IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 1022-1037.

Nonlinear Effects of Climate Change on Economic Growth in the MENA Region: Does Government Effectiveness Matter?

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Received: 28 October 2025 **Accepted:** 26 January 2026 **DOI:** https://doi.org/10.32479/ijeep.22926

ABSTRACT

This study investigates the nonlinear effects of climate change, expressed by temperatures and precipitation patterns, on economic output in the Middle East and North Africa (MENA) region. Using fixed effect panel models for 16 countries over the period 1990-2023, the analysis estimates the temperatures and precipitation thresholds and examines how those thresholds vary across geographic and institutional conditions. The results reveal a robust inverted U-shaped relationship between temperatures and GDP per capita, indicating that moderate warming may initially support economic activity, while higher temperature levels generate adverse growth effects. In contrast, precipitation exerts weak and mostly linear effects on output. Temperature thresholds are found to be higher in North Africa and countries with stronger governance, highlighting the role of institutions in mitigating climate-related economic damages. Overall, the findings point to substantial heterogeneity in climate growth relationships across the MENA region and emphasize that institutional capacity is a key determinant of climate resilience. These results underline the need for climate adaptation strategies that are not only country-specific but also grounded in improvement in governance and public policy effectiveness.

Keywords: Climate Change, Economic Growth, MENA region, Nonlinear effects, Institutional Quality, Temperature threshold, Panel Data
JEL Classifications: Q54, O13, E32, F43, C33

1. INTRODUCTION

Contemporary research increasingly examines the interaction between climate change and economic performance. This growing interest is largely driven by the sustained increase in global temperatures since the start of the industrial revolution, estimated at 1.1°C, which has intensified climate variability through more frequent extreme events, uneven temperature rises, and heightened precipitation volatility (UNDP, 2023; IPCC, 2023). These climatic shifts have profound implications for economic activity, particularly in regions characterized by high exposure to climate risks and limited adaptive capacity.

A substantial body of empirical literature documents climate-related economic losses of varying magnitudes. More recent contributions emphasize that the relationship between climate change and economic growth is inherently nonlinear. Particularly, several studies report an inverted U-shaped relationship, whereby moderate temperature increases may temporarily support output through improvements in agricultural productivity and reduced heating demand, while higher temperature levels exert a detrimental effect on aggregate output (Lanzafame, 2016; Khaliq et al., 2025; Winter et al., 2025). This growing evidence challenges the validity of linear specifications, which impose constant marginal effects and fail to capture climate thresholds beyond which economic damage becomes persistent and severe. Beyond non-linearities, the economic impact of climate change is highly heterogeneous across countries and sectors, reflecting differences in geographical exposure, economic structure, and institutional capacity (Apergis and Rehman, 2025; Desbordes and Eberhardt, 2024). Simply relying on global linear models oversimplifies the complex interplay between climate change and economic growth, potentially producing inaccurate or even misleading results.

Within this context, the Middle East and North Africa (MENA) region constitutes a particularly relevant case of analysis. Owing to its predominantly arid geography, the region faces record-high temperatures and increasing water scarcity, making it one of the most climate-vulnerable regions worldwide (World Bank, 2022). Extreme temperatures in some of the region's areas are projected to reach alarming levels (up to 56°C under a high-emissions scenario), coupled with growing rainfall variability, which is expected to worsen the region's water deficit (World Bank, 2022). These climatic pressures are further amplified by the strong dependence of many MENA economies on climate-sensitive sectors, such as agriculture and extractive industries, as well as by structural economic rigidities and institutional constraints. Despite this pronounced vulnerability, the MENA region remains relatively understudied in the empirical climate-growth literature, and existing studies rarely account for the non-linear effects and cross-country heterogeneity of the region, thereby masking the real complex relation between climate change and economic growth.

Against this backdrop, this paper aims to provide a focused and region-specific analysis of the climate-growth relationship in the MENA region, with particular emphasis on nonlinear dynamics and the role of government effectiveness as a moderating factor. Using annual data for 16 MENA countries over the period 1990-2023, we estimate a sequence of fixed effects models designed to capture the complex nature of climate impacts on economic growth. We begin with a linear specification as a benchmark before introducing the quadratic model to identify potential climate thresholds. We then employ a quadratic regime-switching framework based on government effectiveness to account for the institutional heterogeneity within the MENA region. This approach recognizes that institutional quality conditions the capacity of economies to absorb and adapt to climate change.

This study makes three main contributions. First, it provides new region-specific evidence on threshold-driven climate–growth dynamics in the MENA region, while explicitly accounting for subregional heterogeneity between North Africa and the Middle East, thereby addressing a notable gap in the empirical literature. Second, by explicitly emphasizing government effectiveness as a moderating channel, the paper highlights the primacy of institutional capacity over purely economic buffers in mitigating the adverse effects of climate change on growth within and across MENA sub-regions. Third, the findings offer policy-relevant insights for the design of adaptive and institutional reforms aimed at strengthening climate resilience and safeguarding long-term economic performance in both North African and Middle Eastern economies, which face distinct but interrelated climate vulnerabilities.

The remainder of the paper is organized as follows. Section II reviews the related literature. Section III presents key stylized facts on climatic conditions and economic growth in the MENA region. Section IV describes the data and empirical strategy. Section V discusses the main empirical results, while Section VI drives policy implications of the paper. Finally, Section VII is devoted to the concluding remarks.

2. LITERATURE REVIEW

Early empirical evidence already suggested that economic activity is sensitive to climatic conditions. Huntington (1915) provided one of the first empirical assessments, showing that productivity tends to decline in winter and summer when temperatures are extreme, and rises in spring and autumn when temperatures are moderate. These early findings laid the foundation for subsequent economic research on climate-growth interactions.

Modern growth theory offers a clear framework to understand how climate change affects economic performance. In the neoclassical Solow-Swan model (Solow, 1956), output depends on labor, capital accumulation, and exogenous technical progress, implying that climate change operates as a negative productivity shock that reduces economic growth. Endogenous growth models further emphasize the role that human capital and innovation play in promoting economic growth (Lucas, 1988; Romer, 1990). Within this framework, climate change can distort investment decisions and the innovation process, generating persistent and non-linear reductions in per-capita incomes. More recent theoretical contributions allow for heterogeneous climate impacts across countries depending on institutional, sectoral, and geographic characteristics (Acemoglu et al., 2012; Dell et al., 2014).

Building on these theoretical foundations, a large empirical literature documents the adverse effects of climate variability on economic growth. Temperature increases and weather shocks have been shown to reduce output and growth across countries and regions (Dell et al., 2013; Brenner & Lee, 2014; Hoffmann et al., 2024; and Mohaddes and Raissi 2025). Recent empirical studies challenge linear representations of the climate-growth relationship and provide strong evidence of nonlinear effects. Several contributions identify an inverted U-shaped relationship between temperature and economic growth; whereby moderate warming may temporarily support economic activity while higher temperature levels generate persistent economic losses. (Burke et al., 2015; Lanzafame, 2016; Winter et al., 2025; and Khaliq et al., 2025).

The transmission of climate impacts to economic growth operates through multiple channels. A prominent mechanism involves agricultural productivity, which is highly sensitive to temperature and precipitation (Barrios et al., 2010; Acevedo et al., 2020; Otto et al., 2025). This effect can generate upward pressures on food prices, thereby reducing real incomes and weakening aggregate demand (Saou et al., 2025). Climate change also affects economic performance by reducing investment, deteriorating population health, and lowering labor productivity through heat stress and extreme weather exposure (Deschênes and Greenstone, 2011; Acevedo et al., 2020; Apergis and Rehman, 2025). These effects extend beyond agriculture to vulnerable industrial and service sectors, amplifying aggregate output losses (Jones and Olken, 2010; Hsiang, 2010; Aulia et al., 2025).

Empirical evidence consistently shows that higher temperatures are associated with lower economic growth, while the effects of precipitation remain more ambiguous and context-dependent (Lanzafame, 2012; Kahn et al., 2019; Meyghani et al., 2023). Long-term projections suggest substantial global output losses under high-emissions scenarios. For instance, Burke et al. (2015) estimate cumulative global GDP losses of around 23% by 2100, Mohaddes and Raissi (2025) projected a 24% decline in global output under high emissions scenarios, while Yuan et al. (2025) reported GDP losses of up to 58% by 2100 under the same scenario. Using scenario-based estimations, Kahn et al. (2019) predicted future economic losses due to climate change: an increase in global temperatures of 0.04°C would result in a loss of approximately 7% of the world's GDP by 2100, whereas more extreme scenarios would lead to projected losses of up to 13% compared to only 1% if the nations were to comply with the terms of the Paris Agreement. Winter et al. (2025) estimate that 2-2.6°C warming by 2050 would lead to a decline in global output by 20–40%, with a further 4-5°C warming of global temperatures by 2100 resulting in even greater losses.

Beyond average effects, the literature emphasizes pronounced heterogeneity in climate impacts across countries. Developing economies, characterized by lower income levels, limited fiscal space, and high dependence on climate-sensitive sectors, tend to experience larger growth losses from climate shocks than advanced economies (Dell et al., 2013; Burke et al., 2015; Desbordes and Eberhardt, 2024). Geographic location also matters, as countries located in hot and low-altitude regions face stronger and nonlinear temperature effects (Nordhaus, 2001; Dell et al., 2012a; Kahn et al., 2019; Kotz et al., 2023; Apergis and Rehman, 2025a). Empirical evidence from Africa highlights extreme vulnerabilities in tropical rainforest and arid climate zones, where rising temperatures exert nonlinear negative effects on growth (Barrios et al., 2010; Liu et al., 2023).

A growing strand of literature further investigates the role of institutional quality in shaping economic resilience to climate shocks. Effective institutions enhance a country's capacity to anticipate, absorb, and adapt to adverse climatic conditions through improved policy coordination, efficient public spending, and the implementation of climate-responsive strategies. Government effectiveness captures the quality of public service delivery, policy formulation, and institutional credibility, all of which are critical for managing climate-related risks. Empirical evidence suggests that countries with stronger institutional frameworks experience less persistent output losses following climate shocks, while weak governance environments tend to amplify the adverse effects of rising temperatures on economic growth (Noy, 2007; Apergis and Rehman, 2025). Importantly, institutions are increasingly viewed as conditioning factors that moderate the magnitude of climate impacts rather than as direct transmission channels. This perspective is especially relevant for regions such as MENA, where institutional capacity varies widely across countries and plays a central role in shaping economic vulnerability and adaptive potential to climate change.

Despite the breadth of this literature, empirical studies focusing explicitly on the MENA region remain relatively limited. Existing evidence suggests that rising temperatures generally exert negative effects on economic growth, while precipitation effects are more heterogeneous (Péridy and Brunetto, 2010; Islam et al., 2021; Namdar et al., 2021; Meyghani et al., 2023; and Eltayb et al., 2023). Importantly, climate impacts vary substantially within the region due to differences in climatic conditions, economic structures, and institutional capacity. This heterogeneity underscores the need for subregional analysis, distinguishing between North African and Middle Eastern economies, and for modeling approaches that explicitly account for nonlinear dynamics and institutional moderation in the climate-growth relationship.

Building on the existing literature, the present study tests whether the climate-growth relationship in the MENA region is nonlinear, whether climate impacts differ across North African and Middle Eastern countries, and whether government effectiveness mitigates the adverse growth effects of rising temperatures.

Overall, the literature motivates a nonlinear and institutionally conditioned analysis of the climate-growth relationship, which the present study implements in the context of the MENA region.

3. DATA OVERVIEW AND METHODOLOGY

3.1. Data

We construct a panel dataset covering 16 MENA countries over the period 1990-2023 (see Appendix Table A), using annual observations. Economic performance is measured by real GDP per capita, obtained from the World Bank Development Indicators. Climate variables constitute the main explanatory variables and are sourced from the World Bank climate knowledge portal (see Appendix Table A1). These include annual average temperatures, maximum temperatures, total precipitation, and the number of days with a heat index higher than 35°C. These indicators are widely used in the climate-economy literature as they capture both gradual climatic trends and exposure to extreme heat conditions (Dell et al., 2009;Dell et al., 2012b; Dell et al., 2013; Burke et al., 2015; Baarsch et al. 2020; Abdel-Latif et al., 2021, and Aulia et al., 2025).

To account for unexpected climatic disturbances, we additionally consider deviations of temperature and precipitation from their historical averages, as well as their growth rates. These measures proxy climate shocks and have been employed in several studies examining macroeconomic responses to weather variability (Barrios et al., 2010; Cevik and Tovar Jalles, 2024; and Khaliq et al., 2025). Extreme heat exposure is further approximated by the number of days with heat index exceeding 35°C, a threshold associated with severe thermophysiological stress in the climate-health literature (Raymond et al., 2020).

A set of control variables is included to mitigate omitted variable bias. These controls capture key dimensions of economic structure and macroeconomic conditions, including labor force participation rate, Gross fixed capital formation, trade openness, money supply growth, urbanization, financial openness, and agriculture's share of the added value, which we collected from the World Bank's World Development Indicators and the Chinn-Ito databases. We

Table 1: Summary statistics

Variable	N*T	Mean	SD	Min	Max
Per Capita Income (logged)	544	3.869	0.511	2.831	4.825
Per Capita Income	544	13802.6	14595.9	677.72	66979.16
Temperatures in C°	544	23.25	3.95	13.27	29.69
Maximum Temperatures in C°	544	29.06	4.21	18.02	35.41
Precipitations in mm	544	146.11	145.73	6.11	790.71
Government effectiveness	448	−0.141	0.723	−1.85	1.50
Gross Fixed Capital Formation	544	0.233	0.076	0.0085	0.935
Labor	543	0.528	0.112	0.364	0.7946
Urbanization	544	0.71	0.189	0.28	1
Trade to GDP ratio	544	0.953	4.172	0	97.71
Broad money growth	544	0.1409	0.157	−0.204	1.39
Fin openness index	544	0.352	1.56	−1.93	2.41
Agriculture's share of added value	544	0.0811	0.089	0.0016	0.45

N: Number of regions, T: Number of years. SD: Standard deviation. Summary statistics are reported for the baseline sample from our primary dataset. Temperature and precipitation are usually entered into models in logged form

use the Government Effectiveness Index developed by the World Bank as a moderator variable (Data sources in the Appendix Table A)[1]. Most of the above-mentioned controls are relevant for our study as determinants of growth and are theoretically consistent. Urbanization and labor rates reflect the productive structure (Lewis, 1954, and Henderson, 2010). Physical investment (Solow, 1956) and trade openness (Frankel and Romer, 1999) capture the classic drivers of economic growth. Monetary conditions (Milton Friedman, 1963) and financial openness (Mckinnon, 1973; and Shaw, 1973) control the macro financial environment. Lastly, the share of agriculture, a sector that is highly sensitive to climate, is in line with the literature on climate economics (Mendelsohn and Nordhaus, 1999). Taken together, these variables reduce omission bias and provide a more reliable estimate of the impact of climate variables.

Table 1 reports summary statistics for the main variables. Temperature variables display moderate dispersion across countries and over time, while precipitation exhibits substantial variability, with a standard deviation close to its mean, reflecting pronounced spatial and temporal heterogeneity in rainfall patterns. GDP per capita and government effectiveness show marked dispersion, highlighting significant differences in income levels and institutional quality across the MENA region.

Finally, correlation patterns by temperature quartiles (Table 1a) provide preliminary descriptive evidence of non-linearity. The correlation between temperatures and GDP per capita is positive at the lower quartiles. Still, it becomes negative at higher quartiles, suggesting that economic performance may deteriorate beyond certain temperature levels. This pattern is more apparent in North Africa (see Appendix Figure A1). These patterns are purely descriptive and serve to motivate the nonlinear empirical framework adopted in the subsequent analysis.

3.2. Empirical Strategy

To examine the relationship between climate conditions and economic performance in the MENA region, we begin with a baseline specification in which real GDP per capita depends on climatic factors, standard growth determinants, and unobserved heterogeneity. Formally, the relationship can be expressed as:

$$y_{it} = f(C_{it}, X_{it}) \qquad (1)$$

Where y_{it} denotes real GDP per capita in country i at time t, C_{it} is a vector of climate variables, and X_{it} includes a set of control variables (trade openness, Labor, Gross fixed capital formation, money supply growth, urbanization, and financial openness) capturing macroeconomic and structural characteristics.

Based on poolability tests and Haussman specification tests, a fixed-effects estimator is selected as the most appropriate framework for the analysis. The baseline empirical model is specified as:

$$Y_{it} = \beta_k C_{kit} + \beta_j Xj_{it} + \alpha_i + \alpha_t + \epsilon_{it} \qquad (2)$$

Where α_i denotes country fixed effects capturing time-invariant unobserved heterogeneity, and α_t represents year fixed effects controlling for common global shocks. The dependent variable is expressed in logarithms. The coefficients β_k measure the marginal impact of climate variables on per capita income, while β_j captures the effects of control variables[2].

Country fixed effects account for persistent cross-country differences such as geography or long-standing institutional characteristics, while time fixed effects absorb global trends and shocks common to all countries. This specification provides a benchmark assessment of the climate-income relationship but may mask nonlinear effects suggested by both theory and descriptive evidence.

Table 1a: Quartile - correlation analysis

Average temperature quartile	Q1	Q2	Q3	Q4
Correlation	0.2472	0.0906	−0.2603	−0.0662

Source: Authors calculations

1 For control variables with infrequent missing values, we filled the gaps using interpolation and, when necessary, limited extrapolation at the end of the series

2 The coefficients associated with the control variables (j) are not reported here for the sake of brevity. However, they were included in all model specifications to isolate the effect of temperature on GDP per capita. Their impact on the dependent variable is available upon request.

To allow for potential nonlinearities, we extend the baseline specification by introducing a quadratic form of the climate variable as suggested by empirical studies (Nordhaus, 2001; Deryugina et al., 2014; Burke et al., 2015; Li et al., 2019):

$$Y_{it} = \beta_k CS_{kit} + \beta'_k CS^2_{kit} + \beta_j Xj_{it} + \alpha_i + \alpha_t + \epsilon_{it} \quad (3)$$

This specification enables the identification of threshold effects and diminishing returns, consistent with a concave relationship between climate change and economic performance. A positive linear term combined with a negative quadratic term indicates an inverted U-shaped relationship, implying that climate conditions may initially support economic activity up to a certain threshold, beyond which adverse effects dominate.

To capture heterogeneity in climate impacts across institutional environments, we allow the effect of climate variables to vary across regimes defined by government effectiveness. The resulting specification is given by:

$$Y_{it} = \beta_{hk} CS_{kit} {}^*B_{hit} + \beta'_{hk} CS^2_{kit} {}^*B_{hit} + \beta_j Xj_{it} + \alpha_i + \alpha_t + \epsilon_{it} \quad (4)$$

Where B_{hit} is a binary indicator equal to one when government effectiveness in country i in a time t exceeds the median level of the sample and zero otherwise. This interaction-based specification (4) follows the intuition of a threshold and regime-switching model proposed by Hansen (1999), while allowing for coefficients provides a direct interpretation of how climate sensitivity differs between low and high government effectiveness environments, thereby capturing the moderating role of institutional quality in shaping economic resilience to climate change. To mitigate potential multicollinearity among climate variables, a cascade modeling approach is adopted, whereby climate indicators are introduced separately across alternative specifications[3]. This strategy reduces the estimator instability and allows for a closer assessment of the contribution of each climate measure. Robustness is further assessed by varying functional forms and samples.

3 However, it is still interesting to account for both variables in some specifications, even if a correlation between temperatures and precipitation may occur, Deryugina et al. (2014)

The marginal effect of climate variables is derived as:

$$\frac{dy}{dC} = \beta_k + 2\beta'_k C \text{ with } \beta_k \neq 0 \text{ and } \beta'_k \neq 0 \quad (5)$$

With the corresponding threshold value obtained under the following condition: $(\frac{dy}{dC} = 0)$

$$\beta_k + 2\beta'_k C^* = 0 \quad (6)$$

When climate variables and per capita income are expressed in logarithms, threshold values are recovered in original Celsius units using antilogarithmic transformation. The sign of β'_k determines the shapes of the relationship, distinguishing between U-shaped and inverted U-shaped patterns.

$$C^* = Antilog\left(-\frac{\beta_k}{2\beta'_k}\right) \quad (7)$$

Finally, to limit potential endogeneity concerns, all specifications include country and time fixed effects, and lagged climate variables are considered to reduce simultaneity between climate conditions and economic performance.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Findings

4.1.1. Benchmark linear estimates of average temperature and precipitation on Per Capita Income in the MENA region

Table 2 reports the benchmark fixed effects estimates linking temperatures and precipitation to log GDP per capita. Results are presented for the full MENA sample (columns 1-3) and separately for North Africa (columns 4-6) and the Middle East (columns 7-9) to reflect subregional heterogeneity. In the MENA region, average temperature (LMT) is positively and significantly associated with income per capita, while precipitation (LMP) exhibits a smaller effect. The estimated temperature association is stronger in North Africa, whereas precipitation is generally weak and often not statistically significant in the Middle East.

To assess the robustness of the baseline results, we further examine alternative climate indicators and functional forms. These include

Table 2: Panel estimates of the link between temperature, precipitation, and per capita income in the MENA region

Dependent variable:	MENA			North Africa			Middle East		
Log GDP per capita	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LMT	1.29***		1.412***	2.013***		2.385***	1.56***		1.56***
	(0.38)		(0.38)	(0.631)		(0.656)	(0.56)		(0.56)
LMP		0.05***	0.06***		0.035	0.08*		0.036	0.036
		(0.018)	(0.018)		(0.04)	(0.041)		(0.022)	(0.021)
F-statistic	185.26***	198.9***	188.92***	81.52***	40.56***	45.34***	184.31***	194.34***	177.24***
Adjusted R sq	0.382	0.378	0.394	0.583	0.562	0.588	0.25	0.236	0.257
No Observations	543	543	543	237	237	237	306	306	306
No Countries	16	16	16	7	7	7	9	9	9
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel Residuals Unit Root Test	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***

Note: Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: *** P<0.01, ** P<0.05, * P<0.10.

logged maximum temperatures (LMXT), the number of days with a heat index exceeding 35°C, non-logged temperature levels, as well as temperature and precipitation variations and anomalies relative to the 1980 – 1990 historical average (see Appendix Tables A2, A3-a, A3-b, and A4).

Across these alternative specifications, the main findings remain qualitatively unchanged. Maximum temperatures are positively and significantly associated with per capita income in the full MENA region and in North Africa, while the effects are weaker in the Middle East. In contrast, exposure to extreme heat, proxied by the number of days with a heat index above 35°C, is systematically associated with lower income levels, highlighting the adverse economic impact of extreme temperature events.

Temperature variations and anomalies yield consistent results, confirming the presence of interregional heterogeneity and stability of temperature effects across different climate metrics. By comparison, precipitation continues to display weak and often insignificant effects on economic growth. Taken together, these robustness checks confirm the limited role of rainfall and reinforce the relevance of temperature as the primary climatic driver of economic activity in the MENA region.

These linear specifications provide a useful reference point, but they may conceal threshold effects that have been emphasized in climate-growth literature. We therefore extend the benchmark model in the next subsection to explicitly test nonlinearities.

To assess whether climate effects persist over time, we estimate alternative specifications including lagged values of temperature and precipitation (see Table 3), following the distributed-lag approach used in related panel studies. Across specifications, precipitation effects display limited persistence, while temperature effects are concentrated in the contemporaneous term and weaken quickly when lags are included, these effects are still higher in North Africa than in the Middle East (see Appendix Tables A5 and A6). Therefore, it can be concluded that the estimated effects demonstrate stability despite the change in the functional form, which confirms the robustness and persistence of climate impact, thereby reducing concerns about reverse causality between climate variables and economic performance.

4.1.2. Nonlinear climate effect and implied thresholds

Table 4 introduces quadratic climate terms to test for threshold dynamics. The results provide strong evidence of a nonlinear temperature-income relationship: the linear temperature term is positive while the squared term is negative and statistically significant, consistent with an inverted U-shaped pattern. This implies that moderate warming may be associated with higher income levels up to a threshold, beyond which further temperature increases are associated with lower income.

The implied mean-temperature thresholds are estimated at 24.35°C for the overall MENA sample, 25.95°C for North Africa, and 22.24°C for the Middle East. Estimates based on maximum temperatures yield similar evidence of nonlinear effects, with subregional differences in threshold levels. We identified

Table 3: Alternative lag structures in the MENA region

Dependent variable: Log GDP per capita	(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)	(9)	(10)
LMT	1.412 ***			1.31***	1.185**	LMP	0.06 ***			0.060***	0.06**
	(0.38)			(0.38)	(0.39)		(0.018)			(0.017)	(0.017)
LMT lag1		0.915**		0.73*	0.68*	LMP lag1		0.064***		0.063***	0.062***
		(0.38)		(0.38)	(0.39)			(0.017)		(0.017)	(0.017)
LMT lag2			0.953**		0.52	LMP lag2			0.069***		0.066***
			(0.046)		(0.41)				(0.017)		(0.017)
LMP	0.06 ***	0.054***	0.052***	0.059***	0.057***	LMT	1.412***	1.29***	1.22***	1.40***	0.132***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)		(0.38)	(0.38)	(0.38)	(0.37)	(0.044)
F-statistic	188.92***	186.15***	185.87***	190.16***	190.50***		188.92***	189.74***	191.01***	194.35***	200.63***
Adjusted R sq	0.394	0.385	0.384	0.397	0.40		0.394	0.395	0.398	0.408	0.425
No Observations	543	543	543	543	543		543	543	543	543	543
No Countries	16	16	16	16	16		16	16	16	16	16
Controls	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Panel Residuals Unit Root Test	<1%***	<1%***	<1%***	<1%***	<1%***		<1%***	<1%***	<1%***	<1%***	<1%***

Note: Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. et Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Table 4: Panel estimates of the non-linear link between temperatures, precipitation, and per capita income in MENA

Dependent variable: Log GDP per capita	MENA				North Africa				Middle East			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
LMT	16.5***	1.39***		16.55 ***	32.78***	2.14***		32.48 ***	23.47***	1.67***		24.14***
	(3.31)	(0.39)		(3.32)	(7.96)	(0.69)		(7.96)	(4.03)	(0.566)		(4.03)
LMP	0.045**	0.079	0.058***	0.036	0.07*	0.225	0.089**	0.21	0.013	−0.11	0.026	−0.179*
	(0.018)	(0.081)	(0.018)	(0.079)	(0.04)	(0.138)	(0.041)	(0.13)	(0.021)	(0.111)	(0.021)	(0.105)
LMXT			19.62 ***				43.64***				26.826 ***	
			(5.35)				(11.18)				(6.98)	
LMT²	−5.95***			−5.97***	−11.59***			−11.56***	−8.71***			−8.92***
	(0.150)			(1.3)	(3.02)			(3.02)	(1.59)			(1.58)
LMP²		−0.0054		0.0026		−0.042		−0.041		0.044		0.057
		(0.023)		(0.022)		(0.038)		(0.037)		(0.032)		(0.03)
LMXT²			−6.36***				−14.31***				−9.036***	
			(1.93)				(3.95)				(0.053)	
F statistic	198.12***	179.73***	182.86***	195.08***	41.74***	45.55***	41.49***	41.98***	196.52***	176.13***	169.75***	185.17***
Adjusted R sq	0.393	0.393	0.416	0.417	0.61	0.59	0.63	0.62	0.33	0.25	0.3	0.34
No Observations	543	543	543	543	237	237	237	237	306	306	306	306
No Countries	16	16	16	16	7	7	7	7	9	9	9	9
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel Residuals Unit Root Test	<5%**	<5%**	<1%***	<5%**	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***

Note: Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

thresholds of 33.48°C for North Africa, 30.5°C for the Middle East, and 34.87°C for the overall MENA region. By contrast, precipitation does not exhibit robust nonlinear patterns in the quadratic specification, and the squared precipitation term is generally not statistically significant.

4.1.3. Institutional heterogeneity: Government effectiveness regimes

To examine whether institutional capacity moderates climate sensitivity, we estimate regime-specific nonlinear specifications based on government effectiveness. Countries are split into low and high government effectiveness regimes using a threshold rule described in section 4. Table 5 reports the corresponding estimates. Results indicate that institutional quality conditions temperature's sensitivity. In the full MENA sample, the implied mean-temperature threshold is higher in the high government effectiveness regime (27.36°C) than in the low government effectiveness regime (23.03°C), suggesting that stronger institutional capacity is associated with greater resilience to rising temperatures. This pattern also holds within North Africa (30.87°C vs. 27.659°C) and the Middle East (22.76°C vs. 20.71°C), although threshold levels differ across subregions. Overall, the estimated impact of precipitation on per capita GDP remains weak across specifications. However, when conditioning on government effectiveness, some heterogeneity emerges; the precipitation coefficients tend to be larger and more frequently significant in countries with lower government effectiveness. While they are generally small and statistically insignificant in countries of higher institutional quality (see Appendix Table A7).

The plots of the marginal effects for each of the moderators on the GDP per capita, both in the whole region (Appendix Figure A2) and in the two sub-regions of North Africa (Appendix Figure A3) and the Middle East (Appendix Figure A4), confirm empirical findings from Table 5.

4.2. Discussion

4.2.1. Linear climate effects and regional heterogeneity

The empirical findings indicate that average temperature is positively and significantly associated with per capita income in the MENA region within linear specifications, while precipitation displays a weak and often insignificant effect. This pattern masks substantial regional heterogeneity. The positive temperature effect is more pronounced in North Africa, whereas and less robust in the Middle East, where precipitation generally plays no significant role.

The positive effect of temperatures on economic growth should be interpreted with caution. It may reflect a sectoral compensation mechanism, whereby negative temperature effects on climate-sensitive activities, most notably agriculture, are offset by positive responses in other sectors, particularly services. In economies where services account for a large share of value added, higher temperatures may stimulate activity through channels such as tourism and certain urban services, thereby compensating for agricultural losses at the aggregate level. As a result, linear specifications may capture a net positive effect that conceals opposing sectoral responses.

Table 5: Panel estimates of nonlinear effects of temperature on economic performance in the MENA region: Moderating roles of institutions, macroeconomic conditions, and resource dependence

Dependent variable: Log GDP per capita	MENA (1)	North Africa (2)	Middle East (3)
Moderator	Government effectiveness	Government effectiveness	Government effectiveness
LMT^2 (Moderator=0)	−4.57*** (1.577)	−7.945** (3.854)	−6.965*** (2.04)
LMT^2 (Moderator=1)	−3.46** (1.39)	−6.559* (3.89)	−7.552*** (1.62)
LMT (Moderator=0)	12.45*** (1.57)	22.911** (10.28)	18.335*** (5.20)
LMT (Moderator=1)	9.945*** (4.097)	19.54* (10.26)	20.50*** (4.19)
F statistic	193.63***	39.75***	206.96***
Adjusted R-Sq	0.44	0.63	0.39
No Observations	543	237	306
No Countries	16	7	9
Controls	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Panel Residuals Unit Root Test	<5%**	<5%**	<5%**

Note: Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. et Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

These differences are consistent with the structural composition of the two sub-regions. North African economies retain a relatively larger exposure to climate-sensitive activities like agriculture, which increase their sensitivity to variations in temperatures and rainfall. In contrast, Middle Eastern economies are more heavily oriented toward extractive industries and services, sectors that are less directly dependent on climatic conditions. Moreover, the widespread adoption of capital-intensive technologies such as desalination systems, climate-controlled infrastructure, and irrigation-independent food supply chains appear to dampen the direct macroeconomic impact of rainfall variability in the Middle East.

The dynamic specifications suggest limited persistence in the effects of temperature, while precipitation effects, though generally small, may extend slightly over time in some cases. Importantly, coefficient magnitudes remain broadly stable across alternative climate measures and lag structures, supporting the robustness of the linear findings. At the same time, these results highlight the limitations of linear models, as sectoral compensation effects may generate misleading average relationships. This motivates the use of nonlinear specifications, which allow the identification of temperature thresholds beyond which adverse effects dominate, and the aggregate compensation mechanism breaks down.

4.2.2. Nonlinear effect of average temperature and precipitation on per capita income in the MENA region

To better understand how climate conditions shape regional economic performance, we estimate temperature thresholds beyond which additional warming reduces economic growth. The estimated tolerance levels (reported in the results section) allow a comparison of temperature sensitivities between North Africa and the Middle East. These threshold levels are consistent with Akyapi et al. (2025) and confirm the presence of heterogeneous and nonlinear temperature effects across the MENA region.

At relatively low temperature levels, moderate warming may support economic activity through lower heating demand, favorable agricultural conditions, and increased activity in service-related sectors. However, once the temperature exceeds the estimated threshold, adverse outcomes emerge. These include a productivity drop among workers in exposed sectors (Hsiang, 2010), rising energy costs driven by cooling demand (Clarke et al., 2018) and declining agricultural yields due to heat stress and extreme weather conditions. All these mechanisms translate into lower aggregate output.

The higher threshold observed in North Africa, approximately 3°C above that of the Middle East, indicates a greater tolerance to warming. This difference is consistent with structural characteristics. Agriculture represents a larger share of value added in North Africa (around 12.34%) than in the Middle East (approximately 2.42%)[4], and temperatures ranging between 25°C and 30°C are often considered optimal for plant growth (Chatterjee et al., 2020)[5]. Additionally, greater access to freshwater resources, including river systems, dams, and groundwater, helps mitigate the adverse effects of heat through irrigation.

By contrast, the Middle East is already characterized by extreme baseline temperatures and structural water scarcity, making it more vulnerable to further warming. Persistent heat waves in the MENA region intensify thermal stress (Varela et al., 2020), while urban heat island effects further amplify heat exposure in rapidly urbanizing cities such as Dubai and Riyadh. In addition, heavy reliance on extractive industries increases exposure to temperature-sensitive infrastructure (Cruz & Krausmann 2013). Rising cooling demand and the need to protect infrastructure under extreme heat further exacerbate economic vulnerability Manderson and Considine (2021).

4.2.3. Mitigating heterogeneity via economic and institutional moderators

To further account for heterogeneity in climate impacts, the analysis incorporates institutional characteristics as moderate factors. Among those considered, government effectiveness emerges as the most robust and economically meaningful

4 Authors' calculations based on the World Bank data
5 Chatterjee et al. (2020)

moderator of the temperature-growth relationship.

Results indicate that countries with higher government effectiveness can tolerate higher temperature levels before experiencing negative economic effects. This reflects the capacity for Effective Governments to design public policy that will mitigate climate shock impacts. including investment in climate-resilient infrastructure and green technology to reduce greenhouse gases, targeted support for vulnerable sectors of the economy, and incorporating climate risk assessment into all strategic planning and budgeting processes. All of which can contribute to increased resilience of national economies to rising temperatures. With respect to precipitation (Appendix Table A6), the aggregate effect on economic growth remains weak. However, conditional heterogeneity emerges when institutional quality is considered. Countries with lower government effectiveness exhibit a slightly stronger growth response to rainfall, whereas well-governed countries show little macroeconomic sensitivity to precipitation. This pattern is consistent with greater reliance on rain-fed agriculture in institutionally weaker settings, while modern water management systems in better-governed countries dampen the economic impact of rainfall variability. These findings align with Starke (2009) and Noy (2007), highlighting institutional quality as a key determinant of climate resilience.

5. POLICY INSIGHTS

Our findings yield several policy-relevant insights for the MENA region. First, they confirm that the climate-growth relationship is inherently nonlinear and highly heterogeneous across countries, implying that uniform adaptation strategies are unlikely to be effective. Climate policies must therefore be tailored to national economic structures and institutional capacities.

In North Africa, the strong reliance on rain-fed and conventional agriculture amplifies vulnerability to temperature extremes and precipitation variability. This calls for increased investment in climate-smart agriculture, efficient irrigation systems, and sustainable water management technologies to enhance economic resilience. In contrast, Middle Eastern economies, particularly oil-exporting countries, exhibit lower direct exposure to short-term climate shocks but remain vulnerable through their direct dependence on natural resources rents and rising urban heat stress. These challenges highlight the importance of urban adaptation measures, such as green infrastructure and cooling systems, alongside economic diversification toward renewable energy, energy efficiency, and low-carbon industries.

A key policy insight concerns the moderating role of government effectiveness. Strong institutional capacity significantly enhances resilience to rising temperatures, underscoring the importance of transparent governance, effective public investment, and the integration of climate risks into economic planning. Although precipitation effects on growth are generally weak, chronic water scarcity remains a critical constraint in the region. This reinforces the need for strengthened integrated water resource management and enhanced regional cooperation over shared basins.

Overall, the results highlight the need to adopt country-specific adaptation strategies tailored to the national context of each country in the MENA region. Strengthening institutional frameworks, diversifying economies, and investing in sustainable technologies are essential to reducing vulnerability and fostering sustainable and climate-resilient growth.

6. CONCLUSION

This paper examines the nonlinear relationship between climate change and economic growth in the MENA region, an area that remains relatively underexplored in the empirical climate-growth literature. Using panel fixed-effects models with quadratic climate terms and a regime-switching framework, the analysis reveals a robust inverted U-shaped relationship between temperature and per capita income, while precipitation exerts a weak and largely linear effect.

The estimated temperature thresholds vary substantially across sub-regions and institutional environments, highlighting the strong heterogeneity of climate impacts within the MENA region; North African economies appear more tolerant to moderate temperature increases than those in the Middle East, reflecting differences in sectoral structure and exposure to extreme heat. Moreover, institutional quality emerges as a key moderating factor; countries with higher government effectiveness display significantly greater resilience to rising temperatures.

By contrast, the macroeconomic impact of precipitation remains limited across most specifications. Although rainfall effects are slightly more pronounced in specific institutional contexts, their overall contribution to per capita income dynamics appears weak, in line with previous findings for arid and semi-arid regions.

Several limitations warrant caution in interpreting these results. Annual climate averages may conceal important seasonal and intra-annual variations, particularly relevant for agricultural productivity. In addition, while the analysis controls for agriculture's share in value added, future research could benefit from incorporating crop-specific and seasonal data to better capture sectoral vulnerability to climate shocks. Addressing these extensions would allow for a more granular assessment of climate-growth interactions

Overall, the findings underscore the importance of accounting for the nonlinearities and structural heterogeneity when assessing the economic consequences of climate change in the MENA region. Strengthening institutional capacity, enhancing adaptive infrastructure, and fostering climate-resilient development strategies appear central to mitigating the long-term growth impacts of rising temperatures.

7. ACKNOWLEDGMENT

We are grateful to Mohammed V University of Rabat, the Faculty of Legal, Economic and Social Sciences – Agdal (FSJES-Agdal) and the Laboratory of Applied Economics for their institutional support.

8. FUNDING

This research project was conducted with the support of the National Center for Scientific and Technical Research (CNRST) under the “Ph.D. Associate Scholarship-PASS”.

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APPENDICES

Table A: Data sources

Variable	Source
Per Capita Income	https://data.worldbank.org/
Average Mean Surface Air Temperatures in C°	https://climateknowledgeportal.worldbank.org
Average Maximum Surface Air Temperatures in C°	https://climateknowledgeportal.worldbank.org
Number of Days with Heat Index >35°C	https://climateknowledgeportal.worldbank.org
Precipitations in mm	https://climateknowledgeportal.worldbank.org
Government effectiveness index	https://www.worldbank.org/en/publication/worldwide-governance-indicators/interactive-data-access
Gross Fixed Capital Formation in % of GDP	https://data.worldbank.org/
Labor in % of GDP	https://data.worldbank.org/
Urbanization	https://data.worldbank.org/
Trade to GDP ratio	https://data.worldbank.org/
Broad money growth	https://data.worldbank.org/
Fin openness index	https://web.pdx.edu/~ito/Chinn-Ito_website.htm
Agriculture's share of added value	https://data.worldbank.org/

Source: Compiled by the authors

Table A1: Country list

Country (Sub-region)	
Algeria (NA)	Libya (NA)
Bahrein (ME)	Mauritania (NA)
Egypt (NA)	Morocco (NA)
Iran (ME)	Oman (ME)
Israel (ME)	Saoudi Arabia (ME)
Jordany (ME)	Sudan (NA)
Kuwait (ME)	Tunisia (NA)
Lebanon (ME)	United Arab Emirates (ME)

Source: Compiled by the authors

Table A2: Alternative formalizations of temperatures

Log (GDP per capita)	MENA			North Africa			Middle East		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LMP		0.0711***	0.0524***		0.107**	0.042		0.042*	0.0379*
		(0.018)	(0.0178)		(0.042)	(0.0414)		(0.021)	(0.0211)
LMXT	0.776***	0.915***		2.537***	3.206***		0.95**	1.00***	
	(0.193)	(0.193)		(0.66)	(0.702)		(0.296)	(0.295)	
Number of Days with Heat Index >35°C			−0.0018***			−0.0018			−0.0023***
			(0.00037)			(0.0012)			(0.0004)
F statistic	173.31***	179.23***	197.04***	80.94***	48.28***	25.02***	171.18***	161.34***	147.41***
Adjusted R sq	0.38	0.406	0.4	0.593	0.604	0.566	0.26	0.28	0.34
Panel Residuals Unit Root Test	<1%***	<1%***	<1%***	<1%***	<5%**	<1%***	<5%**	<5%**	<1%***
No Observations	543	543	506	237	237	237	306	306	306
No Countries	16	16	16	7	7	7	9	9	9
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Table A3-a: Alternative formalizations of temperatures and precipitation

Log (GDP per capita)	MENA			North Africa			Middle East		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Temp variation	0.0013			0.0028			0.00084		
	(0.0012)			(0.002)			(0.0018)		
Temperature not logged		0.0142*			0.0344**			0.004	
		(0.008)			(0.0136)			(0.012)	
Precep variation			−1.54e-7 ***			−0.000098			−0.000019
			(0.018)			(0.0001)			(0.00004)
LMP [LMT]	0.057***	0.060***	|1.295]***	0.048	0.067	[1.88]***	0.036	0.036	[1.572]***
	(0.018)	(0.018)	(0.38)	(0.0423)	(0.0427)	(0.647)	(0.0219)	(0.022)	(0.561)
F statistic	198.89	184.69***	184.63***	41.04***	42.53***	81.54***	193.6***	175.45***	181.93***
Adjusted R sq	0.385	0.38	0.396	0.585	0.575	0.589	0.25	0.235	0.257
No Observations	543	543	543	237	237	237	306	306	306
No Countries	16	16	16	7	7	7	9	9	9
Panel Residuals Unit Root Test	<1%***	<1%***	<1%***	<1%***	<1%***	<1%***	<5%**	<5%**	<5%**

Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Table A3-b: Alternative formalizations of temperatures and precipitation

Variable	MENA		North Africa		Middle East	
	(1)	(2)	(3)	(4)	(5)	(6)
Temp Anomaly	0.015*		0.042***		0.00092	
	(0.008)		(0.0142)		(0.0049)	
Precep Anomaly		0.00014**		0.000146		0.00009
		(0.000063)		(0.00013)		(0.00006)
LMP [LMT]	0.059***	|1.52]***	0.093**	[2.712]***	0.036	[1.55]***
	(0.018)	(0.39)	(0.0446)	(0.716)	(0.0224)	(0.561)
F statistic	214.92***	245.18***	37.83***	100.91***	195.82***	188.58***
Adjusted R sq	0.392	0.396	0.585	0.58	0.26	0.257
Panel Residuals Unit Root Test	<1%***	<1%***	<5%**	<5%**	<1%***	<1%***
No Observations	543	543	237	237	306	306
No Countries	16	16	7	7	9	9

Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Table A4: Construction of alternative climate variables

Temp variation	$=\frac{T_t - T_{t-1}}{T_{t-1}}*100$
Precep variation	$=\frac{P_t - P_{t-1}}{P_{t-1}}*100$
Temp Anomaly	$=T_t - \overline{T}_{1980-1990}$
Precep Anomaly	$=P_t - \overline{P}_{1980-1990}$

Source: compiled by the authors

Table A5: Alternative lag structures in temperatures and precipitation in North Africa

Log (GDP per capita)	LGDPC	LGDPC	LGDPC	LGDPC	LGDPC		LGDPC	LGDPC	LGDPC	LGDPC	LGDPC
LMT	2.385***			2.38***	2.34***	LMP	0.08*			0.084**	0.082**
	(0.656)			(0.65)	(0.65)		(0.041)			(0.041)	(0.041)
LMT (lag1)		0.912		0.911	0.985	LMP (lag1)		0.087**		0.091**	0.092**
		(0.65)		(0.63)	(0.63)			(0.004)		(0.038)	(0.038)
LMT (lag2)			1.01		0.982	LMP (lag2)			0.056		0.055
			(0.69)		(0.67)				(0.038)		(0.038)
LMP	0.08*	0.033	0.036	0.078*	0.079*	LMT	2.385***	2.032***	2.05***	2.42***	0.27***
	(0.041)	(0.041)	(0.041)	(0.04)	(0.041)		(0.656)	(0.64)	(0.62)	(0.64)	(0.079)
F statistic	45.34***	41.02***	41.10***	45.88***	46.51***		45.34***	47.46***	45.45***	46.15***	46.14***
Adjusted R sq	0.588	0.572	0.56	0.59	0.59		0.59	0.59	0.59	0.60	0.60
No Observations	237	237	237	237	237		237	237	237	237	237
No Countries	7	7	7	7	7		7	7	7	7	7
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel Residuals Unit Root Test	<1%***	<1%***	<1%***	<1%***	<1%***		<1%***	<1%***	<1%***	<1%***	<1%***

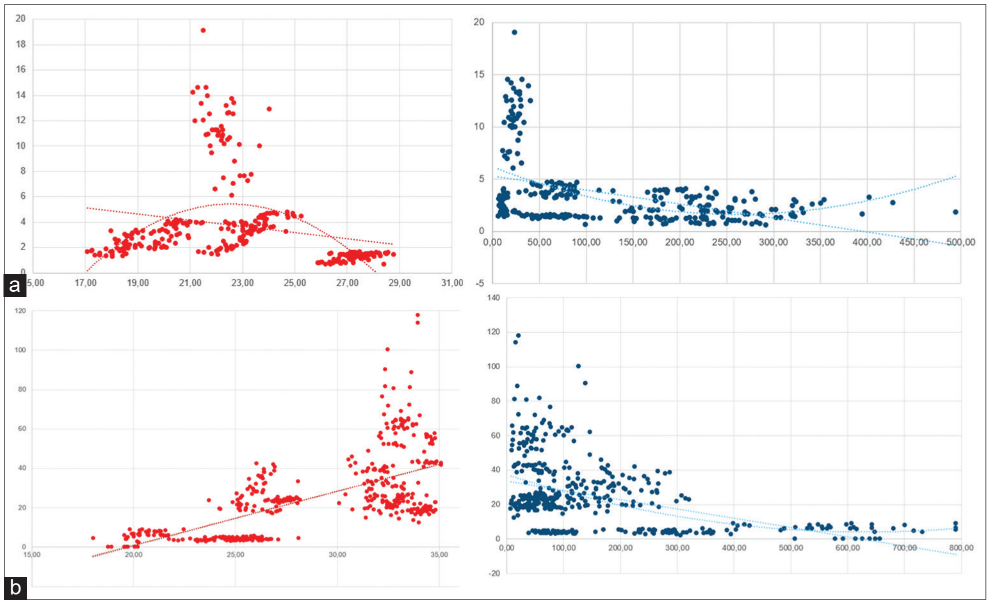
Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Table A6: Alternative lag structures in temperatures and precipitation in the Middle East

Log (GDP per capita)	LGDPC	LGDPC	LGDPC	LGDPC	LGDPC		LGDPC	LGDPC	LGDPC	LGDPC	LGDPC
LMT	1.56***			1.45**	1.21**	LMP	0.036			0.037*	0.036*
	(0.56)			(0.56)	(0.57)		(0.021)			(0.021)	(0.0213)
LMT (lag1)		1.31**		1.17**	1.106*	LMP (lag1)		0.055**		0.055**	0.054**
		(0.57)		(0.56)	(0.56)			(0.021)		(0.021)	(0.021)
LMT (lag2)			1.488**		0.99 (0.64)	LMP (lag2)			0.07***		0.068***
			(0.629)						(0.021)		(0.020)
LMP	0.036	0.038*	0.035	0.038*	0.038*	LMT	1.56***	1.66***	1.51***	1.66***	1.60***
	(0.021)	(0.022)	(0.022)	(0.021)	(0.021)		(0.56)	(0.55)	(0.55)	(0.061)	(0.54)
F statistic	177.24***	176.04***	176.38***	180***	181.3***		177.2***	178.6***	178.26***	176.6***	179.1***
Adjusted R sq	0.257	0.248	0.249	0.264	0.27		0.26	0.273	0.282	0.273	0.3
No Observations	306	306	306	306	306		306	306	306	306	306
No Countries	9	9	9	9	9		9	9	9	9	9
Controls	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Panel Residuals Unit Root Test	<1%***	<1%***	<5%**	<1%***	<1%***		<1%***	<5%**	<5%**	<5%**	<5%**

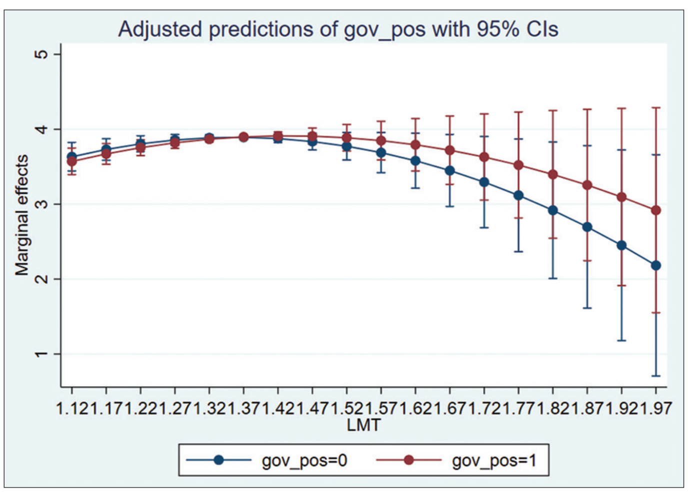
Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. et Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Figure A1: (a) North Africa, (b) Middle East, Correlation between precipitation, temperature (x-axis), and GDP per capita (in thousands of dollars) (y-axis), in the MENA region between 1980 and 2023



Source: Compiled by the authors from the World Bank data

Figure A2: Marginal effects of temperatures on per capita GDP depending on government effectiveness in the MENA region gov_pos is a binary indicator of governance position. gov_pos = 0 refers to countries with lower governance quality, while gov_pos = 1 refers to countries with higher governance quality, based on the sample distribution of the governance index. The figure reports adjusted predictions with 95% confidence intervals.



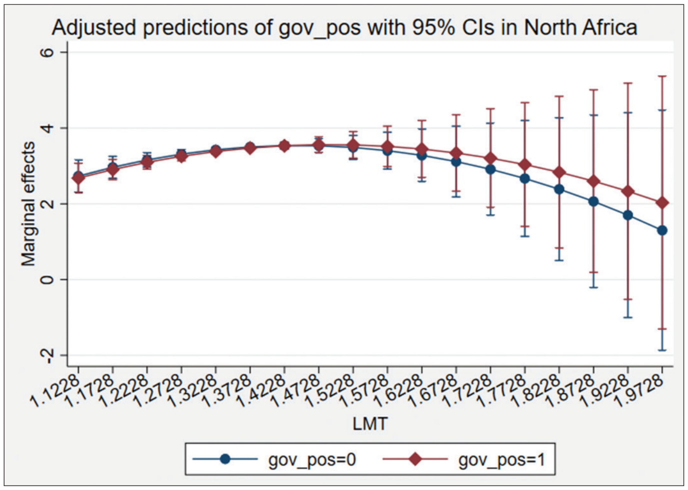
Source: compiled by the authors

Table A7: Panel estimates of nonlinear effects of precipitation on economic performance in North Africa and the Middle East: Moderating roles of institutions

Moderator	LGDPC	LGDPC
	Government effectiveness	Government effectiveness
LMP (moderator=0)	0.074* (0.040)	0.174*** (0.033)
LMP (moderator=1)	0.0052 (0.047)	0.0292 (0.021)
F statistic	46.66***	190***
Country effects	Yes	Yes
Year effects	Yes	Yes
Panel Residuals Unit Root Test	<1%***	<1%***
Adjusted R sq	0.616	0.32
No Observations	237	306
No Countries	7	9

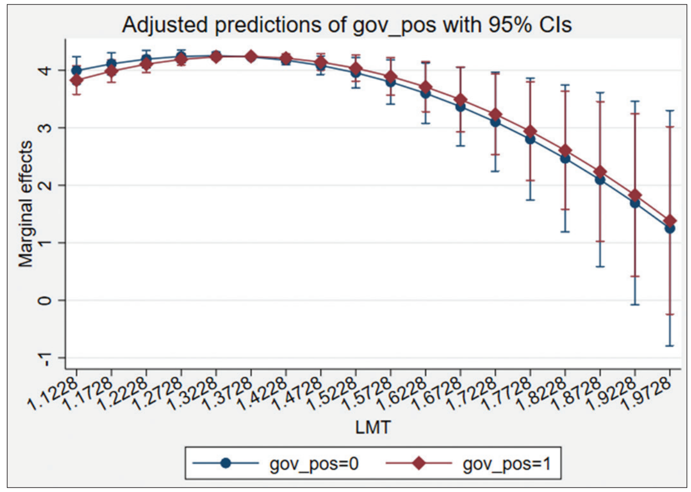
Note: The dependent variable is the logarithm of real GDP per capita. Robust standard errors are reported in parentheses. All specifications include country and year fixed effects, as well as a full set of control variables. Residual-based panel unit root tests reject the null of non-stationarity. Significance levels are denoted as follows: ***P<0.01, **P<0.05, *P<0.10

Figure A3: Marginal effects of temperatures on per capita GDP depending on government effectiveness in North Africa



Source: Compiled by the authors

Figure A4: Marginal effects of temperatures on per capita GDP depending on government effectiveness in the Middle East



Source: Compiled by the authors