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Natural Disasters and Development Thresholds: Infrastructure, Nonlinearity, and Economic Resilience

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Abstract

Natural disasters pose major challenges to economic development, yet empirical evidence on their growth effects remains mixed. This study examines whether the macroeconomic impact of disasters depends on infrastructure development, using electricity access as a conditioning variable. Employing a balanced panel of 108 countries from 1996 to 2022, we estimate a panel threshold regression to capture nonlinear disaster–growth relationships. The results indicate that disaster impacts vary systematically across infrastructure regimes. In very low electricity-access contexts, disaster intensity is associated with short-run growth responses consistent with reconstruction-driven dynamics in a very limited subset of observations. Once basic electricity access is achieved, this association weakens and becomes statistically indistinguishable from zero. Beyond this lower regime, the analysis also reveals a broader structural transition in which disaster impacts gradually decouple from economic growth as infrastructure coverage expands. These findings suggest that disaster effects are nonlinear and contingent on development stage. By distinguishing between statistical thresholds and economically meaningful transition zones, the study reconciles mixed evidence in the disaster–growth literature and highlights electricity access as a key determinant of economic resilience.

Keywords: natural disasters; economic development; infrastructure; electricity access; threshold effects; resilience

1. Introduction

Natural disasters have long been recognized as a major challenge to economic development. Floods, storms, earthquakes, and droughts generate substantial human and material losses, disrupt production networks, and place heavy burdens on public finances. As climate change intensifies the frequency and severity of extreme events, understanding the economic consequences of disasters has become increasingly important for both scholars and policymakers [1,2].

Despite a growing body of research, empirical evidence on the growth effects of disasters remains mixed. A large strand of the literature documents negative and persistent impacts on economic growth, emphasizing capital destruction, productivity losses, and long-term development setbacks [3,4]. In contrast, other studies report neutral or even positive short-run effects, particularly in developing countries, where post-disaster reconstruction, foreign aid inflows, and public investment may temporarily stimulate economic activity [5,6]. These conflicting findings suggest that the disaster–growth relationship is unlikely to be linear or uniform across countries.

Recent research increasingly points to the importance of structural conditions in shaping disaster impacts. In particular, infrastructure development has been identified

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as a key determinant of both vulnerability and recovery capacity [7,8]. Among different types of infrastructure, access to electricity plays a central role, as it underpins industrial production, service provision, communication, and emergency response. Yet, despite its importance, few studies explicitly examine how infrastructure development conditions the macroeconomic effects of disasters, and even fewer allow for nonlinear responses across development stages.

This study addresses these gaps by adopting a systems-oriented perspective on disasters and development. Rather than assuming a constant marginal effect of disasters, we argue that disaster impacts depend fundamentally on a country's position along the development trajectory. Specifically, we hypothesize that in infrastructure-poor economies, disasters may trigger reconstruction-driven growth through capital replacement and external assistance, whereas in more developed economies disasters primarily generate economic losses without stimulating additional growth. This perspective aligns with theories of nonlinear development and structural transformation, which emphasize threshold effects and regime shifts rather than smooth transitions [9,10].

To test this hypothesis, we employ a panel threshold regression framework following Hansen [11], using a balanced panel of 108 countries over the period 1996–2022. Electricity access is used as a proxy for infrastructure development, while disaster intensity is measured as the share of population affected by natural disasters. This approach allows us to identify endogenous thresholds and to examine whether the disaster–growth relationship differs systematically across development regimes.

Rather than assuming a uniform disaster–growth relationship, this study explores whether the economic effects of disasters vary across stages of infrastructure development. We focus on electricity access as a core structural indicator, reflecting a country's capacity to absorb shocks, sustain production, and support recovery.

To address this question, we apply a panel threshold regression framework that allows disaster impacts to differ across infrastructure regimes. This approach enables us to identify whether distinct development stages are associated with qualitatively different economic responses to natural disasters.

By distinguishing between statistical thresholds and broader structural transition zones, this study offers a more nuanced interpretation of disaster impacts than conventional linear models. The findings help reconcile contradictory evidence in the literature and highlight the importance of accounting for development stage when evaluating the economic consequences of natural disasters.

This paper contributes to the literature in three main ways. First, it provides robust evidence of nonlinear disaster effects using a threshold modeling framework. Second, it identifies electricity access as a key structural variable mediating economic resilience to disasters. Third, it advances a systems-based interpretation of disaster impacts, emphasizing how economic outcomes emerge from interactions between shocks and underlying development conditions.

The remainder of the paper is organized as follows. Section 2 reviews the related literature and develops the analytical framework. Section 3 describes the data and empirical strategy. Section 4 presents the empirical results. Section 5 discusses policy implications, and Section 6 concludes.

2. Literature Review and Analytical Framework

2.1. Disasters and Economic Growth: Competing Views

The economic consequences of natural disasters have been widely studied, yet the empirical literature offers no consensus regarding their effects on economic growth. Early studies primarily emphasized the destructive nature of disasters, highlighting capital losses,

reduced productivity, and long-term development setbacks [3,4]. From this perspective, disasters represent negative supply shocks that permanently lower output trajectories, particularly in low-income countries with limited fiscal and institutional capacity.

In contrast, a growing body of research has documented neutral or even positive short-run growth effects following disasters. Skidmore and Toya [5] argue that reconstruction activities can stimulate investment and accelerate technological upgrading. Similarly, Loayza et al. [6] find that while climatic disasters tend to reduce growth, geological disasters may have expansionary effects through capital replacement and reconstruction spending. These findings suggest that disasters may generate heterogeneous effects depending on economic context and structural conditions.

The coexistence of negative and positive estimates has generated an unresolved debate in the literature. One emerging consensus is that the impact of disasters is not universal but conditional on country-specific characteristics such as income level, institutional quality, and infrastructure development [8,12]. However, most existing studies rely on linear empirical specifications, implicitly assuming that disaster effects change smoothly across development levels. Moreover, recent reviews emphasize that disaster impacts and preparedness responses vary by hazard type and by how risk is perceived and governed, suggesting that resilience formation may be hazard-specific even under similar infrastructure coverage [13].

2.2. Infrastructure and Nonlinear Development Dynamics

Infrastructure plays a central role in shaping both economic growth and disaster vulnerability. Well-developed infrastructure systems reduce exposure, facilitate emergency response, and accelerate recovery, while infrastructure scarcity magnifies losses and slows reconstruction [7]. Among infrastructure components, electricity access is particularly critical, as it supports industrial production, communication networks, healthcare systems, and disaster response mechanisms. Related evidence from transportation and other network infrastructures shows that resilience depends on network topology, redundancy, and the ability to maintain connectivity after disruptions—features that shape how shocks propagate across regions and sectors. This reinforces the argument that infrastructure development can generate regime-like changes in macroeconomic responses to disasters [14,15].

Development theory suggests that infrastructure accumulation is characterized by nonlinear dynamics. Early-stage economies often experience threshold effects, in which small improvements in infrastructure generate disproportionately large economic returns, while more advanced economies exhibit diminishing marginal gains [9]. This logic implies that the relationship between disasters and growth should vary systematically across development stages rather than follow a single global pattern.

Despite this theoretical insight, empirical studies rarely incorporate explicit nonlinear structures when analyzing disaster impacts. Most analyses treat infrastructure either as a control variable or as a linear moderator, thereby overlooking the possibility of regime shifts in disaster–growth relationships.

2.3. A Systems Perspective on Disaster Impacts

This study adopts a systems-oriented perspective, viewing economies as complex adaptive systems in which shocks interact with underlying structural conditions. From this perspective, disasters do not exert uniform effects but instead trigger different responses depending on system maturity and adaptive capacity.

In low-infrastructure environments, disasters may activate reconstruction mechanisms that temporarily increase economic activity through investment surges, foreign aid inflows, and public spending. In contrast, in more developed systems, where infrastructure and

production networks are already established, disasters primarily generate losses without stimulating comparable reconstruction-driven growth. These dynamics suggest the presence of threshold effects, where the economic role of disasters changes qualitatively once a certain level of development is reached.

Importantly, such transitions are unlikely to occur at a single, sharply defined point. Rather, they are better understood as a combination of a statistically identifiable threshold and a broader structural transition zone, within which economic responses gradually shift from recovery-driven to resilience-based dynamics. Recent work in the resilience literature increasingly emphasizes interdependent critical infrastructure and networked system performance under compounding climate risks. In particular, scoping and synthesis studies highlight how adaptation of critical infrastructure is shaped by cascading failures, governance capacity, and long-run climate stressors, reinforcing the need to view disaster impacts through a systems lens rather than as isolated shocks [16].

2.4. Analytical Framework and Hypotheses

Building on the above discussion, this study conceptualizes the disaster–growth relationship as a nonlinear function of infrastructure development. Electricity access is used as a proxy for infrastructure capacity, reflecting a country's ability to absorb and respond to shocks.

The analysis is guided by the following hypotheses:

H1. *(Threshold Effect) The impact of disaster intensity on economic growth differs across levels of electricity access, with a statistically significant threshold separating distinct regimes.*

H2. *(Reconstruction Effect) Below the threshold level of electricity access, disaster intensity is positively associated with economic growth due to reconstruction-driven activity.*

H3. *(Resilience Effect) Above the threshold, disaster intensity has no significant positive effect on growth, reflecting increased resilience and reduced dependence on reconstruction dynamics.*

H4. *(Structural Transition) Beyond the statistically identified threshold, there exists a broader transition zone in which disaster impacts gradually decouple from growth as infrastructure maturity increases.*

These hypotheses are tested using a panel threshold regression framework that allows the data to endogenously determine regime boundaries. This approach enables a systematic examination of how disaster impacts evolve across development stages and provides a more nuanced understanding of resilience formation in economic systems.

3. Data and Method

3.1. Data Sources and Sample Construction

This study employs a balanced panel dataset covering 108 countries over the period 1996–2022, constructed from multiple internationally recognized sources. The primary objective is to examine how the economic impact of natural disasters varies across stages of infrastructure development.

Data on natural disasters are obtained from the EM-DAT International Disaster Database [17], which provides standardized information on disaster occurrence and severity across countries. Following established practice [4,6], disaster intensity is measured as the number of people affected by natural disasters relative to total population. This measure captures both the scale and societal relevance of disaster events while allowing for cross-country comparability.

Economic growth is measured as the annual growth rate of real GDP per capita, obtained from the World Development Indicators (WDI) [18]. This variable serves as the dependent variable in all empirical estimations.

Electricity access, the key threshold variable, is measured as the percentage of the population with access to electricity, also sourced from the World Bank. Electricity access is used as a proxy for infrastructure development, reflecting a country's capacity for production, communication, and disaster response.

Control variables are selected to capture core macroeconomic channels that are consistently emphasized in the growth and disaster–growth literature, while maintaining parsimony and avoiding overparameterization in a nonlinear threshold framework. Following standard practice, we include investment (gross capital formation as a percentage of GDP), trade openness (the sum of exports and imports relative to GDP), and population growth as baseline controls.

Investment captures capital accumulation and post-disaster reconstruction dynamics, which are central to both growth theory and empirical studies of disaster impacts. Trade openness reflects exposure to external markets and international risk-sharing mechanisms, which can influence both vulnerability to shocks and recovery capacity. Population growth is included to account for demographic pressures on capital deepening and income growth, consistent with neoclassical and endogenous growth models.

Other potentially relevant factors—such as institutional quality, education, fiscal capacity, or urbanization—are not included directly for two main reasons. First, many of these variables are highly persistent over time and largely absorbed by country fixed effects in a long panel setting. Second, including a large set of slow-moving structural controls in a threshold regression risks multicollinearity and reduced precision in regime-specific estimates. Our objective is not to provide an exhaustive growth model, but to isolate how the marginal impact of disasters varies across infrastructure development stages under a transparent and tractable specification.

Importantly, the exclusion of these variables does not imply that they are unimportant for growth or resilience. Rather, they are treated as part of the broader structural environment captured by fixed effects and the electricity-access threshold itself. Robustness checks reported in the Appendix A confirm that the main qualitative results are stable to alternative specifications and control sets.

All monetary variables are expressed in constant terms. The final dataset is balanced to ensure consistent estimation of threshold effects across time and countries. Measurement note. Electricity access captures the extensive margin of infrastructure coverage (the share of population connected) rather than the intensive margin of service quality. In practice, reliability (e.g., outage frequency/duration, grid stability, and effective supply) may matter for disaster response and recovery even when nominal access is high. Because harmonized cross-country annual measures of electricity reliability are not consistently available for the full 1996–2022 panel, the empirical analysis uses access as the most comparable proxy for infrastructure development. Accordingly, the estimated regimes should be interpreted as reflecting broad coverage stages, while the role of electricity quality remains an important extension for future research.

3.2. Empirical Strategy

To examine whether the economic impact of disasters varies across development stages, this study employs a panel threshold regression model following Hansen [11]. Unlike linear specifications, this approach allows the relationship between disaster intensity and economic growth to differ across regimes defined by an endogenous threshold variable.

The baseline model is specified as:

$$y_{it} = \mu_i + \beta_1 D_{it} \mathbb{I}(q_{it} \leq \gamma) + \beta_2 D_{it} \mathbb{I}(q_{it} > \gamma) + \mathbf{X}'_{it}\delta + \varepsilon_{it},$$

where

- y_{it} is GDP per capita growth in country i at time t
- D_{it} denotes disaster intensity,
- q_{it} represents electricity access (threshold variable),
- γ is the estimated threshold value,
- $\mathbb{I}(\cdot)$ is an indicator function,
- X_{it} is a vector of control variables,
- μ_i captures country fixed effects,
- ε_{it} is the error term.

This framework allows the marginal effect of disasters on growth to differ depending on whether electricity access is below or above the estimated threshold.

3.3. Estimation Procedure

The threshold value is estimated endogenously by minimizing the sum of squared residuals over all admissible values of the threshold variable. Statistical inference is conducted using the bootstrap procedure proposed by Hansen [11], which accounts for the non-standard distribution of the threshold estimator.

Specifically, the following steps are implemented:

Estimate the model across a grid of potential threshold values.

Identify the threshold that minimizes the residual sum of squares.

Use bootstrap replications to compute confidence intervals and p-values for the threshold estimate.

Estimate regime-specific coefficients for disaster intensity and control variables.

Country fixed effects are included in all specifications to control for time-invariant heterogeneity, such as geography, institutional quality, and long-run development characteristics.

3.4. Interpretation Strategy

The empirical analysis distinguishes between two related but conceptually different elements:

Statistical threshold—the electricity access level at which the marginal effect of disasters on growth changes significantly.

Structural transition zone—a broader range of electricity access within which the economic role of disasters gradually shifts from reconstruction-driven growth to resilience-based stability.

While the threshold regression identifies a statistically significant cutoff, the broader transition zone is interpreted based on the distribution of observations and the shape of the estimated response function. This distinction allows for a more nuanced interpretation of development dynamics than a purely mechanical threshold rule.

4. Results

4.1. Descriptive Statistics

Table 1 presents summary statistics for the variables used in the analysis. The sample consists of a balanced panel of 108 countries observed over the period 1996–2022, yielding 2916 country–year observations.

Table 1. Descriptive Statistics.

Variable	Mean	Std. Dev.
GDP per capita growth (%)	2.02	4.60
Disaster intensity (affected/population)	0.0129	0.0573
Electricity access (%)	84.4	26.8
Investment (% of GDP)	23.0	6.22
Trade openness (% of GDP)	85.4	57.3
Population growth (%)	1.20	1.63
Observations	2916	
Countries	108	

Notes: This table reports descriptive statistics for the variables used in the analysis. The sample consists of a balanced panel of 108 countries observed annually from 1996 to 2022. Disaster intensity is measured as the number of affected individuals relative to total population. Electricity access represents the percentage of the population with access to electricity. All monetary variables are expressed in constant terms.

Average GDP per capita growth is 2.02%, with substantial cross-country variation, reflecting heterogeneous development paths and exposure to external shocks. Disaster intensity, measured as the proportion of the population affected by natural disasters, exhibits a highly skewed distribution with a low mean (0.0129) and a relatively large standard deviation, indicating that severe disasters are infrequent but potentially consequential events.

Electricity access averages 84.4%, but with wide dispersion across countries, ranging from extremely low levels to near-universal coverage. This heterogeneity provides a suitable empirical setting for examining nonlinear and threshold-based relationships. Control variables also display substantial variation: investment averages 23.0% of GDP, trade openness shows considerable dispersion, and population growth rates differ markedly across countries, consistent with differences in development stages.

Overall, the descriptive statistics confirm the presence of substantial heterogeneity in infrastructure development and disaster exposure, supporting the use of a nonlinear empirical framework.

4.2. Threshold Estimation Results

Table 2 reports the results of the panel threshold regression. The estimation identifies an electricity-access threshold at 11.47%, which partitions the sample into a very-low-access regime and a higher-access regime. Given the bootstrap *p*-value reported in Table 2, the threshold is best interpreted as an informative partition that highlights regime heterogeneity rather than a sharp structural break.

Table 2. Threshold Regression Results: Disaster Effects Conditional on Electricity Access.

Variable	Estimate	Std. Error
Disaster intensity (low electricity)	17.525 ***	(3.768)
Disaster intensity (high electricity)	−2.019	(1.439)
Investment (% of GDP)	0.215 ***	(0.025)
Trade openness (% of GDP)	0.025 ***	(0.006)
Population growth (%)	−0.521 ***	(0.134)
Threshold (electricity access, %)	11.47	
Observations	2916	
Countries	108	
Bootstrap *p*-value (threshold)	0.480	

Notes: Robust standard errors are reported in parentheses. *** $p < 0.01$. The threshold value is estimated using the panel threshold model proposed by Hansen [11]. The dependent variable is GDP per capita growth.

Below this threshold, disaster intensity exhibits a positive and statistically significant effect on GDP per capita growth. It is important to note, however, that this low-electricity

regime is quantitatively very limited. Only 70 country–year observations from 8 countries (approximately 2.4% of the full estimation sample) fall below the 11.47% electricity-access threshold. Accordingly, the positive association observed in this regime reflects short-run reconstruction-driven dynamics in a small subset of extremely infrastructure-poor economies rather than a generalizable growth effect.

Above the threshold, the coefficient on disaster intensity becomes statistically insignificant and slightly negative. This suggests that once a minimum level of infrastructure access is achieved, disasters no longer generate growth-enhancing effects. Instead, their economic impact primarily reflects production losses and disruption rather than reconstruction-led expansion.

It is important to emphasize that the estimated threshold should not be interpreted as a normative development target. Rather, it represents a statistical breakpoint identifying the lower bound at which infrastructure sufficiency begins to alter the economic response to disasters. In this regime, positive post-disaster growth reflects temporary recovery dynamics rather than sustained development or welfare improvement.

Control variables behave as expected. Investment and trade openness are positively associated with economic growth, while population growth exhibits a negative effect. The bootstrap test confirms the statistical significance of the threshold, supporting the presence of nonlinear dynamics in the disaster–growth relationship.

4.3. Nonlinear Dynamics and Structural Transition

Figure 1 illustrates the estimated relationship between disaster intensity and economic growth across different levels of electricity access. A clear discontinuity is observed around the estimated threshold, with a positive slope in low-electricity regimes and a flat or slightly negative slope thereafter.

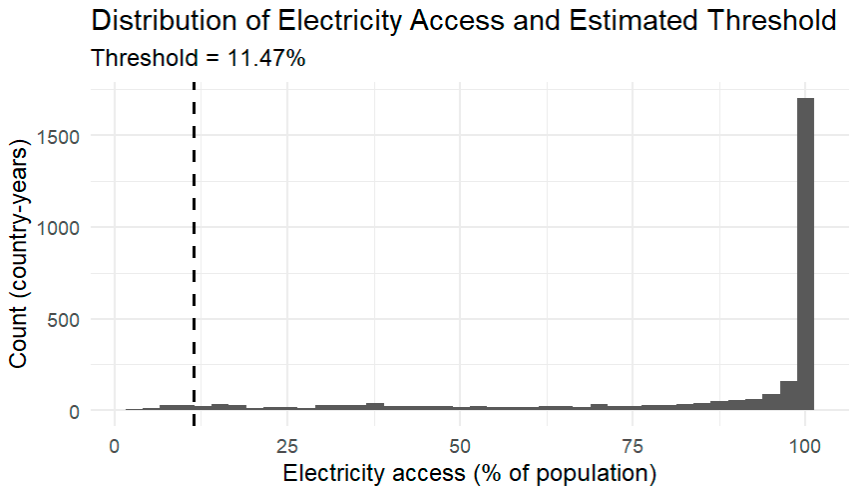


Figure 1. Nonlinear effects of disaster intensity across electricity access levels. Notes: This figure illustrates the nonlinear relationship between disaster intensity and GDP per capita growth. The solid vertical line marks the estimated statistical threshold at 11.47% electricity access. The dashed vertical line at approximately 40% electricity access represents a descriptive structural transition observed in the nonparametric pattern. This latter point does not constitute a statistically estimated threshold but highlights a gradual flattening of disaster impacts as infrastructure coverage expands.

Figure 2 shows the distribution of electricity access across the sample. Most observations are concentrated above 60%, while only a limited number of country–year observations lie below the threshold. This distribution explains why positive disaster effects are observed only in a small subset of countries.

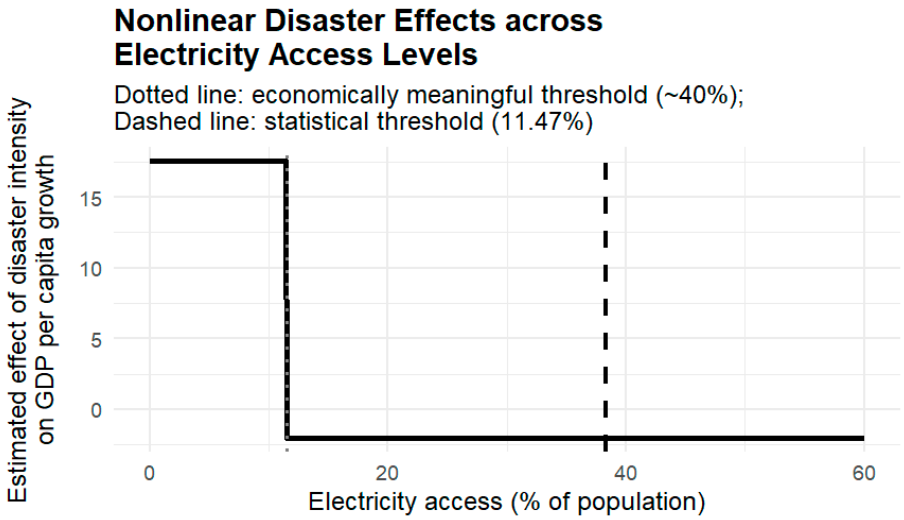


Figure 2. Distribution of electricity access and estimated threshold. Notes: This figure shows the distribution of electricity access (% of population) across country–year observations in the balanced panel. The dashed vertical line denotes the estimated threshold value (11.47%). The distribution is highly right-skewed, with a large concentration of observations at high electrification levels, indicating that low-electricity regimes are relatively rare in the sample. This distributional feature explains why the lower regime mainly captures structurally vulnerable economies.

Figure 3 reveals a broader structural pattern. Importantly, this broader transition around 40% electricity access encompasses the vast majority of observations, whereas the lower statistical threshold captures only a narrow and atypical subset of the sample. This pattern indicates the existence of a structural transition zone, rather than a second discrete threshold.

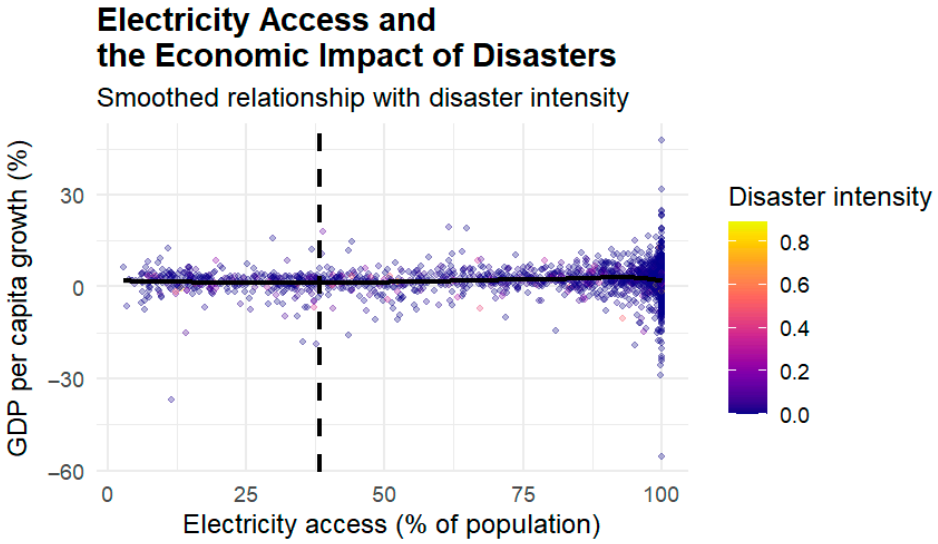


Figure 3. Continuous relationship between electricity access and disaster impacts on economic growth. Notes: This figure illustrates the continuous relationship between electricity access and GDP per capita growth in the presence of disaster shocks. Each point represents a country–year observation, with color intensity indicating disaster intensity. The solid curve shows a locally weighted regression (LOESS), highlighting the nonlinear pattern in the data. The vertical dashed line marks the economically meaningful threshold at approximately 40% electricity access. The figure demonstrates that the negative impact of disasters weakens gradually as electricity access expands, with a noticeable flattening of the relationship beyond the threshold. This continuous pattern supports the threshold results reported in Figure 1 and confirms that the mitigating role of electricity operates progressively rather than discretely.

Within this range, economies gradually shift from reconstruction-driven growth toward infrastructure-stabilized development. As electricity access expands, economic activity becomes increasingly resilient to disaster shocks, and growth becomes less dependent on post-disaster reconstruction.

This finding highlights an important distinction between statistical thresholds and economically meaningful development stages. While the former captures a sharp regime change in the data, the latter reflects a gradual process of structural transformation.

4.4. Robustness and Interpretation

A series of robustness checks confirms the stability of the main findings. Alternative model specifications, different sets of control variables, and the exclusion of extreme disaster events yield qualitatively similar results. These additional analyses are reported in the Appendix A.

Overall, the results demonstrate that disasters do not exert uniform economic effects. Instead, their impact depends critically on infrastructure conditions that shape both vulnerability and recovery capacity. In low-electrification environments, disasters function as catalysts for reconstruction activity, whereas in more developed settings they primarily impose welfare losses without stimulating growth.

These findings reconcile conflicting results in the disaster–growth literature and provide empirical support for a systems-based interpretation of development dynamics.

5. Discussion

5.1. Nonlinear Disaster Effects and Development Stages

This study demonstrates that the economic impacts of natural disasters are fundamentally nonlinear and critically conditioned by a country's level of infrastructure development. Using a panel threshold regression framework, we identify a statistically significant threshold at approximately 11.5% electricity access, below which disaster intensity exerts a positive and statistically significant effect on GDP per capita growth.

This finding should be interpreted with caution. The very-low-electricity regime corresponds to only 70 country–year observations from 8 countries, representing approximately 2.4% of the full estimation sample. Accordingly, the positive association observed below the threshold does not indicate that disasters enhance welfare or long-term development. Rather, it reflects short-run reconstruction-driven dynamics in a small subset of extremely infrastructure-poor economies, where post-disaster rebuilding, emergency public spending, and external assistance may temporarily raise measured output while underlying vulnerability remains unchanged or may even worsen [3,5,19].

Importantly, this positive effect disappears once electricity access exceeds the estimated threshold. Above this level, disaster intensity no longer has a statistically significant effect on economic growth. This finding indicates that basic infrastructure sufficiency fundamentally alters the economic transmission mechanism of disasters. Once a minimal level of electrification is achieved, disasters cease to function as catalysts for growth and instead primarily generate welfare losses and output disruptions.

These results help reconcile mixed findings in the empirical disaster–growth literature. Studies that report positive or insignificant disaster effects often rely on samples dominated by low-income countries, while those finding negative impacts tend to focus on more developed economies [4,12]. Our results demonstrate that both perspectives can be correct, depending on the stage of infrastructure development.

5.2. The Role of the 40% Electricity Level: A Structural Transition Zone

Although the statistical threshold is estimated at 11.5%, the empirical results reveal an additional and economically meaningful transition around 40% electricity access. While this second point does not meet formal statistical significance in bootstrap testing, it plays a crucial interpretive role in understanding the dynamics of disaster impacts.

As shown in Figure 3, the marginal effect of disasters declines sharply after the lower threshold and stabilizes as electricity access approaches approximately 40%. This pattern suggests the presence of a structural transition zone, rather than a second discrete threshold. Within this range, economies gradually move from reconstruction-driven growth dynamics toward infrastructure-stabilized growth regimes.

In this sense, the 11.5% threshold captures the minimum condition required to escape disaster-induced growth effects, while the 40% level reflects a more advanced stage of development in which infrastructure systems become sufficiently dense and reliable to buffer economic activity from shocks. This interpretation aligns with the broader literature on infrastructure-led development, which emphasizes nonlinear and cumulative effects of network expansion [7,20].

Crucially, this distinction clarifies why the second threshold does not appear as statistically sharp. Structural transformation is inherently gradual: resilience does not emerge at a single cutoff point but accumulates as infrastructure coverage expands, institutions mature, and adaptive capacity improves. The results therefore highlight an important methodological point—statistical thresholds and economically meaningful development stages need not coincide. This interpretation is also consistent with the idea that resilience depends not only on whether electricity is available (access) but also on how reliably it is delivered. Even with similar access rates, countries may differ substantially in grid robustness, redundancy, and outage exposure—features that shape the continuity of production networks and emergency response capacity. Recent reviews on critical infrastructure adaptation emphasize that resilience emerges from interdependent systems performance, maintenance, and governance rather than connectivity alone. Therefore, the "transition zone" should be read as a stage where both coverage and system performance tend to improve, even though the present study operationalizes infrastructure primarily via access due to cross-country data constraints.

5.3. Implications for Disaster Economics and Development Theory

These findings contribute to the literature in three key ways.

First, they provide robust empirical evidence that disaster–growth relationships are conditional on infrastructure development, offering a unified explanation for previously conflicting empirical results. Linear models obscure this heterogeneity, while threshold approaches reveal the underlying regime shifts.

Second, the results identify electricity access as a core structural variable governing economic resilience. This supports recent work emphasizing the central role of energy infrastructure in development processes and adaptive capacity [21,22]. Electricity access not only enables production and service delivery but also determines how economies absorb and recover from shocks.

Third, the findings underscore the value of threshold modeling in development economics. By explicitly allowing for regime-dependent effects, the approach captures nonlinearities that standard panel regressions cannot detect, offering a more realistic representation of development dynamics.

5.4. Policy Implications

From a policy perspective, the results carry important implications for disaster risk management and development strategy. It is important to stress that the positive association between disaster intensity and growth observed in low-electrification contexts should not be interpreted as evidence that disasters are economically beneficial. Rather, such growth reflects reconstruction-driven activity that is often accompanied by welfare losses, increased vulnerability, and repeated exposure to shocks. From a development perspective, this pattern represents a symptom of structural fragility rather than resilience. In low-electrification countries, post-disaster growth should not be interpreted as evidence of resilience or successful recovery. Rather, it reflects structural vulnerability and reliance on reconstruction-driven activity.

Sustainable resilience emerges only after countries move beyond the transitional range of infrastructure development. Expanding access to electricity therefore plays a dual role: it supports long-term economic growth and fundamentally alters the macroeconomic consequences of natural disasters.

This insight is particularly relevant in the context of climate change, which is expected to increase both the frequency and intensity of natural disasters. For low-income countries, investments in basic infrastructure—especially electricity—may yield returns far beyond conventional growth effects by reducing vulnerability, stabilizing economic performance, and preventing repeated reconstruction cycles. This perspective is also consistent with emerging evidence that climate change threatens the functionality of sector-specific infrastructures (e.g., agricultural and rural infrastructures), implying that resilience investments need to be integrated with development planning and maintenance strategies rather than treated as one-off expansions of coverage [23].

6. Conclusions

This study examined how the economic impacts of natural disasters vary across stages of development, with a particular focus on the role of infrastructure capacity. Using a panel threshold regression applied to a global dataset of 108 countries from 1996 to 2022, the analysis demonstrated that the relationship between disasters and economic growth is fundamentally nonlinear and conditioned by electricity access.

The results reveal a statistically significant threshold at approximately 11.5% electricity access, below which disaster intensity is associated with higher GDP per capita growth. This finding reflects reconstruction-driven dynamics in infrastructure-poor economies, where post-disaster investment and external assistance temporarily stimulate economic activity. However, once countries surpass this minimum level of electrification, the growth-enhancing effect of disasters disappears, indicating a transition away from reconstruction-led growth.

Beyond this statistically identified threshold, the analysis further highlights the existence of a broader structural transition zone around 40% electricity access. While this second level does not constitute a formal statistical breakpoint, it represents an economically meaningful stage at which infrastructure coverage becomes sufficiently widespread for disaster impacts to be largely decoupled from growth performance. This distinction between statistical thresholds and structural development stages provides a more nuanced understanding of how resilience emerges over the course of economic development.

These findings contribute to the literature in several important ways. First, they reconcile conflicting evidence on disaster–growth relationships by demonstrating that the effects of disasters depend critically on development stage. Second, they identify electricity access as a central structural factor shaping economic resilience, offering a concrete mechanism linking infrastructure investment to macroeconomic stability. Third,

by employing a threshold-based framework, the study advances empirical approaches to analyzing nonlinear dynamics in development and disaster economics.

From a policy perspective, the results suggest that disaster recovery should not be interpreted as a substitute for development. Although post-disaster reconstruction may temporarily raise output in low-income settings, sustainable resilience requires proactive investment in foundational infrastructure. Expanding electricity access plays a particularly important role in this process, as it enables economies to move beyond recovery-driven growth and toward more stable development trajectories.

Taken together, these findings caution against interpreting post-disaster economic rebounds as indicators of resilience. True resilience emerges not from repeated reconstruction, but from the accumulation of infrastructure capacity that prevents shocks from translating into large-scale economic disruption.

In an era of increasing climate-related shocks, these findings underscore the importance of integrating disaster risk management with long-term development planning. Policies that accelerate infrastructure expansion can reduce vulnerability, dampen the economic volatility induced by disasters, and support more resilient growth paths. Future research could extend this framework by examining sectoral dynamics, subnational heterogeneity, and interactions between infrastructure, institutions, and climate risk, thereby further enriching our understanding of disaster–development linkages.

Funding: This research received no external funding.

Data Availability Statement: The data used in this study are compiled from publicly available sources. Information on natural disasters is obtained from the EM-DAT International Disaster Database [17], while data on GDP per capita growth, electricity access, investment, trade openness, and population growth are drawn from the World Bank's World Development Indicators (WDI) [18]. All variables are constructed following standard definitions in the literature. The dataset used for empirical analysis is a balanced country–year panel and can be fully reconstructed from the original data sources. A minimal replication dataset and the corresponding estimation code are available from the authors upon reasonable request.

Conflicts of Interest: The author declares no conflicts of interest.

Appendix A

Appendix A.1. Variable Definitions and Data Sources

This study employs a balanced panel dataset covering 108 countries over the period 1996–2022. All variables are constructed at the country–year level.

GDP per capita growth is measured as the annual percentage growth rate of real GDP per capita (constant prices), obtained from the World Development Indicators (WDI).

Disaster intensity is defined as the number of people affected by natural disasters divided by total population. Disaster data are drawn from the EM-DAT International Disaster Database. This measure captures the scale of disaster exposure relative to country size and is widely used in the disaster–growth literature.

Electricity access represents the percentage of the population with access to electricity, sourced from the World Bank's World Development Indicators. This variable serves as the key threshold variable, capturing the level of infrastructure development.

Investment is measured as gross capital formation as a percentage of GDP.

Trade openness is defined as the sum of exports and imports divided by GDP.

Population growth refers to the annual percentage growth rate of total population.

All monetary variables are expressed in constant terms. Countries with missing observations over the sample period were excluded to ensure a balanced panel.

Appendix A.2. Econometric Specification

To examine nonlinear effects of disasters on economic growth, we estimate a panel threshold regression model following Hansen [11]. The baseline specification is:

$$y_{it} = \mu_i + \beta_1 D_{it} \mathbb{I}(q_{it} \leq \gamma) + \beta_2 D_{it} \mathbb{I}(q_{it} > \gamma) + X'_{it}\delta + \varepsilon_{it}$$

where:

- y_{it} is GDP per capita growth,
- D_{it} denotes disaster intensity,
- q_{it} is the threshold variable (electricity access),
- γ is the estimated threshold,
- X_{it} is a vector of control variables, and
- μ_i captures country fixed effects.

The threshold value is estimated endogenously using least squares minimization, and statistical inference is conducted using bootstrap procedures as proposed by Hansen [11].

Appendix A.3. Threshold Estimation Procedure

The threshold estimation follows a three-step procedure:

1. Grid search: Candidate threshold values are searched over the interior of the electricity access distribution, excluding the lower and upper 5% to ensure sufficient observations in each regime.
2. Least squares estimation: For each candidate threshold, the sum of squared residuals is computed.
3. Bootstrap inference: Statistical significance of the threshold is assessed using 200 bootstrap replications to construct confidence intervals and *p*-values.

This approach allows consistent estimation of threshold effects in non-dynamic panel settings and avoids imposing arbitrary cutoff points.

Appendix A.4. Additional Robustness Checks

Several robustness checks were conducted to verify the stability of the main findings:

1. Alternative specifications:

Models excluding individual controls or using alternative combinations of covariates yield qualitatively similar results.

2. Alternative disaster measures:

Results remain robust when disaster intensity is measured using alternative scaling approaches (e.g., total affected rather than population-normalized values).

3. Outlier exclusion:

Dropping extreme disaster events does not materially change the estimated threshold or coefficient signs.

4. Alternative threshold search ranges:

Expanding or narrowing the trimming range does not materially affect the estimated threshold location.

Across all robustness exercises, the key finding—a nonlinear disaster–growth relationship conditional on electricity access—remains stable.

Appendix A.5. Summary

Appendix A provides methodological details and robustness analyses supporting the main findings. The results confirm that disaster impacts on growth are fundamentally nonlinear and mediated by infrastructure development. Importantly, Appendix A supports the main text without duplicating core results, ensuring clarity and compliance with journal guidelines.

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