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Asymmetric Impact of Climate Change Vulnerability and Adaptive Capacity on Economic Growth in Developing Economies

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ABSTRACT

Climate change has become a significant global issue, particularly impacting economic systems in developing nations. This study highlights the complex relationship between climate vulnerability (CV), adaptive capacity (AC), and economic growth (GDP) in developing economies. While previous research has largely focused on the direct effects of climate change on GDP, this study advances the literature by investigating both direct and indirect pathways using Structural Equation Modelling (SEM). Data from Asian emerging economies, covering the period 2000–2022, were sourced from the World Bank. The results reveal a significant negative direct effect of CV on GDP growth ($\beta = -0.214$, $p < 0.01$) and a positive, significant effect of CV on AC ($\beta = 22.16$, $p < 0.001$), indicating that greater climate vulnerability drives increased investment in adaptation. The findings also show that AC has a positive impact on economic growth ($\beta = 0.007$, $p < 0.01$), suggesting a partial mediation effect that mitigates the negative consequences of CV on GDP. These results emphasize the importance of adaptive systems in reducing climate risks and enhancing economic resilience. The study offers actionable insights for researchers and policymakers aiming to achieve resilient growth.

1. Introduction

Climate change has emerged as a critical global challenge, exerting profound impacts on economic systems. The climate change impact on economic growth is not uniform, as the climate vulnerability and adaptive capacity vary from region to region [1]. The global climate change consequences have far-reaching impacts, which may lead to reduced water availability, hindered plant growth, and threats to food security [2]. These changes can cause economic losses to those sectors heavily reliant on specific climatic conditions, like agriculture and tourism [3]. Developing countries are more vulnerable to share this burden due to their economic structure, limited adaptive capacities and geographical locations[4]. Due to climate change, subsistence agriculture and small landholders have to face a complex web of changes, with factors like health and productivity of

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labourers [5]. The negative consequences of environmental changes are increased health costs, reduced agricultural productivity, higher health care costs and damage to infrastructure, which have repercussions for economic growth [2, 6, 7].

Climate change has a significant influence on economic systems, particularly in developing countries, because of their geographic locations, economic systems, and limited capacity for adaptation; these countries frequently face increased vulnerability. [8-11]. Devendra *et.al* [12] projected that by 2049, climate change could lead to a permanent income reduction of up to 19% globally, with the most profound impacts in low-latitude, low-income regions. The climate vulnerabilities in these nations are attributed to multiple factors, including low adaptive capacity, inadequate infrastructure, limited technology, and insufficient human and physical capital [13]. These economies' socio-economic conditions amplify their vulnerabilities to climate change [14]. The developed nations use economic resources and cutting-edge technology to increase their capacity for adaptation, while developing nations frequently lack these resources. The development of infrastructure and the availability of climate data both demonstrate this discrepancy [13, 15]. Therefore, understanding the asymmetric impact of climate change vulnerability and adaptive capacity on economic growth is important for formulating effective policy responses for developing countries.

The Sustainable Livelihoods Framework (SLF) provides an organised method for examining the effects of external shocks such as climate change on the welfare of people, households, and countries, specifically in the context of developing economies. The SLF highlights the vulnerability context, which includes exposure to climate risks (such as floods, droughts, and deforestation) and adaptive strategies represented by adaptive capacity (AC) used to absorb or adapt to these shocks and the livelihood outcomes in terms of GDP growth, well-being, and income generation. The theory holds that the presence of strong adaptive capacity via physical, human, natural, financial, and social capital reduces the negative impact of vulnerability and enables sustainable economic outcomes [16].

The agricultural sector, a cornerstone of many developing economies, is particularly vulnerable, with its dependence on predictable weather patterns making it susceptible to droughts, floods, and changing growing seasons. The intricate interactions of diverse crop and livestock species, coupled with the significance of nonmarket relationships in production and marketing, amplify the complexities of both the impacts and subsequent adaptations, contrasting sharply with commercial farms that have a narrower range of crops [5]. Climate change has not only affected the agriculture sector but also on food security of millions of people reliant on this sector *Piontek et.al,* [17] indicates that the main drivers of economic growth are technological advancement, labor force expansion, and capital accumulation. Climate change has to potential to alter the growth trajectory through altering these drivers [18]. The Ramsey-type growth model presented by Piontek *et.al,* [17] highlighted that climate shocks have varying impacts on economic growth, which depend on the type and persistence of shocks. The climate shocks have a significant impact on long-term growth and welfare, which underscores the significance of developing adaptive capacity.

Developing economies are constantly exposed to climate-related risks that have long-term impacts on their resilient growth. Despite global attention on climate change, there has been limited research on resource-constrained economies. The motivation for this study stems from pressing needs to empirically investigate the asymmetric impact of climate change vulnerability (CV), adaptive capacity (AC) on the economic growth of Asian emerging economies. By investigating the direct and indirect impact of CV and AC on economic growth, this study aims to provide insight for targeted policy interventions and sustainable growth.

The current study objective is to empirically investigate the role of climate vulnerability in fostering adaptive capacity of emerging economies. Investments in climate resilience have the potential to promote economic growth by employing green innovation and promoting sustainable industries. This synergy between climate resilience and economic growth has led to the emergence of sustainable growth strategies to simultaneously address environmental challenges and promote economic development. The UN sustainable development goal encourages governments and businesses to opt for sustainable practices by addressing the potential of climate-resilient technologies and practices to create new markets, jobs, and competitive advantages. Incorporating climate resilience considerations into long-term economic planning and policy-making processes is therefore becoming more and more popular. The study further explores how adaptive capacity not only mitigates climate-related disruptions but also fosters sustainable economic growth in developing economies.

The existing literature has investigated the general impact of climate change on economic growth. but still, there exists a gap in current studies, as no study has focused on the asymmetric effects of climate vulnerability and adaptive capacity in developing countries. Most studies have adopted a one-size-fits-all approach, failing to account for the heterogeneity among developing nations in terms of their exposure to climate risks and their capacities to adapt. The current study objective is to empirically investigate the asymmetric impact of climate change vulnerability (CV), adaptive capacity (AC) on the economic growth of Asian emerging economies. The objectives of the study are as under:

i. To assess the extent to which climate change vulnerability affects economic growth in developing countries.
ii. To evaluate the role of adaptive capacity in mediating the relationship between climate change and economic growth.
iii. To identify the differential impacts of climate change on economic growth across countries with varying levels of adaptive capacity.

This study's findings will contribute to the existing body of knowledge by presenting empirical evidence of the asymmetric effects of climate change vulnerability and adaptive capacity on economic growth in developing economies. The findings highlight the significance of adaptive capacity as a mediator in climate-resilient economy nexus by highlighting factors that enhance or hinder adaptive capacity, policymakers can design targeted interventions to bolster resilience and promote sustainable economic development, understanding the asymmetric impact of climate change vulnerability and adaptive capacity on economic growth is vital for formulating effective policy responses.

The remainder of this paper is structured as follows: Section 2 presents a review of the related literature and highlights the research gap. Section 3 discusses the data and methodology. Section 4 presents the empirical results. Section 5 discusses the findings. Finally, Section 6 concludes the study.

2. Literature Review

Global economic stability is seriously threatened by climate change, and the impacts of climate change on economic growth are not equally distributed because of regional and national differences in vulnerability and adaptive capacity [1, 19]. Vulnerability to climate change is defined as exposure and sensitivity to climate events, which are interlinked with socio-economic factors like food security, public health and livelihood, have a potential impact on growth trajectories and create inequalities [20]. These impacts of global climate change create scarcity of water, risks to food security and decrease the yield of crops [2] and could lead to significant financial losses to the sectors reliant on consistent weather patterns, like tourism and agriculture.

Developing nations disproportionately experience climate change effects due to geographical location, economic structure, limited infrastructure, and insufficient resources [4, 14, 21]. For instance, Bosna *et al.* [22] documented structural economic disparities across Europe, emphasizing the need for human capital development in Southeastern regions. Climate vulnerability is closely tied to resource dependence [23], while developed countries show reduced vulnerability due to robust institutions and economic resources [14]. Persistent poverty, low literacy, demographic stress, and reliance on public support further exacerbate vulnerability in rural developing regions [24, 25].

Despite contributing less to global greenhouse gas emissions, developing countries bear the brunt of climate consequences due to limited adaptive capacity [15, 23]. Economic growth in low-income nations is more effective at reducing vulnerability than mitigation strategies alone, underscoring the need for context-specific approaches [26].

Several studies confirm the negative impact of climate-related shocks on economic performance [2, 6, 7]. The Potsdam Institute projects a 19% decline in global income by 2049 due to climate change, equivalent to $38 trillion in annual losses. In China, economic development reduced fatalities from disasters, but direct GDP losses have increased, revealing the dual nature of growth in managing climate risks [27]. In Africa, each 1°C rise in temperature is expected to reduce GDP growth by 0.67 percentage points [28]. These findings suggest that inclusive, pro-poor growth that emphasizes infrastructure and market resilience is key to reducing vulnerability [29]. Climate vulnerability manifests through rising temperatures, erratic precipitation, and increasing disasters, all negatively influencing growth. At 1.5°C warming, economic impacts are already visible, and a 2°C rise could significantly reduce global growth [30].

Adaptive capacity refers to the institutional, technological, and financial ability to respond to climate impacts [31]. Countries with high adaptive capacity can mitigate or exploit climate shifts through proactive adjustments [32, 33]. Developed nations possess stronger adaptive mechanisms due to better governance and infrastructure [13, 15]. A global analysis of 192 nations confirmed lower susceptibility among developed countries [34]. Tourism and health sectors show how adaptive capacity enhances resilience: destinations integrate climate resilience in planning [35], and public health systems prepare for new hazards [36].

In China, developed regions demonstrate stronger adaptive capacity due to investments in ecosystem and energy transitions [37]. Similarly, financial inclusion plays a key role, Maity *et al.* [38] observed disparities in G20 banking services, stressing inclusion for growth. In Mexico, resilience strategies focus on food security and infrastructure to stabilize the economy [39].

Emerging economies rely heavily on agriculture, a sector highly sensitive to climate change. Weather extremes like droughts and floods jeopardize productivity and livelihoods [40]. Food production could fall 10–25% in many developing countries and up to 40% in India without intervention [30, 41], increasing poverty and economic fragility [42]. Health challenges, particularly for vulnerable populations, further strain resilience [43]. Rapid population growth, as Maja *et. al,* [44] notes, worsens service delivery and economic vulnerability.

Adaptive capacity does not guarantee resilience unless acted upon. In Australia's Mount Dandenong, households had resources but lacked action—showing risk perception and trust matter [45]. Not all climate-sensitive areas are equally vulnerable; higher adaptive capacity enables better recovery [46]. However, most developing nations still face financial and institutional limitations in developing robust systems. For example, India's Indo-Gangetic Plain, while climate-sensitive, had lower vulnerability due to its stronger adaptive base [47]. A global ecosystem study [48] revealed that even ecologically intact regions remain at risk due to exposure. Aquaculture hotspots in developing countries are especially vulnerable due to fragile infrastructure and outdated technologies [13, 49].

In Bangladesh, high aquaculture vulnerability stemmed from low adaptive capacity more than exposure or sensitivity [49]. This calls for broad and sector-specific strategies to enhance resilience, particularly in agriculture [50]. Prioritizing vulnerable regions, such as in Uganda, Vietnam, and Nicaragua—can improve the effectiveness and efficiency of adaptation. Population pressures further erode adaptive potential [51].

Climate change presents unique challenges for developing countries. Their limited resources, institutional weaknesses, and high exposure intensify vulnerability. While adaptive capacity is critical, it is not a cure-all. The literature has explored climate change's general impacts on economic growth, but few studies investigate the asymmetric effects of climate vulnerability (CV) and adaptive capacity (AC) together. Most analyses apply a uniform lens, ignoring the heterogeneity among developing countries. This study aims to empirically assess the asymmetric influence of CV and AC on economic growth in Asian emerging economies, contributing to a more differentiated and actionable understanding of climate resilience.

3. Methodology

The primary objective of this study is to investigate the asymmetric impact of climate change vulnerability and adaptive capacity on economic growth across developing economies. The study utilises a dataset of selected emerging Asian economies over the period 2000 to 2022, with data sourced from the World Bank's World Development Indicators (WDI). According to the ND-GAIN Climate Vulnerability Index and World Bank assessments, the most vulnerable countries to climate change were selected. Another criterion of selecting a sample is based on the availability of the data, so the final sample consists of India, Pakistan, Iran, Indonesia, Malaysia, Vietnam, and the Philippines. This group's selection provides a wide and varied view of developing Asia, covering a variety of geographic features, governance structures, income levels, and demographic trends. The study's depth and applicability are improved by this diversity, which also helps us understand how climate dynamics affect economic development in a variety of national contexts. In addition, their economies are heavily reliant on natural resources and the agricultural sectors that are particularly sensitive to climatic shifts. This makes them especially suitable for exploring the asymmetric effects of climate vulnerability (CV) and adaptive capacity (AC) on economic growth. The theoretical framework is grounded in the Climate Resilience and Sustainable Development nexus, aligning with the Environmental Kuznets Curve (EKC) approach and contemporary literature on environmental stressors and macroeconomic performance. The constructs are modelled using structural equation modelling (SEM), leveraging latent variable techniques to capture complex interdependencies among observed indicators and latent constructs.

Based on the review of extant literature and the underlying theory, the following hypotheses were developed:

i. H1: Climate vulnerability (CV) has a significant negative effect on GDP.
ii. H2: Climate vulnerability (CV) has a significant effect on adaptive capacity (AC).
iii. H3: Adaptive capacity (AC) has a significant positive effect on GDP.
iv. H4: Adaptive capacity (AC) mediates the relationship between climate vulnerability (CV) and GDP.

These hypotheses form the structural foundation of the model tested using SEM with bootstrapping to assess both direct and indirect effects using STATA 17.

The dataset comprises secondary data collected for 7 Asian developing countries. Climate vulnerability and adaptive capacity indicators are drawn from the World Bank Development Indicators (WDI). All variables were standardised and log-transformed where appropriate to meet normality assumptions and to reduce skewness. To test the proposed model, structural equation modelling (SEM) was employed using Stata's sem command with the MLMV estimation method (maximum likelihood with missing values). This method was chosen for its robustness in handling non-normality and missing data. The model includes both measurement and structural components. The measurement model specifies the relationship between the latent construct CV and its observed indicators (ln_perc, ln_up, ln_agr). The structural model examines the causal paths from CV to AC and from both CV and AC to GDP. Fit statistics were used to evaluate the model's adequacy. Standard model diagnostics, including standardized root mean squared residual (SRMR) and coefficient of determination (CD), were assessed. SRMR values less than 0.08 and CD values close to 1 indicate acceptable model fit. To provide more reliable standard errors and confidence intervals, particularly for indirect effects (mediation), non-parametric bootstrapping was conducted with 500 replications. Bias-corrected (BC) confidence intervals were reported to account for any potential bias introduced by sampling variability. The bootstrap approach allows for more robust inferences about indirect effects, which are typically non-normally distributed. The significance of the mediation effect (CV → AC → ln_gdp) was assessed using the bias-corrected confidence intervals from bootstrapped estimates.

Vulnerability to climate change broadly means the degree to which a system (country, economy, population) is susceptible to, or unable to cope with, adverse effects of climate change. Climate vulnerability is modelled as a latent construct within the structural equation modelling (SEM) framework, representing the underlying, unobserved dimension of a country's risk to climate-related shocks. This latent variable is reflected through three observed indicators: agriculture value added (% of GDP), average annual precipitation (mm), and urban population growth rate. These indicators are selected based on theoretical and empirical justifications, capturing the multidimensional aspects of exposure, sensitivity, and adaptive capacity that define climate vulnerability in developing economies. Agriculture in developing economies is highly sensitive to climate variability (droughts, floods, temperature shifts). A higher share of agriculture in GDP means the economy is more exposed and vulnerable to climate shocks [52]. Nelson *et al.* [53] highlighted agriculture as a key sector affected by climate change, especially in developing countries heavily reliant on it [54] Agriculture's dependency on climate is a major vulnerability driver in poor economies. The variability or extremes in precipitation increase vulnerability by causing floods, droughts, and crop failures [55, 56]. The changes in rain patterns are central to climate vulnerability. Population exposure to coastal hazards is a major climate vulnerability indicator. Coastal population as a critical vulnerability measure [57, 58].

Adaptive capacity refers to a system's ability to adjust to climate change, thereby mitigating damage, capitalising on opportunities, or coping with consequences. Education improves knowledge, skills, and technology adoption, which strengthens climate resilience. Education enhances adaptive capacity by empowering communities [59]. Education levels are a strong predictor of adaptive capacity [60]. Infrastructure like electricity enables early warning systems, irrigation, and technological adaptation. Electrification is a proxy for the development level and capacity to respond to shocks. Infrastructure investments are crucial for adaptive capacity [61]. Electricity access is central to climate adaptation [62]. Healthcare systems mitigate health risks from climate events (heat stress, disease outbreaks). Health sector investment is critical for climate resilience [63]. Health spending reflects institutional capacity to cope with climate-induced health shocks; health system capacity is a core adaptive capacity component [63]. Following methodological practices of the studies [13, 26], adaptive capacity is operationalised as a composite of variables representing different sectors of resilience, i.e. education, infrastructure, and healthcare. Inflation is included as a control variable in this SEM analysis to account for macroeconomic stability, which can significantly influence both the economic outcomes and the adaptive capacity of a country. High inflation impacts on purchasing power, increases uncertainty in economic planning, and affects the ability of governments and households to invest in long-term adaptive infrastructure such as education, healthcare, and climate-resilient technologies. Controlling for inflation helps isolate the true effects of the core constructs—climate vulnerability, adaptive capacity, and GDP—by removing potential confounding variation caused by fluctuations in price levels. This ensures that the estimated relationships among latent variables are not biased due to omitted variable effects. Moreover, inflation has been shown to influence investment behaviour, government spending, and real income levels, all of which are critical for economic resilience and environmental sustainability [64]. As such, excluding inflation may lead to model misspecification and spurious associations in SEM pathways. SEM is particularly well-suited for this research due to its ability to assess complex relationships between observed and latent variables while accounting for measurement error [65, 66].

The dataset has been carefully screened, and countries with incomplete or missing data for key variables have been excluded to ensure the robustness of the analysis. The final sample includes seven developing countries based on data availability and consistency. The chosen countries together represent over 40% of the global developing world population and hold significant positions in global climate policy forums (e.g., COP28, UNESCAP), making them high-impact cases for policy generalisation.

After conducting descriptive statistics and correlation analysis. This methodological framework enables a comprehensive analysis of how varying levels of climate vulnerability and adaptive capacity shape the economic performance of developing nations in the face of climate change. This study employs a quantitative research design using SEM techniques to investigate the asymmetric effects of climate change vulnerability and adaptive capacity on economic growth in developing economies. The analysis focuses on capturing both positive and negative shocks of vulnerability and adaptive capacity to understand their differential impacts on economic performance. This study utilises publicly available secondary data extracted from WDI, adopts a quantitative approach, and the SEM analysis was performed by using Stata 17.

4. Results

The descriptive statistics presented in Table 1, include mean, standard deviation, minimum, maximum and the correlation of the variables of the study. The Table 1 results indicates that the average GDP growth rate across the sample is 4.62%, reflecting modest economic expansion among the observed developing economies. However, the relatively high standard deviation (3.33) and wide range from -9.52% to 9.69% suggest substantial variation in economic performance, likely driven by differing macroeconomic conditions and structural vulnerabilities.

Climate vulnerability (CV) exhibits a mean of 0.42, with values ranging from -1.28 to 2.71, indicating significant heterogeneity in countries' exposure and sensitivity to climate-related risks. The standard deviation of 0.845 also confirms the variation in the data. With an average value of 1.71 and a comparatively high standard deviation of 3.014, adaptive capacity (AC) varies significantly throughout the sample. From a low of -4.05 to a high of 15.94, the observed range shows a sharp disparity in the capacity of nations to tolerate and adapt to climate challenges. While some countries have made significant progress in enhancing resilience through better healthcare, education, and infrastructure, others are still woefully unprepared and lack the institutional frameworks necessary to effectively manage climate risks. Similarly, with a mean rate of 8.27% and a large standard deviation of 9.88, inflation (INF) exhibits wide fluctuations. The extremes, which range from -1.14% to 44.58%, highlight periods of macroeconomic instability in several nations. The relationship between economic growth and climate-related factors may be disrupted by such instability, highlighting the necessity of suitable controls in empirical modelling. The notable dispersion in key variables—particularly adaptive capacity, inflation, and trade openness—reflects the uneven development trajectories of the sampled developing economies and highlights the importance of context-specific analysis in climate-economic research.

Table 1
Descriptive Statistics

Variable	Mean	SD	Min	Max	1	2	3	4
GDP	4.62	3.33	-9.52	9.69	1.00			
CV	67.43	8.18	51.64	90.31	0.24	1.00		
AC	1.71	3.01	-4.05	15.94	0.22	-0.07	1.00	
INF	8.26	9.88	-1.14	44.58	-0.19	-0.34	0.01	1.00

The author's calculation

A Confirmatory Factor Analysis (CFA) was performed to validate the measurement of Climate Vulnerability (CV) using three indicators: the logarithm of agricultural dependence (ln_agr), percentage-related variable (ln_perc), and urban population (ln_up). The result of the CV factor loading presented in Table 2 demonstrated an excellent model fit with SRMR = 0.000 and CD = 0.938. Factor loadings of CV indicated that ln_agr was a strong positive indicator of CV (fixed at 1 for model identification), while ln_perc ($\beta = -2.47$, $p < 0.001$) and ln_up ($\beta = -1.16$, $p < 0.001$) were significantly and negatively associated with the latent construct. All indicator loadings were significant at the 1% level, and measurement error variances were within acceptable limits, supporting the validity of the construct measurement. These values indicate that precipitation has the strongest contribution to climate vulnerability, followed by urban population growth and agricultural dependency. The associated error variances are relatively small, confirming good reliability of the measurement model.

Table 2
Factor Loading of CV

Indicator	Standardized Loading	Error Variance (ε)	R2 (Reliability)
Agr	1.00 (fixed)	0.043	0.70
Percep	-2.50	0.110	0.85
u_pop	-1.20	0.0098	0.92

The author's calculation

To assess whether residuals across countries in the panel data exhibit cross-sectional dependence—a common concern in macro-panel settings—Pesaran's test for cross-sectional dependence (CD) was conducted. The test produced the following result Pesaran CD Statistic = 1.680 with p-value = 0.093, Average absolute value of off-diagonal correlations = 0.271. The null hypothesis of this test posits that residuals are cross-sectionally independent. At the conventional 5% significance level, the null hypothesis cannot be rejected since the p-value (0.093) exceeds 0.05. This suggests no strong evidence of cross-sectional dependence among the entities (countries) in the panel. However, the result is marginally significant at the 10% level, which may warrant caution depending on the sensitivity of subsequent estimation techniques to cross-sectional correlation.

The average absolute correlation between the residuals of cross-sectional units was 0.271, indicating a moderate degree of residual association, though not statistically significant at conventional thresholds. Hence, the estimation approach is unlikely to suffer from significant bias due to cross-sectional dependence.

The SEM results presented in Figure 1 indicate that the Climate vulnerability has a positive and statistically significant effect on adaptive capacity (β = 4,501,250, p < 0.001). This finding suggests that increased vulnerability stimulates greater investments or responses in adaptive capacity, aligning with literature on reactive adaptation strategies in developing economies [60].

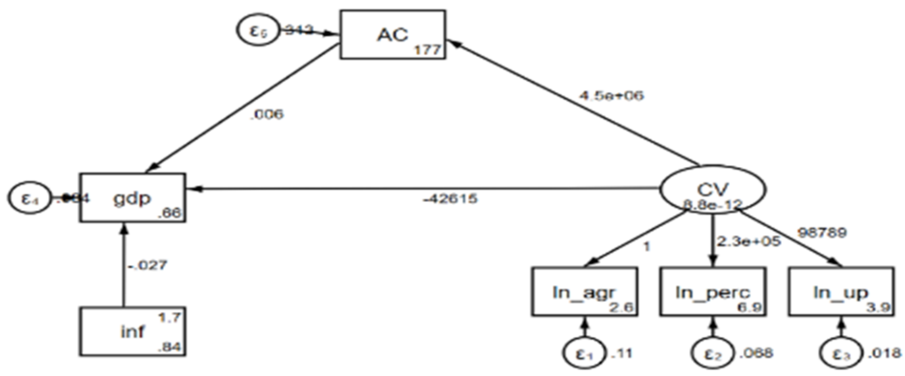

Fig. 1. SEM Model for Path Coefficients

The result of direct path coefficients is presented in Table 3, indicating that all the hypotheses of the study were supported, as CV has a significant impact on GDP, as p<0.000. In contrast, the control variable inflation has an insignificant impact on the economic growth of emerging economies.

Table 3
Direct path coefficients of the Model

Hypothesis	Paths	Estimates	Z	P-value
H1 (Direct)	CV → GDP	-42,615	-3.11	0.00
H2 (Direct)	CV → AC	450,1250	8.36	0.00
H4 (Direct)	AC → GDP	0.006	2.67	0.00
H5	INF→ GDP	-0.027	-1.06	0.29

The author's calculation

To test the mediating path bootstrapping method was utilized [67], with bootstrapping of 500 replications 95% confidence interval was estimated to examine the direct and indirect effects of Climate Vulnerability (CV) and Adaptive Capacity (AC) on economic growth. The coefficient 0.007 implies that for every one-unit increase in Adaptive Capacity (AC), holding Climate Vulnerability (CV) constant, since the p-value is 0.00 (< 0.05), this effect is statistically significant. The results highlight that countries with better adaptive capacity (e.g., institutional readiness, infrastructure, disaster resilience) tend to achieve higher economic performance, as measured by GDP.

Table 4 presents the results of the SEM Model, bootstrapping confirms the robustness of the estimate. With 497 valid replications, the results are reliable despite a few failed iterations. The results indicate that CV has a statistically significant negative direct effect on ln_gdp (β = -0.214, p <

0.01), suggesting that higher climate vulnerability is associated with reduced economic growth. In contrast, AC exhibits a positive and statistically significant direct effect on ln_gdp (β = 0.007, $p < 0.01$), implying that greater adaptive capacity contributes positively to economic performance.

Furthermore, CV has a strong positive effect on AC (β = 22.165, $p < 0.001$), indicating that regions with higher climate vulnerability tend to invest more in adaptive capacity, possibly as a coping mechanism. The bootstrapped analysis revealed a statistically significant positive indirect effect of CV on ln_gdp through AC (β = 0.155, SE = 0.056, z = 2.75, p = 0.006; 95% BC CI [0.044, 0.265]). This finding confirms a partial mediation, where increased climate vulnerability indirectly promotes economic growth by fostering adaptive capacity, even while the direct effect remains negative.

The total effect of CV on ln_gdp, accounting for both the direct and indirect pathways, is negative but statistically insignificant (β = -0.060, p = 0.322). This suggests that the positive mediating role of adaptive capacity partially offsets the adverse direct effect of climate vulnerability on economic growth. The indirect effect is statistically significant, indicating full mediation of the impact of CV on GDP via adaptive capacity. The total effect of CV on ln_gdp (-0.06) becomes non-significant when AC is included in the model, confirming the presence of mediation.

Table 4
95% BC CI with Bootstrapping

Hypothesis	Paths	Coefficients (β)	Bootstrapped SE	Z	P-value	95% BC CI
H1 (Direct)	CV → GDP	-0.214	0.07221	-2.97	0.003	-0.35,-.07
H2 (Direct)	AC→ GDP	0.007	0.00266	2.62	0.009	0.002, 0.012
H3 (Direct)	CV → AC	22.165	3.61	6.15	0.000	16.26, 29.54
H4 (Indirect)	CV → AC→ GDP	0.155	0.05619	2.75	0.006	0.04, 0.26

The author's calculation

The Model Fit and Replication Robustness was assessed using residual-based fit indices. The Standardised Root Mean Squared Residual (SRMR) was 0.000, indicating an excellent model fit (values < 0.08 are considered acceptable). Furthermore, the coefficient of determination (CD) was 0.938, suggesting that approximately 93.8% of the variance in the dependent constructs is explained by the model, demonstrating a high level of explanatory power. All coefficients are standardized. Bootstrap Confidence Intervals (CI) are Bias-Corrected (BC). N = 98; Bootstrap replications = 497. The model convergence was achieved in 494 out of 497 bootstrap samples, indicating high robustness.

To Compare Country Performance in SEM (CV → AC → GDP) by following the Structural Equation Modelling (SEM) estimation, a cluster-based comparative analysis was conducted to further explore the differentiated impacts of climate vulnerability (CV) and adaptive capacity (AC) on GDP across countries. The predicted GDP values (gdp_hat) were analysed alongside CV and AC metrics, with countries grouped into three distinct clusters (CV_AC_Clusters) based on their combined vulnerability and adaptive capacity profiles. Countries in Cluster 1 (e.g., Pakistan, early-period India) are characterised by high climate vulnerability and low adaptive capacity, reflecting relatively lower predicted GDP values, suggesting that high exposure to climate risks without sufficient adaptation mechanisms is detrimental to economic performance. Cluster 2 includes countries in transition (e.g., mid-period India, early-phase Viet Nam and Malaysia), which show moderate vulnerability and improving adaptive capacity, corresponding with moderate gains in predicted GDP. In contrast, Cluster 3 comprises economies such as Iran, Malaysia (later period), and Viet Nam (recent years), which exhibit lower or positive CV scores and higher adaptive capacities, aligning with higher levels of predicted GDP. The Regression results are presented in Table 5.

Table 5
Regression Analysis of Predicted GDP

Dependent variable: GDP	Coefficients	Standard Error	t	p-value
CV	-45678.35***	0.002	-3.00e+07	0.00
AC	0.006457***	4.78e-10	1.40e+07	0.00
CV_AC_cluster2	2.36e-08	2.20e-08	1.07	0.29
CV_AC_cluster3	3.56e-08	2.98e-08	1.19	0.24
Constant	0.534***	6.54e-08	8.20e+06	0.00

The author's calculation

The regression analysis reveals a highly significant negative relationship between climate vulnerability (CV) and GDP. This underscores the detrimental effect of climate risks on economic performance in emerging Asian economies. While the adaptive capacity (AC) shows a positive and significant effect on GDP ($\beta = 0.006457$, $p < .001$), indicating its role in mitigating the adverse impacts of climate vulnerability. Countries with greater adaptive capacity are better able to sustain or enhance GDP growth even under climate stress. The cluster dummies (Cluster 2 and Cluster 3, relative to Cluster 1) do not have statistically significant effects on GDP ($p > .05$). Moreover, within countries, transitions across clusters reflect dynamic shifts in policy effectiveness and resilience-building efforts over time, thereby validating the mediating role of adaptive capacity and the asymmetry in climate-growth relationships revealed through SEM in developing economies.

5. Discussion

This study contributes to the existing literature of climate change and economic development research by modelling climate vulnerability (CV) as a multidimensional latent construct derived from agricultural dependence, average precipitation, and urban population growth, reflecting the multidimensional nature of climate risks. Moving beyond traditional indices, the framework aligns with contemporary resilience theories [59, 60]. This approach moves beyond conventional indices and captures the dynamic interplay of exposure, sensitivity, and adaptive capacity. Climate Change presents significant challenges to growth in developing countries, limited resources, fragile institutions, and exposure to environmental risks combine to heighten their vulnerability. Adaptive capacity plays a central role in mitigating these risks. The prior studies have addressed either CV or AC in isolation; the current study has focused on the asymmetric effects of climate vulnerability and adaptive capacity in developing countries.

The Structural Equation Modelling (SEM) with maximum likelihood mean-variance adjusted (MLMV) estimation results demonstrate that climate vulnerability has a negative and significant direct impact on economic growth (GDP), confirming that higher climate risk exposure adversely affects productivity and growth. These findings are consistent with prior empirical evidence that climate shocks undermine productivity and infrastructure, especially in agriculture-based economies [68].

Adaptive capacity showed a significant and positive effect on economic growth, suggesting that improvements in education, healthcare, and infrastructure (as represented by AC) contribute to economic growth. This supports endogenous growth theory [69], where human capital and institutional capacity drive long-term economic development.

The analysis also reveals a statistically significant indirect path CV → AC → GDP, indicating partial mediation effect. This suggests that although climate vulnerability directly constrains economic growth, it can also promote adaptive responses through the channel of enhanced adaptive capacity, such as investment in resilience infrastructure. This dual pathway illustrates a trade-off, where vulnerability triggers adaptation efforts that may, in turn, boost growth. This pattern reflects a “resilience loop”—where exposure to climate risks initially damages output but also catalyses institutional or human capital investments that can mitigate future losses [26].

These findings highlight the significance of adaptive capacity that not only acts as a buffer against climate change but also as a source of resilient economic growth. These findings suggest that the policy makers in vulnerable regions should prioritize adaptive capacities that build institutional readiness and human capital, enabling a proactive rather than reactive approach to climate change risk.

6. Theoretical and Managerial Contribution

A key theoretical contribution is the introduction of adaptive capacity (AC) as a mediating variable between climate vulnerability and economic performance (GDP). Using Structural Equation Modelling (SEM), the study demonstrates how stronger adaptive systems—represented by education, healthcare, and electricity access—can mitigate the adverse effects of climate stress on development outcomes. The developing country cluster-wise comparison also highlights that asymmetric CV impact on economic growth and AC. This framework integrates elements of endogenous growth theory [69], highlighting how climate adaptation supports long-term economic growth.

Practically, the findings indicate the importance of investing in social infrastructure to enhance resilience. They offer policymakers evidence to integrate adaptation strategies into economic planning, particularly in climate-exposed developing Asian economies. The SEM framework also provides a replicable tool for designing national vulnerability assessments. Finally, the study advocates for climate adaptation and contributing directly to SDG 13 (Climate Action) and SDG 8 (Decent Work and Economic Growth).

7. Conclusion

This research empirically investigates the nexus between climate vulnerability, adaptive capacity, and economic growth in Asian emerging economies using structural equation modelling (SEM). The results highlight that climate vulnerability significantly undermines GDP growth, but this effect is partially mediated by adaptive capacity, which positively contributes to economic resilience. The findings underscore the critical role of investments in adaptive capacity, particularly in education, health, and infrastructure, to promote sustainable economic growth in the face of climate change. For countries already grappling with resource constraints and institutional fragility, targeted adaptation strategies could provide a pathway to inclusive and climate-resilient growth.

The study contributes to both theoretical and practical domains, but the research is bounded by its data limitations and scope, suggesting directions for future studies such as the inclusion of more countries, time-varying indicators, and more granular proxies for climate risk and response. This study reaffirms that adaptive capacity is not merely a defensive mechanism but a strategic asset for developing countries to harness in the pursuit of long-term sustainable growth. Future research can expand on this framework by incorporating institutional quality, innovation, and regional integration into the climate development discourse.

8. Ethical Considerations

This research relies entirely on secondary data from reputable sources such as the World Bank and the ND-GAIN Index. No primary data collection involving human subjects was undertaken, and thus, ethical clearance was not required. Limitations of this study include the cross-sectional nature of the data, which restricts causal inference, and potential omitted variable bias.

Author Contributions

Conceptualization, Methodology, Formal analysis, Investigation, U.A., S.L.R., S.A., M.B.A., and F.S.; Resources, M.B.A., and F.S.; Writing—original draft preparation, Writing—review and editing, U.A., S.L.R., S.A., M.B.A., and F.S.; Visualization, Supervision, S.L.R., S.A., and M.B.A.; Funding acquisition, U.A. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The secondary panel data used in this study were obtained from publicly available sources and can be accessed via the World Bank Open Data portal at https://data.worldbank.org . No new data were generated for this study.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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