdemir 2016; Fraga et al. 2020a). Rising temperatures, altered precipitation patterns, and increased water scarcity have disrupted traditional growing conditions, placing immense pressure on olive oil producers to adapt. These climatic changes are especially consequential for Palestine, where olive oil is a vital economic and cultural commodity.

The link between climate change and olive production has been extensively documented in other Mediterranean countries, offering valuable context for this research. For instance, studies in southern Spain and Lebanon highlight the adverse effects of rising temperatures and water scarcity, which have decreased the suitability of these regions for olive cultivation (Arenas-Castro et al. 2020; Kaniewski et al. 2023). In Italy, increased aridity during summer has been shown to reduce olive yields, with higher temperatures negatively and precipitation positively correlated with productivity (Orlandi et al. 2020). Research has also identified an optimal annual average temperature of 16.9 ± 0.3°C for olive flowering, with projections suggesting that some Mediterranean regions, including Lebanon, may exceed this threshold by the latter half of the twenty-first century (Kaniewski et al. 2023).

Indeed, temperature and rainfall, two critical climatic variables, profoundly influence olive oil production. Elevated temperatures during fruit development reduce fruit weight and oil concentration, though the magnitude of these effects can vary by cultivar (Nissim et al. 2020). In addition, seasonal climatic variations impact the chemical composition of olive oil, including its acidity, fatty acid profile, and antioxidant content (Bedbabis et al. 2015). Rainfall patterns also play an important role, with higher rainfall during key months such as August and December associated with increased yields (Rodrigo-Comino et al. 2021). Conversely, water shortages and higher temperatures accelerate fruit ripening, potentially compromising oil quality (Sevim et al.

2022). These dynamics illustrate the delicate balance required to maintain both the quantity and quality of olive oil production under changing climatic conditions.

The broader impacts of climate change extend beyond yields to include the timing of key phenological stages. Shifts in flowering and accelerated fruit ripening due to rising temperatures have led to earlier harvests, often at lower maturity levels, which can adversely affect both fruit yield and oil quality (Sevim, Varol, and Köseoğlu 2022; Orlandi et al. 2014). Furthermore, higher temperatures during processing, particularly during malaxation, have been shown to influence the chemical properties of olive oil. While moderate temperature increases (20°C to 27°C) during malaxation can enhance yield and quality, excessive temperatures can lead to undesirable changes in flavor and composition, including the development of rancid compounds (Guerrini et al. 2019; Kalua et al. 2006).

Palestine, as part of the Mediterranean basin, faces many of the same challenges documented in neighboring regions, but its unique socio-political and environmental context necessitates localized research. The agricultural sector in Palestine—already constrained by limited water resources and geopolitical challenges—is further strained by the pressures of climate change. Understanding how these climatic shifts affect olive oil production provides critical insights into the resilience of this essential industry. Moreover, the identification of temperature- and drought-resistant olive cultivars, alongside adaptive agricultural practices, emerges as a key priority for ensuring the sustainability of olive oil production in the face of ongoing climate challenges (Ben-Ari et al. 2021; Sevim, Varol, and Köseoğlu 2022).

According to the 2021 Agricultural Census, the cultivated land area in the West Bank and Gaza Strip was distributed as follows: tree horticulture constituted 61.7 percent, field crops made up 19.8 percent, and vegetables accounted for 18.5 percent of total cultivated land. Tree horticulture had the largest share, with olive trees constituting 85 percent of that share, highlighting their crucial importance in the agricultural landscape. Regionally, the Jenin Governorate held the largest share of the total cultivated area, at approximately 25.6 percent (PCBS 2021).

The olive sector is a vital component of the Palestinian agricultural economy, representing over 45 percent of the total cultivated area. It directly supports the livelihoods of approximately 100,000 households.[1] Its economic importance arises from its dual role as a key driver of social and economic development in Palestine, as well as being a staple food source for the population. Additionally, olives are essential for the agro-processing industry, especially in the production of olive oil and other value-added products (MOA 2019). Beyond its economic significance, the olive tree also holds symbolic meaning, representing Palestinian resilience and a connection to the land. It is closely tied to the ongoing political struggle and resistance against Israeli occupation policies.

The olive sector in Palestine faces several structural and productivity-related challenges that hinder its potential contribution to agricultural GDP and rural livelihoods. One primary issue is the low productivity per olive tree, largely due to reduced farmer engagement, the prevalence of pests and diseases, and the aging of olive orchards. Additionally, the sector suffers from significant land fragmentation, resulting in economically inefficient farm sizes. Data from the agricultural census indicate that nearly 56 percent of olive landholdings are smaller than 5 dunams (equivalent to 0.5 hectares), which limits economies of scale and discourages investment in mechanization, irrigation, and modern agronomic practices. This fragmentation is a consequence of both historical inheritance patterns and limited access to consolidated land development initiatives (MOA 2019).

All of these difficulties are compounded by two major challenges facing Palestinian farmers: settler violence and Israeli policies that restrict their access to land, along with the impacts of climate change. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), more than 52,300 trees have been destroyed since October 7, 2023, which accounts for around 4 percent of the region's olive trees. Farmers have also encountered additional obstacles due to Israeli military-imposed roadblocks, curfews, and permit restrictions, especially on lands near settlements. In 2023, access to 110,000 dunams of land was denied, and

[1] In good years, the olive sector is worth between €150 million and €190 million, according to estimates from the Palestinian Trade Center (Lorusso 2022).

in 2024, access to another 35,000 dunams was restricted. These restrictions led to a loss of approximately 1,365 tons of olive oil, valued at around $8.5 million (Fitt 2025).

This study examines how climate shocks have impacted olive oil production in Palestine using district-level data spanning 2005 to 2018, alongside climate data from the Palestinian Meteorological Department. It contributes to the growing body of literature by examining the relationship between climate shocks (particularly temperature and rainfall trends) and olive oil production. Our identification strategy, which assumes that these climate shocks are exogenous, offers a framework for establishing causality and provides a valuable contribution compared to more descriptive approaches. Our analysis quantifies the effect of climatic variables on production and offers evidence-based recommendations for adaptation strategies tailored to Palestinian agriculture. Furthermore, this study complements recent qualitative research such as Qassis (2024), which explores olive production in the context of occupation, and builds on prior work by Kashiwagi (2017) who assessed land and labor efficiency in oil production. Kashiwagi's additional research on organic farming and its effects on agricultural outputs, including olives, also provides an important context for understanding production dynamics in Palestine (Kashiwagi & Kamiyama, 2023).

The structure of the paper is as follows. After the introduction, we present the data and the sources of the data used in our study, followed by the estimation model in Section 3. The main results, heterogeneity analyses, and additional results are presented in Section 4. Section 5 concludes the study.

2. DATA

This research utilizes data from the Palestine Olive Press Survey, spanning the period from 2005 to 2018, and compiled by the Palestinian Central Bureau of Statistics (PCBS). Data on climate variability was sourced from the Palestinian Meteorological Department. The study is based on a panel dataset consisting of 2,627 press-year–level observations. The primary outcome variables include several natural logarithms: the olive-to-oil extraction ratio, the quantity of oil extracted (in kilograms), the amount of cultivated olives (in kilograms), and the oil price per kilogram (in local currency-New Israeli Shekels). Applying logarithmic transformations helps to correct for skewed distributions and allows for elasticity interpretation in the regression analysis.

Summary statistics for these variables are shown in Table 1.

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Ratio (Olives to oil)	2627	.243	.034	.019	.448
Log Ratio	2627	-1.428	.163	-3.964	-.804
Quantity of extracted oil (Kg)	2627	60991.499	49507.091	30	245550
Log (Quantity of extracted oil)	2627	10.634	1.002	3.401	12.411
Quantity of cultivated olives (Kg)	2627	254506.16	208448.18	500	1143165
Log (Quantity of cultivated olives)	2627	12.062	.994	6.215	13.949
Oil price per Kg (NIS)	2627	24.504	5.162	14	43
Log (Oil price per Kg)	2627	3.178	.203	2.639	3.761
Total Annual Rainfall (mm)	2627	516.638	177.99	99.8	1012.8
Total Annual Rainfall (std)	2627	.355	.786	-1.485	2.544
Average maximum temperature (c)	2627	24.002	2.056	18.622	28
Average maximum temperature (std)	2627	-.468	.618	-2.084	.733
Average minimum temperature (c)	2627	14.998	1.518	10.551	19.262
Average minimum temperature (std)	2627	-.278	.979	-3.146	2.472
Press type (1 = Traditional)	2627	.667	.471	0	1
Zebar Waste disposal (1 = Cesspool)	2627	.339	.474	0	1
Water Waste disposal (1 = Cesspool)	2627	.384	.487	0	1
Olive Cake disposal (1 = Owner)	2627	.952	.215	0	1

Calculated by authors based on Palestine Olive Press Survey (2005-18) obtained from PCBS and Palestinian Metrological Department data.

The standard deviations for both extracted oil and cultivated olives are approximately 0.99, reflecting substantial variability both across presses and over time. The average logged oil price per kilogram is 3.1, indicating relative price stability in nominal terms. This dataset structure enables an investigation into the effect of climate variability on agricultural productivity and economic outcomes within the olive oil sector, contributing to the broader literature on the economic effects of climate shocks in vulnerable settings.

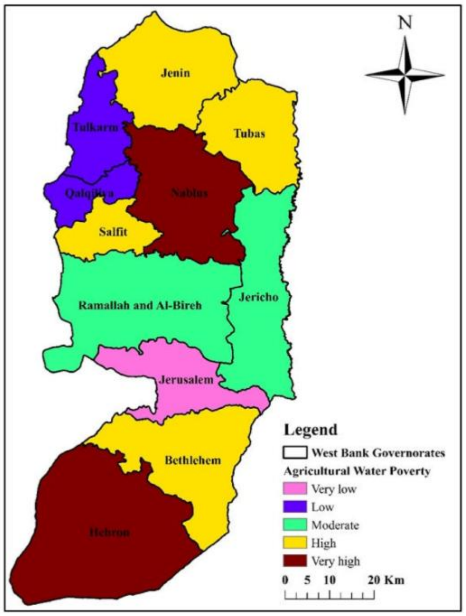
Figure A1 in the appendix offers region-specific overviews of interannual rainfall and temperature variations[2] throughout the study period for the northern, central, and southern districts, respectively. This three-way regional division was chosen to reflect key differences in climate gradients, irrigation dependence, and agricultural practices across the West Bank.[3] In the northern districts, a Mediterranean climate brings relatively high and variable rainfall (up to around 800 mm per year) and milder temperatures, supporting predominantly rain-fed agriculture such as olives, grapes, and grains (Shadeed et al. 2020; UNCTAD 1995). The northern and central regions of the West Bank receive higher rainfall compared with the south, as weather depressions primarily affect the northern and northwestern areas (PCBS 2024).

On the other hand, Figure 1 illustrates the Agricultural Water Poverty (AWP) levels across the West Bank. The data reveals that six out of the 11 districts experience high to very high AWP, including Hebron, Bethlehem, Salfit, Nablus, Tubas, and Jenin. In contrast, Qalqilya and Tulkarm fall under low AWP, while Jerusalem has the lowest AWP among all governorates (Shadeed et al. 2020).

[2] Figures A2, A3, and A4 in the appendix show the histograms for total annual rainfall and average maximum and minimum temperatures in Palestine (2005–18)

[3] The West Bank (occupied Palestine) is an arid to semi-arid region in the Middle East, covering approximately 5,860 km². With a population of nearly 2.9 million, it is divided into 11 districts (Shadeed et al. 2020).

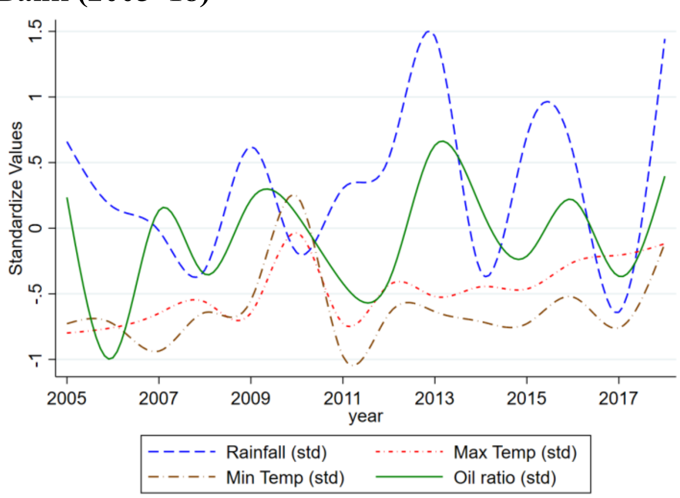
Figure 1: Agricultural Water Poverty Map in the West Bank



Source: (Shadeed et al. 2020)

Figure 2 shows the standardized trends of key climate variables alongside the standardized olive-to-oil production ratio in the West Bank. The graph reveals clear interannual variability in all indicators, with rainfall showing particularly sharp fluctuations that often coincide with peaks and troughs in the oil ratio. Maximum and minimum temperatures display more gradual trends, but their sustained elevation during certain years corresponds with periods of declining oil productivity.

Figure 2: The Association Between Climate Indicators and Olive-to-Oil Ratio in the West Bank (2005–18)



Source: Authors, based on Palestine Olive Press Survey and Palestinian Metrological Department data (2005–18)

3. ESTIMATION MODEL

In this paper, we analyze four key outcome variables: the ratio of olives to oil, the quantity of extracted oil (kg), the amount of cultivated olives (kg), and the price of olive oil per kilogram (in local currency, New Israeli Shekel). These outcomes are measured across 11 districts in the West Bank over a 13-year period. The main econometric specification is as follows:

$$Ln\,Y_{ijt} = \alpha_0 + \beta_1 Rain_{jt} + \beta_2 Max.Temp_{jt} + \beta_3 Min.Temp_{jt} + \gamma X_{ijt} + \omega_j + \lambda_t + \epsilon_{ijt} \quad (1)$$

where Y_{ijt} represents each of the four olive production outcomes and the price per kilogram of olive oil at press *i*, located in district *j*, and observed in year *t*. For the purposes of our analysis, we apply the natural logarithm transformation to each outcome variable.[4]

The coefficients β_1, β_2, and β_3 represent the coefficients of our variables of interest: the annual variation in precipitation and the average maximum and minimum temperatures across districts during the study period. Before estimation, we standardize all climate variables; both rainfall and temperature. This transformation puts all climate indicators on the same scale, allowing for direct comparison of the effects of temperature and precipitation shocks. Without standardization, interpreting the results would be problematic due to differences in unit, as rainfall is measured in millimeters while temperature is measured in degrees Celsius. Standardization also addresses this issue and improves the numerical stability of the estimation. Furthermore, the coefficients on the standardized variables represent the effect of a one-standard-deviation change in climate conditions, providing an informative metric for policymakers regarding how olive output responds to unusually hot or rainy years in relation to historical averages. Another advantage of the model is that it utilizes multiple climate indicators together (Marchetta et al. 2019). Our methodology aligns with established practices in empirical climate research (Hansen et al. 2012;

[4] The motivation for using the natural logarithm of outcome variables instead of their absolute values is that it allows for a simpler interpretation of regression coefficients as semi-elasticities or elasticities. This type of interpretation is particularly beneficial in agricultural and environmental economics, where understanding relative changes is often more important than absolute changes (Wooldridge 2013; Hsiang 2010). Further, the log transformation is frequently used to overcome problems like skewed distributions and heteroskedasticity (Gujarati and Porter 2009). Finally, it is used to allow for better comparability across diverse units, such as olive presses or districts, making the results more generalizable and relevant to policy (Baltagi 2008).

Zarch et al. 2015; Hallaq & Daas 2024), facilitating comparisons across studies and enhancing the interpretability of our results within the broader literature.

The term X_{ijt} captures press-specific characteristics, specifically whether the press is traditional or non-traditional. Traditional presses are labor-intensive, relying on manual or hydraulic methods. They typically produce lower yields and variable oil quality, often resulting in higher acidity and limited hygiene standards. In contrast, non-traditional olive presses produce a better quality and quantity of oil, require less labor, and demonstrate improved environmental management (Qassis 2024). We also include district-fixed effects, ω_j, to account for time-invariant disparities within districts, along with year-fixed effects, λ_t , to address annual shocks that affect all districts.[5] The robust error term is represented by ϵ_{ijt}.

In another estimation, equation (2), we consider the press-fixed effect model (δ_j) where we capture each time-invariant unobserved heterogeneity at the olive-press level, such as efficiency, management style, and cost of operation.

$$Ln\, Y_{ijt} \;=\; \alpha_0 + \beta_1 Rain_{jt} + \beta_2 Max.Temp_{jt} + \beta_3 Min.Temp_{jt} + \delta_j + \;\lambda_t + \epsilon_{ijt} \quad (2)$$

This model leverages the panel structure of the data to control for time-invariant, press-specific characteristics that may confound the relationship between climate and productivity outcomes. Consistent with established literature, we assume that annual variation in climate across Palestinian districts is exogenous and plausibly satisfies the conditions for identifying causal effects. This approach is supported by studies that treat year-to-year weather fluctuations as quasi-random shocks, allowing for credible estimation of climate impacts on economic outcomes (Hsiang 2016; Zhang, Zhang, and Chen 2017; Auffhammer et al. 2013; Gallé and Katzenberger 2025). However, the model could still be affected by omitted variable bias. For instance, some

[5] Between 2010 and 2017, the Palestinian olive sector experienced an exceptional period of sustained high productivity, during which the typical phenomenon of alternate bearing disappeared. This productivity boom is attributed to a wave of targeted government and donor interventions initiated in 2005, which included investments in farmer training, mechanization, pest management, land reclamation, and modern storage infrastructure. The effects of this support became visible by 2010 and persisted until the withdrawal of assistance in 2017, after which traditional yield fluctuations resumed (WAFA 2024; Lorusso 2022)

farmers may receive more agricultural subsidies to cope with weather shocks or may benefit from agricultural insurance, which could impact their olive prices. Others may have access to better training to improve their cultivation practices. Additionally, access to water resources can vary among farmers, as can access to their land during the olive harvesting season due to the threats of Israeli army actions or violence from Israeli settlers against Palestinian farmers (Nazzal 2019; Daas 2025). Moreover, changes in local infrastructure or labor availability could also be potential confounders correlated with the outcomes. As we indicated, we employed year, district, and olive-press–fixed effects to mitigate the potential risks associated with these factors.

Another concern in the identification process is related to the three main output indicators: the ratio of olives to oil, the amount of oil extracted, and the cultivated olive area. These indicators were derived from the olive press data and merged with the weather shock data for each district. However, a potential issue arises when farmers cultivate their olives in one district and send them to an olive press in a different district, which could reduce the reliability of the analysis as the weather conditions in the district where the olives were pressed may not accurately reflect the conditions under which they were grown. Regardless, the likelihood of this occurring is considered low due to the presence of several active olive presses in each district. Furthermore, the high restrictions on movement in the West Bank, particularly regarding olive cultivation, significantly diminish the threat this assumption poses to our identification strategy. Concerning the fourth outcome, the price of olives, various factors must be considered that may influence olive prices, in addition to the climate shock (our primary variable of interest). To mitigate the impact of omitted-variable bias, we incorporate the press-fixed effect which accounts for the production costs associated with each press, and is also an indicator of the olives produced at each press to further diminish the potential for omitted-variable bias.

4. RESULTS AND DISCUSSION

4.1 Main Results

Table 2 estimates the impact of climate variables on four outcomes: the log of the olive-to-oil ratio (oil yield percentage), log extracted oil quantity, log cultivated olive quantity, and log oil price. Two model specifications are shown. Panel A uses press-fixed effects (thus exploiting within-press variation over time) without additional press-level controls, while Panel B includes press characteristics without fixed effects.

Across both specifications, rainfall has a positive effect on oil yields. In Panel A (col.1–4), a single SD increase in annual precipitation raises the log yield ratio by 0.022. The effect on log olives cultivated is positive but not statistically significant. These results indicate that years with more rainfall allow presses to convert olives into more oil (a higher oil percentage), consistent with the broader literature on olive irrigation. For example, Rodrigo-Comino et al. (2021) found that Spanish olives benefit greatly from rainfall in late summer and autumn, boosting yields markedly. Similarly, Orlandi et al. (2020) reported a positive correlation between precipitation and olive production in Italy.

Therefore, our findings are consistent with previous research: higher rainfall substantially increases olive productivity. Panel B shows a nearly identical positive effect of rainfall on the yield ratio when controlling for press characteristics. In economic terms, increased rain (by raising supply) tends to reduce price; we find a significant negative effect on the log price in both panels (−0.011** in Panel A and −0.012** in Panel B). This is the expected supply response: in wetter years, olives produce more oil and thus moderate prices, akin to commodity-market logic.

Maximum daily temperature has a negative impact on oil production quantities. In Panel B, a 1 SD increase in average annual maximum temperature is associated with a 0.308-unit drop in extracted oil and a 0.337-unit drop in cultivated olives. These are large elasticities; for example, a 1°C warmer year would reduce oil output by roughly 33 percent. This negative sign is not robust across models; Panel A (when controlling for press fixed effect) does not yield similar results. These findings in Panel B, however, mirror prior experimental and field studies, showing that high heat stress reduces olive fruit growth and oil content. Nissim et al. (2020) demonstrated that exposing olive trees to high summer temperatures significantly lowers fruit weight and oil concentration. Likewise, Orlandi et al. (2020) reported that greater spring–summer temperatures depress total production. Our results extend these observations econometrically: hotter years see sharply lower harvests, likely due to accelerated fruit maturation, drought stress, and physiological limits on oil synthesis.

Table 2 The Impact of Climate Shocks on Olive Oil Production and Prices

VARIABLES	(1) Log (Ratio Olives to oil)	(2) Log (Extracted Oil)	(3) Log (cultivated Olives)	(4) Log (Oil Price)
	Panel A (with press FE, No Press Characteristics, No district FE)			
Total amount of rainfall (STD)	0.022***	0.049	0.026	-0.011**
	(0.008)	(0.049)	(0.048)	(0.005)
Average maximum temperature (Std)	0.003	-0.099	-0.101	-0.026**
	(0.017)	(0.097)	(0.098)	(0.012)
Average minimum temperature (Std)	-0.001	0.138**	0.138**	0.007
	(0.009)	(0.056)	(0.056)	(0.006)
R-squared	0.438	0.566	0.579	0.883
	Panel B (with Press Characteristics with District FE, No press FE)			
Total amount of rainfall (STD)	0.020***	0.064	0.044	-0.012**
	(0.006)	(0.046)	(0.044)	(0.005)
Average maximum temperature (Std)	0.029**	-0.308***	-0.337***	-0.001
	(0.015)	(0.100)	(0.099)	(0.011)
Average minimum temperature (Std)	-0.019**	0.260***	0.279***	-0.004
	(0.009)	(0.059)	(0.059)	(0.006)
R-squared	0.249	0.233	0.253	0.839
Observations	2,627	2,627	2,627	2,627
Years Fixed Effects	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

By contrast, higher minimum temperatures have a positive effect on production. In Panel A, 1 SD increase in average annual minimum temperature raises log oil and olives output by 0.13 points. Thus, milder nights boost production. This could reflect that moderate temperatures during key developmental periods lengthen the growing season and improve fruit filling (Rallo et al. 1993). For instance, higher minimums can maintain metabolic activity overnight, leading to better yields. In Panel B, a 1 SD rise in minimum temp similarly increases log oil (0.26), log olives (0.28), though intriguingly it slightly reduces the log oil-to-olive ratio by 0.019. Our results thus show that rainfall and temperature exert opposite influences on olive production, consistent with the dual climate dynamics typical in Mediterranean horticulture. Rainfall is uniformly beneficial (up to a point), whereas extreme daytime heat is harmful. These findings align with previous studies. For example, Orlandi et al. (2020) found negative correlations of temperature and positive correlations of precipitation with productivity in Italy, and Kaniewski et al. (2023) warned that warming beyond optimal thresholds reduces flowering and yields in the Levant. The significant negative temperature therefore confirms that Palestinian olive producers are already experiencing these stress effects. The price results are also plausible, as output falls in hotter or drier years, prices adjust; rising when production is squeezed and vice versa. In Panel A, the price elasticity is significant for rainfall (−0.011) and for high temperature (- 0.026), whereas in Panel B it is imprecise for most variables (except for rainfall); this may reflect complex market factors beyond our model. Nevertheless, in both models, higher rainfall lowers price (since it boosts supply) and higher maximum temperature tends to raise price (via the supply drop). The two-panel comparison in Table 2 highlights model robustness to some extent. The press-fixed effects version (Panel A) likely captures unobserved heterogeneity (e.g., press efficiency) and emphasizes within-press temporal changes. Panel B, by including press characteristics instead of press FE, provides similar results, indicating that omitted press factors are not driving the climate coefficients entirely. The slightly larger magnitude of the temperature coefficients in Panel B suggests that some (perhaps more efficient) press types experienced greater relative gains from cooler conditions. In any case, the consistency of sign and significance across panels strengthens confidence in these climate impacts. The results provide that yearly climate shocks have economically meaningful effects on both production and price, reinforcing the vulnerability of Palestinian olive oil to interannual weather variability. We now turn to whether these effects differ by region.

4.2 **Heterogeneity Analysis**

Table 3 explores whether the effects in Table 2 vary across Palestine’s northern, central, and southern districts. Columns 1–6 report separate regressions for each region’s log ratio and log oil price, using a model analogous to Panel A of Table 2 (fixed effects, no press controls).

Several patterns emerge. First, rainfall matters most in the south compared with the other regions. In the southern governorates (cols. 1–2), annual rainfall has a strong positive impact on the oil yield ratio, 0.18. In the northern and central (cols. 3–6) districts, the effect of rain on the ratio is much smaller (0.014 in the north and insignificant in central). This is plausible: southern areas are much drier on average (see Figure 3 in the data section), so an extra millimeter of rain there can improve tree water status and fruit development. In contrast, northern districts often already have adequate precipitation, so marginal rain has a weaker effect on oil concentration. This aligns with the finding in Rodrigo-Comino et al. (2021) that productivity is sensitive to rainfall deficits in arid zones. The significant rainfall coefficient in the north on price (−0.012) reflects that even modest rain increases slightly depress prices through higher yield.

Table 3 Heterogeneity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	South Govts		North Govts		Central Govts	
VARIABLES	Log (Ratio Olives to oil)	Log (Oil Price)	Log (Ratio Olives to oil)	Log (Oil Price)	Log (Ratio Olives to oil)	Log (Oil Price)
Total amount of rainfall (STD)	0.181***	-0.032	0.014**	-0.012**	-0.089	-0.029
	(0.029)	(0.024)	(0.007)	(0.005)	(0.079)	(0.027)
Average maximum temperature (Std)	-0.233	0.519***	0.005	-0.018**	0.026	0.141**
	(0.196)	(0.156)	(0.014)	(0.009)	(0.124)	(0.071)
Average minimum temperature (Std)	-0.201***	0.537***	-0.009	0.005	-0.071	-0.076*
	(0.069)	(0.039)	(0.007)	(0.005)	(0.078)	(0.039)
Observations	195	195	1,965	1,965	467	467
R-squared	0.481	0.891	0.401	0.901	0.427	0.835
Olive Press Fixed Effects	YES	YES	YES	YES	YES	YES
District Fixed Effects	NO	NO	NO	NO	NO	NO
Years Fixed Effects	YES	YES	YES	YES	YES	YES
Press Characteristics	NO	NO	NO	NO	NO	NO

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Second, temperature effects vary by region. Maximum temperature has a significantly negative effect on production in the northern and central districts (implied by results in Table 2 on output, and by positive price effects here). In the northern districts (cols. 3–4), higher maximum temperature does not significantly change the oil ratio but does cause a small decrease in oil price (−0.018). In the central districts (cols. 5–6), maximum temperature positively affects price

(0.14), again consistent with lower supply from heat. In the south (cols. 1–2), interestingly, maximum temperature has no significant effect on the ratio but has a positive effect on price (0.51). In plain terms, hotter years modestly reduce efficiency in the south and raise prices substantially. This may reflect that the south is already hot, and thus further warming there sharply cuts into yield, leading to spikes in price.

Minimum temperature exerts strong effects on southern output but does not have the same effect in the northern or central regions. In southern districts, a 1 SD increase in average minimum temperature reduces the oil ratio by 0.2 (col. 1) but raises prices by 0.53 (col. 2). This result suggests that warmer nights lower oil yield. A possible explanation is that unusually mild winters in the south may disrupt normal chilling requirements for olive flowering, leading to poor fruit set but with fewer surviving fruits containing relatively less oil; hence creating a lower ratio and much less total oil (driving prices up). In the northern (cols. 3-4) and central (cols. 5–6) regions, minimum temperature has no significant effect on the ratio or price. Northern olives may be less sensitive to winter warmth because they typically receive enough chilling anyway, whereas central districts show only a small negative price effect (–0.076, col. 6) for warmer nights, perhaps reflecting slightly decreased quality or quantity.

These regional contrasts echo broader patterns reported in the literature. The Mediterranean basin exhibits substantial heterogeneity in climate impact; some locales suffer more under warming than others (Ponti et al. 2014; Kaniewski et al. 2023). Kaniewski et al. (2023) specifically project that southern Levantine olive groves will become too hot for optimal flowering and fruiting in coming decades, a warning presaged by our finding that the southern governorates' oil production is highly sensitive (and negatively so) to high temperatures. Similarly, Orlandi et al. (2020) found that cooler, wetter Italian sites showed smaller yield declines than hotter, drier ones—consistent with our smaller coefficients in the wetter north. Moreover, the rain dependency in the south is reminiscent the observation of Rodrigo-Comino et al. (2021) that Andalusian olive output peaks in years with rain in summer and autumn.

Our results imply that price response to climate shocks also differs regionally. For instance, higher maximum temperatures in the south yield a very large price increase (0.519), indicating drastic supply shortfalls, whereas in the north, maximum temperature actually lowers prices slightly (–0.018), perhaps because relatively minor heat changes might improve oil quality or trigger market dynamics differently. These nuanced differences suggest that climate adaptation may require region-specific strategies. Southern farmers might prioritize drought-resistant practices and cultivar selection to mitigate rain variability, while northern producers might focus on heat stress resilience even though they have more rain.

Thus, the heterogeneity analysis confirms that climate shocks do not affect all olive-growing areas of Palestine equally. The same 1°C warming or 10 millimeter rainfall deficit has much larger effects in the south than in the north. This shows the importance of local context; northern regions already near the ideal climate are buffered, while marginal southern regions face outsized impacts. It also suggests that aggregated national effects may understate the plight of the most vulnerable areas. These results are consistent with Mediterranean-wide studies highlighting "winners and losers" under climate change (Ponti et al. 2014).

4.3 Additional Results

Although these results are robust across various specifications, further investigation is needed to confirm their stability and assess potential nonlinearities. Such analysis will help validate the climate-yield relationship. Thus, below we examine robustness and nonlinearities to strengthen our findings.

Table 4 allows for nonlinear (quadratic) relationships between climate variables and our outcomes. It includes both linear and squared terms for annual rainfall, maximum temperature, and minimum temperature, so one can observe diminishing or reversing effects at extreme values.

Table 4 Non-Linearity Effects of Climate Variability on Olive Oil Production

	(1)	(2)	(3)	(4)
VARIABLES	Log (Ratio Olives to oil)	Log (Extracted Oil)	Log (cultivated Olives)	Log (Oil Price)
Total Annual Rainfall mm	0.001***	0.001	0.001	-0.001***

	(0.001)	(0.001)	(0.001)	(0.001)
Total Annual Rainfall Squared	-0.001***	-0.001	-0.001	0.001***
	(0.001)	(0.001)	(0.001)	(0.000)
Average maximum temperature C	0.077*	-1.116***	-1.193***	0.107***
	(0.039)	(0.203)	(0.198)	(0.023)
Average maximum temperature squared	-0.002*	0.024***	0.026***	-0.003***
	(0.001)	(0.004)	(0.004)	(0.000)
Average minimum temperature C	-0.042	-0.184	-0.142	-0.017
	(0.047)	(0.276)	(0.266)	(0.034)
Average minimum temperature squared	0.001	0.007	0.006	0.001
	(0.001)	(0.008)	(0.008)	(0.001)
Observations	2,627	2,627	2,627	2,627
R-squared	0.442	0.573	0.586	0.886
Olive Press Fixed Effects	YES	YES	YES	YES
District Fixed Effects	NO	NO	NO	NO
Years Fixed Effects	YES	YES	YES	YES
Press Characteristics	NO	NO	NO	NO

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The coefficients reveal diminishing returns and optimal ranges. Consider rainfall; the linear term (0.001) is positive for the olive-oil ratio, but the squared term is negative (−0.001). This means that additional rain raises oil yield up to a point, but excessive rainfall eventually yields less benefit (perhaps due to waterlogging or pest pressure). Olive oil yields are known to respond negatively to overly wet conditions as the relationship between rainfall and oil yield is non-linear (Rodrigo-Comino et al. 2021; Mafrica et al. 2021), so this concavity makes agronomic sense. Precipitation has a very small negative linear effect on price and a positive squared effect on price, indicating that moderate rain lowers price (via higher supply) but extremely heavy rain might actually raise price slightly.

For maximum temperature, the pattern is more pronounced. The linear coefficient on log oil and log olives is strongly negative (nearly –1.2) while the squared term is positive (0.02). This implies an inverted-U relationship: production falls as max temps increase, but the rate of decline slows at higher temperature. Conversely, the olive-oil ratio has a positive linear (0.077) and negative squared (–0.002) term, indicating a hump-shaped effect on ratio. Solving roughly, the oil ratio is maximized around 19.25°C (since[6] $f(T)=0.077T-0.002T^2$). Similarly, oil quantity peaks around 22.9°C. These “optimal temperature” values are informative as they suggest that summer maxima near the 20s degrees Celsius produce the most oil, in line with Mediterranean norms. Kaniewski et al. (2023) identified an optimal annual mean of ~16.9°C for flowering, which roughly corresponds to these maxima (assuming daily ranges). Beyond the peak, yields begin to drop. This quadratic result aligns with reality; very cool summers can under-develop fruit, while very hot summers scorch trees. In practice, olive trees thrive in moderate warmth but suffer at temperature extremes (Nissim et al. 2020). The significant squared coefficients confirm that the relationship between heat and yield is nonlinear. On the other hand, average minimum temperature shows a weaker nonlinear effect. None of the linear coefficients for minimum temperature are significant, so are the squared terms.

Our results thus indicate that there are thresholds in climate impact, and support the idea of an optimal climate window for olives; too little or too much of a variable can be suboptimal. The quadratic terms echo findings from other agroclimatic study (Ponti et al. 2014). For Palestine, these results imply that marginal changes in temperature or rainfall have non-constant effects on output. For instance, a small increase in summer maximum temperature from a cool baseline might even raise the oil ratio (as the linear term suggests), but beyond ~23°C, further heat diminishes yields. Similarly, rainfall boosts yields most when starting from a dry state (linear term), but very high precipitation yields less incremental gain. These insights caution that adaptation must consider nonlinearity; moderate warming might even be tolerable, but surpassing critical thresholds (especially in southern regions) will cause steep losses. The nonlinear model corroborates the earlier linear results but adds nuance, revealing optimal points and potential curvature. Crucially, it confirms that our earlier estimates are not just linear artifacts but reflect real response patterns documented in the literature. The existence of turning points is consistent with traditional olive agronomy, which identifies best temperature and moisture ranges for fruit set. In practice, it suggests policymakers should monitor for emerging extremes (e.g., heat waves and deluges), as these will drive the next shocks to production beyond what a simple linear model predicts.

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[6] The parabola equation is $Y=\beta_0+\beta_1X+\beta_2X^2$ to calculate the turning point or vertex of the parabola $X^* = -\beta_1/2\beta_2$

5. CONCLUSION

This paper presents empirical evidence that climate shocks, specifically changes in temperature and precipitation, significantly affect olive oil production and pricing in Palestine. Elevated maximum temperatures reduce both cultivated olive volumes and oil outputs, likely due to heat stress and accelerated fruit maturation, while increased minimum temperatures enhance productivity, possibly by promoting longer growing seasons. Rainfall, especially in arid southern districts, boosts yields but lowers prices due to increased supply, showing the delicate supply-demand dynamics in the olive oil market.

The regional heterogeneity in climate sensitivity emphasizes that a "one-size-fits-all" approach to adaptation is insufficient. Southern districts are more vulnerable to climate extremes and therefore require urgent interventions such as drought-resistant cultivars, improved irrigation infrastructure, and tailored extension services. Meanwhile, northern and central regions might benefit from early-warning systems and heat stress mitigation strategies. Moreover, the non-linear effects identified in our analysis caution against viewing moderate climate change as benign; crossing specific temperature or rainfall thresholds could lead to sharp declines in output.

The policy implications are clear. Climate adaptation in Palestinian agriculture must be localized, data-driven, and cognizant of climatic thresholds. Investment in climate-resilient agricultural technologies, better weather forecasting, and institutional support for small-scale farmers will be critical. Additionally, integrating these findings into national agricultural policy and climate risk assessments will be essential for safeguarding a vital economic and cultural sector in Palestine's rural economy.

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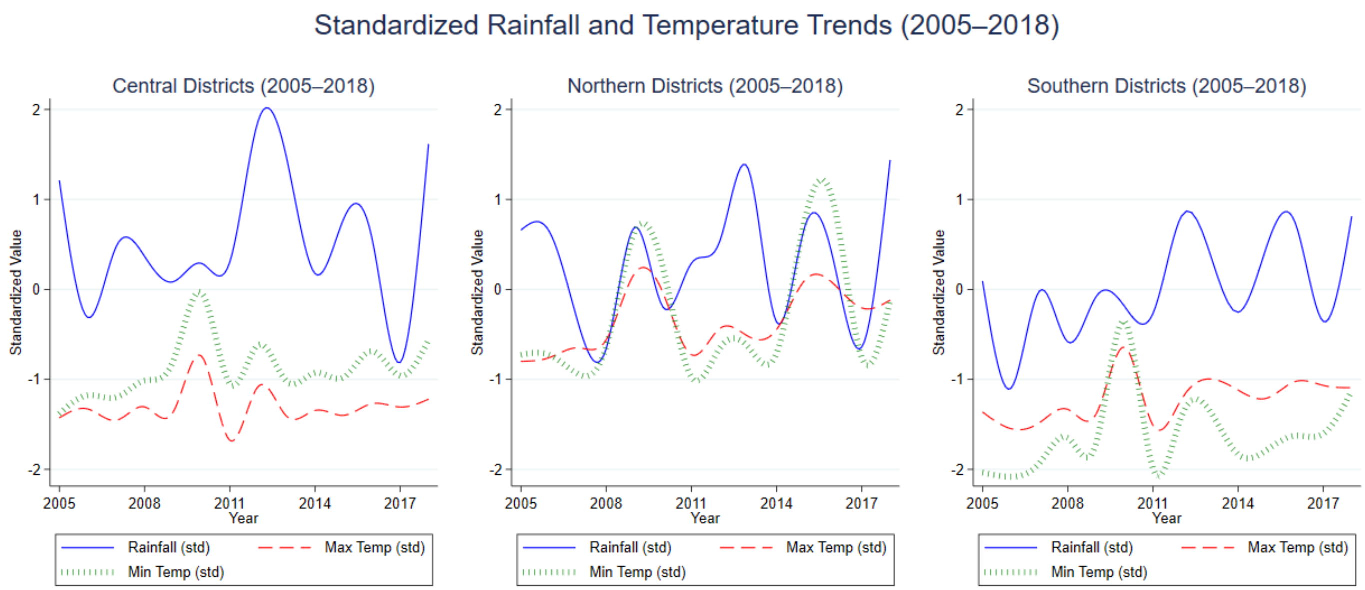
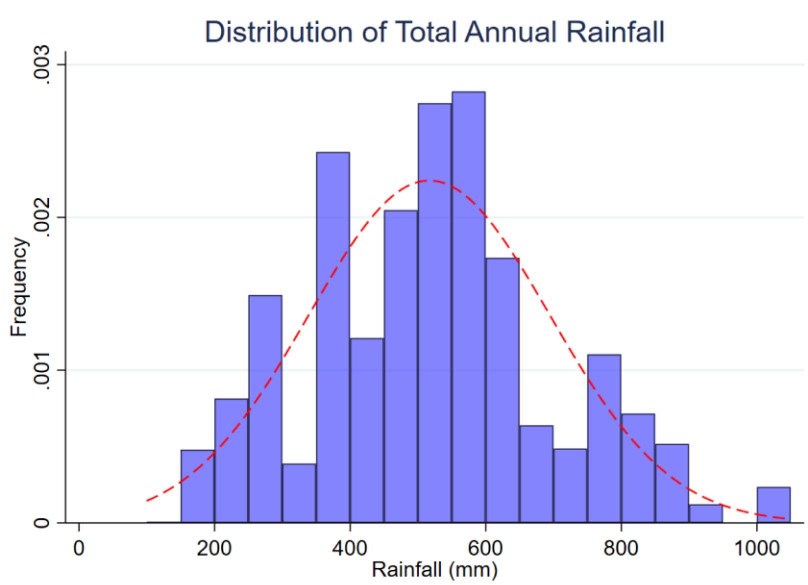
APPENDIX

Figure A1 Rainfall and Temperature Variability Across the West Bank



Source: Made by Authors based on Palestinian Metrological Department data (2005–18)

Figure A2: Distribution of Total Annual Rainfall.



Source: Made by Authors based on Palestine Metrological Department data (2005–18)

Figure A3: Distribution of Average Maximum Temperature

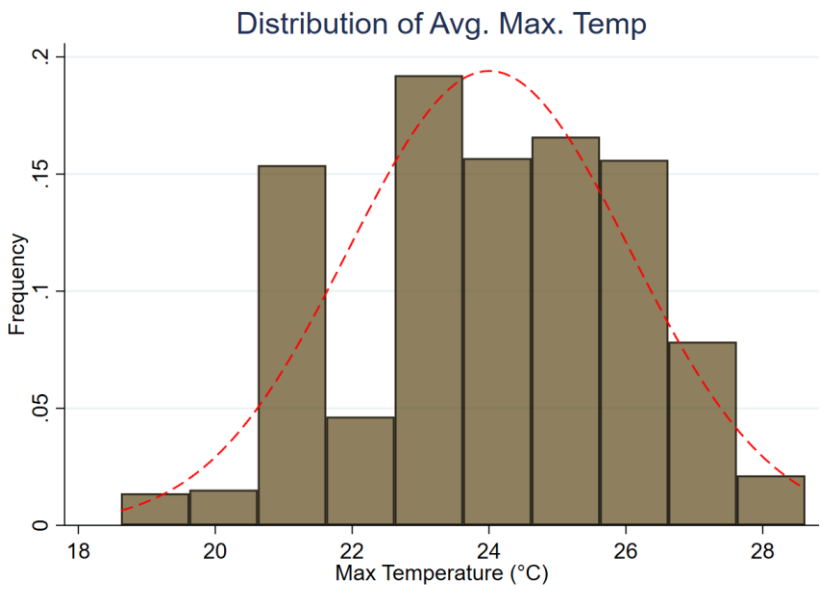


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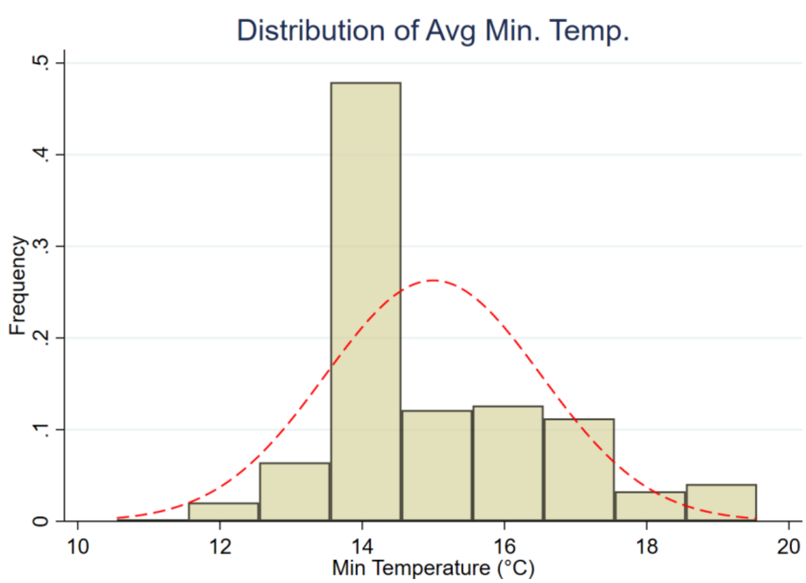
Figure A4: Distribution of Average Minimum Temperature.



Source: Made by Authors based on Palestine Metrological Department data (2005–18)