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The Threshold Effects of External Debt on Sustainable Economic Growth Considering Heterogeneity in Regulatory Quality and Government Institutional Quality

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ABSTRACT

The present study examines the threshold effects of external debt on sustainable economic growth while taking into account the heterogeneity in regulatory quality and government institutional quality. Using a Panel Smooth Transition Regression (PSTR) model in which external debt is considered the transition variable, the sustainable development function is modeled. Following confirmation of the nonlinear model, the results of the nonlinear section are analyzed. According to the estimated nonlinear model, the coefficient of external debt (ED) is 0.49, indicating a negative effect of external debt on sustainable development in the selected countries. Given the corresponding probability value of this coefficient (0.0069), which is less than 0.05, this effect is statistically significant at the 95% confidence level. Furthermore, the coefficients and computed probability values for institutional quality, regulatory quality, and rule of law are 0.016, 0.089, and 0.235, with corresponding probability values of 0.0355, 0.0015, and 0.0053, respectively. These results indicate that the effects of regulatory quality, institutional quality, and the rule of law on improving sustainable development are positive and statistically significant.

Keywords: External debt, sustainable economic growth, regulatory quality, government institutional quality, threshold model

Introduction

The pursuit of sustainable economic growth has become a central priority for policymakers, especially in developing and resource-dependent economies exposed to volatile external conditions, environmental pressures, and structural vulnerabilities (1, 2). In such contexts, external debt, trade openness, and institutional quality jointly shape the trajectory of growth, with important implications for the ability of countries to achieve the Sustainable Development Goals (SDGs) and balance economic, social, and environmental objectives (3, 4). While access to external borrowing can relax fiscal and savings constraints, enabling investment in infrastructure, human capital, and green technologies, excessive or poorly managed debt may generate debt overhang, macroeconomic instability, and crowding out of productive expenditure (5, 6). Understanding how the impact of external debt on sustainable economic performance depends on country-specific structural features—particularly trade integration and institutional quality—has therefore become an urgent empirical and policy question (7, 8).

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A large and growing literature examines the nexus between external or public debt and economic growth, increasingly focusing on nonlinear and threshold effects rather than assuming a uniform linear relationship across countries and time (5, 6). Recent evidence for Sub-Saharan Africa shows that external debt can support capital formation when accompanied by sound institutions, but becomes detrimental at higher levels or in weak governance environments (1, 9). Similar findings emerge for MENA countries, where public debt exhibits threshold effects, and the growth impact depends on energy endowments and structural characteristics (8). Studies employing advanced panel techniques have begun to model these nonlinearities explicitly, including panel smooth transition regression approaches that allow the marginal effect of debt on growth to change across regimes defined by institutional or macroeconomic indicators (7, 10). This body of work suggests that the sustainability of debt cannot be assessed independently of governance, policy frameworks, and the broader integration of economies into global trade and financial systems.

Institutional quality and governance have emerged as key moderating factors in the debt–growth–sustainability nexus. Strong institutions enhance the efficiency of public spending, reduce leakage and corruption, and enable governments to allocate borrowed resources towards productive and environmentally responsible uses (1, 4). Evidence from African economies indicates that institutional quality also conditions the role of renewable energy and sectoral growth in mitigating carbon emissions, underscoring how governance influences both economic and environmental dimensions of development (11, 12). In regions where public sector management is heterogeneous, such as Sub-Saharan Africa and parts of the Middle East, the same level of external debt can generate very different outcomes depending on transparency, regulatory effectiveness, and the rule of law (6, 13). This reinforces the need for empirical models that explicitly capture heterogeneity in institutional quality and allow for regime-dependent effects, rather than imposing homogeneous coefficients across structurally diverse economies (7, 10).

In parallel, trade openness is widely recognized as a double-edged sword in the context of sustainable development. On one hand, trade liberalization can facilitate technology transfer, scale economies, export diversification, and access to green technologies, thereby fostering growth and supporting environmental improvements (2, 14, 15). On the other hand, increased trade may exacerbate environmental degradation through pollution haven effects, resource over-extraction, and carbon-intensive production, particularly in economies reliant on fossil fuel exports or weak environmental regulation (4, 16, 17). Empirical work for high-income and OECD economies shows that the interplay between trade openness and environmental sustainability depends crucially on the stringency and enforcement of environmental policies and regulatory frameworks (18-20). Studies on the Asia-Pacific region and Latin America further highlight that trade openness can align with sustainable development when complemented by robust regulations, investment in green innovation, and long-term policy commitments (3, 21-23).

Recent research on trade openness and sustainable development in emerging and developing regions adds nuance to this picture. Evidence from Sub-Saharan Africa and Middle Eastern economies suggests that trade liberalization may support sustainable growth when paired with effective environmental policies and structural reforms, but can worsen ecological pressures in their absence (14, 16, 24). Analyses of G20 and industrialized economies similarly show that trade can help mitigate climate change if it accelerates the diffusion of clean technologies and renewable energy, but can lock countries into carbon-intensive pathways when driven by fossil fuel–dependent comparative advantage (13, 25, 26). Evidence from OECD and emerging economies also underscores that “green growth” requires integrating trade policy, environmental regulation, and innovation systems rather than treating these domains separately (20, 27, 28).

Foreign direct investment (FDI), renewable energy, and green innovation add further layers to the relationship between external integration and sustainable development. Studies show that FDI and trade openness can stimulate green innovation and cleaner production in developing countries, provided that regulatory frameworks and institutional quality are supportive (2, 22). Evidence from developing and G20 economies highlights the role of renewable energy adoption and sectoral growth patterns in shaping carbon emissions trajectories and reconciling economic expansion with environmental sustainability (11, 12, 26). In many resource-rich and oil-exporting economies, however, weak diversification, volatile commodity markets, and procyclical fiscal policies complicate this transition and interact with external debt dynamics in nontrivial ways (4, 8). These structural features make it particularly important to study how external debt, trade openness, and institutional quality jointly affect sustainable economic growth in regions that are both heavily integrated into global energy markets and highly exposed to environmental risks.

At the same time, rapid technological change—especially in digital technologies and artificial intelligence—is transforming production structures, trade patterns, and institutional capacities, generating both opportunities and risks for sustainable development. Generative AI and related digital tools are reshaping the future of work, productivity, and skill requirements, with significant macroeconomic and distributional implications (29). In the education sector, AI applications offer new modalities for teaching, assessment, and personalization, though they also raise governance and equity challenges (30, 31). In marketing and e-commerce, AI-driven analytics and automation are restructuring firm strategies and consumer engagement (32). In the architecture, engineering, and construction industries, integration of building information modelling (BIM) with generative AI illustrates how digital technologies can enhance project management, resource efficiency, and innovation (33). More broadly, information systems and IT capabilities can help firms and economies overcome structural deficiencies and support both closed and open innovation models, which in turn feed into productivity and growth dynamics at the macro level (34).

Technological change is also transforming the way data are generated, monitored, and used in economic policy and sustainability assessment. Evidence-based decision-making frameworks emphasize the importance of systematically synthesizing and applying empirical evidence in domains such as conservation and public policy (35). Advances in AI and machine learning are increasingly used to monitor environmental indicators, forecast market conditions, and manage complex systems, ranging from financial markets—where volatility surged during the COVID-19 pandemic—to agricultural and ecological domains (36-38). Although these developments are not directly modelled in traditional macroeconomic frameworks of external debt and growth, they underscore the evolving context in which debt-financed investments, trade integration, and institutional reforms operate, and highlight the premium on adaptive, information-rich governance (29, 33).

Despite these advances, significant gaps remain in the empirical literature. First, many studies of external debt and growth focus on aggregate GDP growth without explicitly incorporating multidimensional measures of sustainable economic performance that reflect environmental and social dimensions (1, 2). Second, while the importance of institutional quality is widely acknowledged, relatively few studies explicitly model debt–growth relationships as nonlinear functions of governance and regulatory indicators, especially in the context of oil-exporting and energy-intensive economies (6, 7). Third, although the trade openness–environment–growth nexus has been extensively examined across different regions, evidence is still mixed on whether trade liberalization systematically promotes or undermines sustainable development in resource-dependent and middle-income economies, where external debt, trade structure, and institutional quality interact in complex ways (14, 16, 23, 24).

Finally, the growing role of digitalization and AI in shaping trade, investment, and institutional capabilities further complicates these relationships, yet is rarely considered in empirical macro models (29-31).

Methodologically, there is also a need to move beyond purely linear panel models and adopt approaches that can capture regime-dependent and threshold effects in the relationship between external debt and sustainable economic outcomes. Traditional fixed-effects and random-effects estimators may fail to uncover important nonlinearities and heterogeneities that arise when the impact of debt depends on governance quality, trade openness, or macroeconomic volatility (10, 36). Panel smooth transition regression (PSTR) models, which allow coefficients to change smoothly across regimes defined by transition variables, have recently been applied to examine debt, institutional quality, and growth in African and emerging economies, and offer a suitable framework for analysing threshold effects in a multi-country setting (6, 7). Incorporating trade openness, institutional quality, and macroeconomic control variables such as inflation and fiscal balance into such models can provide richer insights into the conditions under which external debt supports or undermines sustainable economic growth, particularly in structurally specific contexts such as oil-exporting Middle Eastern economies (4, 8, 21).

Against this backdrop, and building on the strands of literature on external debt thresholds, trade openness, institutional quality, and sustainable development, the present study aims to investigate the threshold effects of external debt on sustainable economic growth in selected oil-exporting Middle Eastern countries.

Methods and Materials

This research is descriptive in nature and method, and applied in purpose. In the present study, the current status of the variables was analyzed using data collection through historical (ex post facto) information. The statistical sample consists of data related to the economies of selected Middle Eastern oil-exporting countries during the period 2000–2023. The selected countries include Algeria, Bahrain, Egypt, Iraq, Iran, Jordan, Kuwait, Oman, Saudi Arabia, and the United Arab Emirates.

Following the studies of Sandu et al. (2022) and Ahmad et al. (2021), the present article examines the impact of external debt on sustainable economic growth, taking into account heterogeneity in regulatory quality and government institutional quality (Smooth Transition Nonlinear Effects Test) for selected Middle Eastern oil-exporting countries. The Panel Smooth Transition Regression (PSTR) threshold model was developed by Terasvirta and Anderson (1992) and Terasvirta (1994). Unlike TAR models, which use indicator functions to control regime-switching processes, PSTR models use logistic and exponential functions for this purpose. According to van Dijk and Terasvirta (2002), these models are highly suitable for analyzing asymmetric variable cycles, and many studies have shown their ability to accurately model regime-switching in nonlinear dynamics. The PSTR model uses the transition variable and slope parameter to continuously model nonlinear relationships among variables. The Smooth Transition Regression (STR) model (Terasvirta, 1994) is specified as follows (clean text for Word):

Formula (1):

$$y_t = \pi' z_t + \theta' z_t + F(s_t, \gamma, c) + u_t$$

where zt is the vector of exogenous variables; π is the vector of linear parameters; θ is the vector of nonlinear parameters; ut is the error term assumed to be i.i.d. with mean zero and constant variance (ut ~ iid(0 , σ²)).

The transition function F(st , γ , c) can be logistic or exponential, specified as:

Formula (2) – Logistic Transition Function:

$$F(s_t, \gamma, c) = \left[\frac{1}{1 + exp(-\gamma(s_t - c))} - \frac{1}{2}\right]$$

Formula (3) – Exponential Transition Function:

$$F(s_t, \gamma, c) = \left[1 - \exp\left(-\gamma(s_t - c)\right)^2\right]$$

In these functions, st is the transition variable; γ is the slope parameter; and c is the threshold value at which regime switching occurs.

If the slope parameter γ tends toward infinity, the PSTR model becomes a TAR model. In that case:

– If st > c, then F = 1

– If st < c, then F = 0

If γ approaches zero, the STAR model becomes linear.

The final model of this study is specified as follows:

Formula (4):

$$SD_i = \alpha_0 + \beta_1 ED_t + \beta_2 RQ_t + \beta_3 RO_t + \beta_4 FD_t + \beta_5 POP_t + \beta_6 OPEN_t + \beta_7 INF_t + \beta_8 RL_t + \beta_9 BD_t\ (\theta_1 ED_t + \theta_2 RQ_t + \theta_3 RO_t + \theta_4 FD_t + \theta_5 POP_t + \theta_6 OPEN_t + \theta_7 INF_t + \theta_8 RL_t + \theta_9 BD_t) F(S_t, \gamma, c) + u_t$$

SD: Sustainable development index. This study uses the World Bank's sustainable development index, which provides the most recent and comprehensive global development data. It measures achievements in poverty, health, hunger, global warming, gender inequality, water scarcity, energy, and environmental degradation. Values range from 0 to 1, with higher scores representing higher sustainable development (World Bank, 2020).

RQ: Institutional quality. This index is constructed from five aggregated components:

1. Size of government
2. Legal system and property rights
3. Accountability and transparency
4. International trade freedom
5. Regulatory environment for credit, labor, and business
6. The Fraser Institute assigns numerical values for each category, and the average produces the institutional quality index. Scores range from 0 (lowest quality) to 5 (highest quality).

BD: Government budget deficit.

ED: Total external debt as a percentage of gross domestic product (GDP).

FD: Financial development, measured as liquidity as a percentage of GDP.

OPEN: Trade openness, measured as (exports + imports) / GDP.

RO: Regulatory quality, measured using a percentile rank from 0 to 100. Higher values indicate better regulatory quality.

RL: Rule of law, measured using a percentile rank from 0 to 100. Higher values indicate stronger rule of law.

POP: Population growth rate.

INF: Inflation rate.

Findings and Results

Before estimating the model, a unit root test must be conducted to prevent the problem of spurious regression for the variables. Econometric literature on unit roots indicates that panel-based unit root tests have higher power

and accuracy compared to time-series unit root tests. In this article, the LLC unit root test is used to examine the stationarity of the variables. The LLC unit root test allows for heterogeneity among individual effects.

Table 1. Unit Root Test (LLC) for Variables

Variable Code	LLC W-stat (Computed Statistic)	Probability	Stationarity Level
BD	3.59707	0.0002	I(0)
ED	-2.49838	0.0062	I(0)
FD	-2.19661	0.0140	I(0)
INF	-5.66308	0.0000	I(0)
OPEN	-2.60541	0.0046	I(0)
POP	-5.34528	0.0000	I(0)
RL	-3.25844	0.0006	I(0)
RO	-9.47306	0.0000	I(0)
RQ	-4.31890	0.0000	I(0)
SD	-11.7389	0.0000	I(0)

The results of Table 1 and examination of the computed statistics and their probability values show that all research variables are stationary at level.

To examine the existence of a linear or nonlinear relationship among model variables, it must be determined whether *m* (number of regime parameters) equals one. It should be noted that in the following tests, the null hypothesis assumes a linear model, and the alternative hypothesis assumes a logistic PSTR model (m = 1) or an exponential PSTR model (m = 2).

The diagnostic results in Table (2) indicate that linearity (null hypothesis) is rejected; therefore, a nonlinear relationship exists between institutional quality, external debt, and sustainable development in the selected countries. Accordingly, PSTR must be used to estimate the model parameters.

Table 2. Linearity Hypothesis Test (BBC Test)

Selected Countries	Null Hypothesis	F-Statistic	Significance Level
Wald Test	—	3.785	0.000
Fisher Test	—	2.638	0.001
LRT Test	—	2.957	0.012

As shown in Table (2), the hypothesis of linearity among the variables is rejected; thus, the possibility of a linear relationship is ruled out. The PSTR model proposed by the selected transition variable is therefore appropriate for estimation in the selected countries.

To do so, following Gonzalez et al. (2005) and Colletaz & Hurlin (2006), the null hypothesis of a PSTR structure with one transition function is tested against the alternative of at least two transition functions. Results are shown in Table (3). The results indicate that the null hypothesis cannot be rejected for either one or two thresholds; therefore, one transition function is sufficient to capture the threshold effects of external debt on sustainable economic growth, considering heterogeneity in regulatory quality and institutional quality.

Table 3. Test for Nonlinear Relationship (Remaining Nonlinearity Test)

Selected Oil-Exporting Countries	One Threshold (M = 1)	Two Thresholds (M = 2)
LR	1.432 (0.654)	1.297 (0.802)
LMf	1.471 (0.630)	1.362 (0.751)
LMw	1.352 (0.743)	1.425 (0.675)

H0: r = 1, H1: r = 2

With confirmation of a nonlinear relationship and sufficiency of one transition function, the optimal choice between one or two thresholds must be made. Based on residual sum of squares, Schwarz, and Akaike criteria, the PSTR with one threshold is selected as the optimal model.

Using a PSTR model in which external debt is the transition variable, the sustainable development function is modeled. Following confirmation of nonlinearity, nonlinear results are analyzed.

The nonlinear estimation shows that the coefficient of external debt (ED) is −0.49, indicating a negative effect of external debt on sustainable development in the selected countries. The associated probability value is 0.0069, lower than 0.05; therefore, the effect is statistically significant at the 95% confidence level.

The coefficients for institutional quality, regulatory quality, and rule of law are 0.016, 0.089, and 0.235, with respective probabilities 0.0355, 0.0015, and 0.0053, indicating positive and significant effects on sustainable development.

Inflation and budget deficit have negative and significant effects on sustainable development. Trade openness (coefficient = 0.05, probability = 0.0165) has a positive and significant impact on sustainable development in the selected oil-exporting countries.

Table 4. Model Estimation Using PSTR

Variable	Coefficient	Std. Error	t-Statistic	Probability
Linear Component of the Model				
CONSTANT	0.329059	0.136048	2.418698	0.0234
ED	−0.158886	0.075984	−2.091051	0.0419
RQ	0.582868	0.239013	2.438644	0.0149
RO	0.096233	0.026454	3.637702	0.0003
FD	0.110132	0.055542	1.982849	0.0491
POP	0.212527	0.090308	2.353357	0.0356
OPEN	0.393667	0.142781	2.757139	0.0201
INF	−0.642607	0.230948	−2.782475	0.0200
RL	0.097980	0.028983	3.380603	0.0008
BD	−0.433451	0.159418	−2.718959	0.0218
Nonlinear Component of the Model				
CONSTANT	0.016839	0.006021	2.796881	0.0049
ED	−0.496421	0.175702	−2.825358	0.0069
RQ	0.016559	0.007091	2.335214	0.0355
RO	0.089278	0.027937	3.195642	0.0015
FD	0.197885	0.085146	2.324058	0.0201
POP	0.022717	0.010298	2.205968	0.0274
OPEN	0.053752	0.022425	2.396934	0.0165
INF	−0.012901	0.004822	−2.675502	0.0077
RL	0.235516	0.085117	2.762255	0.0053
BD	−0.014838	0.006607	−2.245690	0.0378
Threshold (c)	−6.21114	0.042362	−4.98441	0.0000
Slope Parameter (γ)	0.73577	0.21569	3.41115	0.0007
Adjusted R^2	0.85	—	—	—

Comparing coefficients across regimes shows that once external debt crosses the estimated threshold (−0.21), the reaction of sustainable development sharply increases. Higher levels of external debt cause a stronger adverse response in sustainable development.

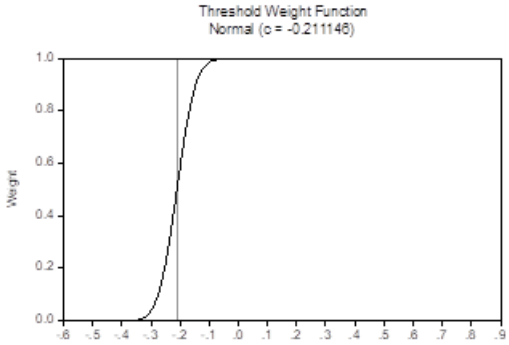

Figure 1. Relationship Between Transition Function and Transition Variable

The Durbin–Watson test is applied to examine autocorrelation.

Table 5. Autocorrelation Test Results

Selected Countries	F-Statistic	Probability	Durbin–Watson
Middle Eastern Oil-Exporting Countries	1.235	0.69	2.236

The Durbin–Watson test results indicate no autocorrelation; therefore, the classical assumption of no autocorrelation is not violated, and the estimators remain efficient.

A second classical assumption is homoscedasticity. The Breusch–Pagan–Godfrey test is used.

Table 6. Heteroskedasticity Test Results

Selected Countries	F-Statistic	Probability	Breusch–Pagan–Godfrey
Middle Eastern Oil-Exporting Countries	1.298	0.556	1.327

The results indicate no evidence of heteroskedasticity.

Another important diagnostic concerns the stability of coefficients across regimes. If the estimated model is appropriate, coefficients should remain stable.

Table 7. Smooth Transition Parameter Stability Test

Selected Countries	Null Hypothesis	F-Statistic	Probability
Middle Eastern Oil-Exporting Countries	b1 = b2 = b3 = b4 = 0	0.745	0.754
	b1 = b2 = b3 = 0	0.798	0.712
	b1 = b2 = 0	0.821	0.695
	b1 = 0	0.836	0.674

The results show that switching between regimes does not lead to coefficient instability.

Discussion and Conclusion

The findings of this study demonstrate a clear and significant nonlinear relationship between external debt and sustainable economic growth in the selected oil-exporting Middle Eastern countries. The negative coefficient for external debt in the nonlinear regime indicates that, once a specific threshold is exceeded, the burden of external borrowing intensifies its adverse effects on sustainable development. This outcome aligns with the growing body of empirical literature showing that debt overhang, rising interest obligations, and fiscal vulnerabilities undermine long-term economic and environmental objectives when external borrowing surpasses a manageable level (1, 5). Studies focusing on Sub-Saharan Africa and developing economies consistently report similar results, emphasizing that beyond certain thresholds, external debt contributes to macroeconomic instability, constrains public investment,

and weakens the capacity of governments to pursue sustainable development targets (6, 9). The negative marginal impact observed in this study is particularly consistent with the argument that debt-dependent economies, especially resource-reliant ones, face increasing vulnerabilities in periods of global uncertainty, volatility in oil prices, and tightening international financial conditions (7).

The analysis further reveals that institutional quality, regulatory effectiveness, and the rule of law exert significant positive effects on sustainable economic growth. These results reinforce the idea that strong governance structures play a decisive role in determining whether external debt becomes a catalyst for development or a source of economic fragility. Prior studies confirm that governance quality moderates debt–growth dynamics by improving public resource allocation, reducing corruption, enhancing transparency, and ensuring that debt-financed expenditures are directed toward productive and environmentally sustainable uses (1, 9). Research on institutional quality within the African and emerging-market contexts similarly documents that countries with stronger legal frameworks, more effective regulations, and higher administrative capacity manage debt more efficiently and face lower risks of fiscal mismanagement (11, 12). The finding that regulatory quality and rule of law contribute significantly to sustainable development also corresponds to evidence from OECD and high-income nations, where regulatory clarity and effective environmental governance underpin green innovation and sustainable trade practices (18-20). Thus, this study strengthens the argument that institutions are not merely background conditions but active determinants shaping the impact of external debt on development outcomes.

Trade openness also shows a positive and significant effect on sustainable development in the selected countries. This finding is consistent with research showing that trade integration can facilitate access to cleaner technologies, expand markets for diversified production, and create incentives for environmental regulation when paired with strong institutional capacity (14, 21, 27). Evidence from Sub-Saharan Africa, Latin America, and Asia-Pacific countries increasingly suggests that trade openness alone does not guarantee sustainable outcomes; rather, its benefits materialize when economies adopt complementary policies that promote green innovation, renewable energy investment, and environmental accountability (22, 24, 25). The results here support such findings, as the observed positive effect of trade openness coincides with countries exhibiting varied but generally improving institutional conditions. In line with research on G20 and OECD countries, the findings imply that trade liberalization contributes to sustainable development when it strengthens technology transfer and environmental policy diffusion rather than reinforcing resource-dependent or carbon-intensive production (26, 28).

The study also identifies a negative and significant effect of inflation and budget deficit on sustainable development. These outcomes align with empirical work showing that macroeconomic instability undermines sustainable growth by eroding purchasing power, increasing uncertainty, reducing public investment capacity, and threatening social welfare (4, 13). Inflation in particular can weaken environmental policy enforcement and raise the costs of renewable energy adoption when economies become more vulnerable to external shocks (17). Likewise, budget deficits reduce fiscal space, making it more difficult for governments to allocate funds toward sustainability-enhancing investments such as clean energy infrastructure, environmental protection, or human capital development (21). These findings affirm that achieving sustainable economic development requires not only external debt management and institutional strengthening but also macroeconomic stability and sound fiscal governance.

Moreover, the nonlinear structure detected in the PSTR model underscores the importance of considering threshold effects in the debt–sustainability relationship. As suggested by previous studies, linear models may

obscure critical dynamics, particularly in economies characterized by structural heterogeneity, resource dependency, or fluctuating institutional capacity (6, 10). The behavior observed in this study—where the marginal impact of debt becomes significantly more severe beyond a particular threshold—is consistent with evidence from developing regions that nonlinearity is intrinsic to debt dynamics. Several studies suggest that borrowing initially stimulates growth by expanding fiscal space but generates diminishing or negative returns as debt accumulates (5, 15). The results here contribute to this literature by quantifying such nonlinear effects within the context of oil-exporting Middle Eastern economies, where dependence on commodity revenues adds an additional layer of vulnerability.

The role of technological change and global digital transformation, although not directly measured in this study, offers important contextual relevance for interpreting the results. Recent literature highlights how artificial intelligence, advanced data analytics, and digitalization influence productivity, public sector efficiency, and environmental monitoring (29, 30). AI-based tools in education, construction, and management have the potential to reduce resource wastage, improve innovation processes, and enhance the quality of public decision-making (31, 33). These developments reinforce the argument that institutional quality can amplify the benefits of new technologies while mitigating risks—further supporting the findings that governance plays a pivotal role in shaping sustainable development outcomes. As digital governance capabilities expand, countries with stronger regulatory institutions may be better positioned to leverage borrowing for technologically driven sustainability projects.

Overall, the findings of this study contribute to the diverse strands of research on sustainability, trade, external debt, and institutional economics by emphasizing that sustainable economic growth in oil-exporting Middle Eastern economies is shaped by a complex interplay between macroeconomic indicators, governance frameworks, trade integration, and nonlinear debt dynamics. The results highlight that external debt can either support or hinder sustainable development depending on structural conditions, aligning with global evidence that effective institutions and integration into environmentally responsible global markets are essential prerequisites for transforming debt into a catalyst for long-term growth.

This study is subject to several limitations. First, the analysis relies on secondary macroeconomic data, which may contain measurement errors or inconsistencies across countries. Second, the study focuses exclusively on oil-exporting Middle Eastern economies, limiting the generalizability of the results to other regions. Third, the institutional quality indicators used may not fully capture deeper governance characteristics such as political stability, informal institutions, or cultural dimensions. Fourth, the model does not account for exogenous shocks such as geopolitical conflicts, pandemics, or global energy crises, which could influence debt dynamics and sustainability outcomes. Finally, although the PSTR model effectively captures nonlinearities, it does not isolate causal pathways or explore the micro-level mechanisms through which institutions influence debt management.

Future research could extend the current analysis by incorporating additional institutional dimensions such as political stability, anti-corruption measures, and government effectiveness. Comparative studies across regions with different resource endowments would provide deeper insights into the heterogeneity of debt–growth dynamics. Research may also integrate environmental indicators such as carbon emissions, renewable energy adoption, or environmental governance indices to better capture the sustainability dimension. Incorporating structural breaks, geopolitical events, and global energy market fluctuations could also improve model robustness. Future work might employ mixed-methods approaches combining econometric modeling with qualitative assessments to better

understand institutional processes. Finally, exploring the role of digital governance and AI-driven public sector innovations may offer new perspectives on strengthening institutional capacity in debt management.

Policymakers should strengthen regulatory quality and institutional frameworks to ensure that external debt is channeled into productive and environmentally sustainable sectors. Governments should prioritize macroeconomic stability by managing inflation and fiscal deficits to maintain the conditions necessary for sustainable growth. Regional cooperation among Middle Eastern oil-exporting countries may enhance resilience through knowledge sharing, trade diversification, and coordinated environmental policies. Investments in digital governance systems can improve debt management transparency and strengthen evidence-based decision-making. Finally, policymakers should pursue trade openness strategically by fostering green innovation, encouraging renewable energy adoption, and negotiating trade agreements that support environmental sustainability.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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