Climate Shocks and the Debt Sustainability Trilemma: Evidence from 68 Emerging and Frontier Markets, 2000–2024

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ABSTRACT

Climate shocks are stretching the fiscal capabilities of the world's most fragile economies, but the pathways by which climate shocks can affect the terms of debt sustainability are under-measured. In this paper, we propose the notion of a Debt Sustainability Trilemma for Small Emerging and Frontier Markets, which has three mutually reinforcing dimensions: climate vulnerability, limited fiscal space, and restricted access to external financing. We create a new Climate Shock Index (CSI) based on the frequency, physical damage, mortality, and meteorological intensity of the disaster and for a panel of 68 emerging markets during 2000–2024 (about 1,700 country-year observations). Panel fixed effects, instrumental variable (IV-2SLS), local projection, and threshold regression techniques yield a range of estimates between 0.39 and 0.61 percentage points of GDP for the fiscal balance effect on impact and 1.77 pp cumulatively over 5 years, and 1.8 to 2.5 pp of GDP on impact and 10.8 pp cumulatively over 5 years for the effect on debt-to-GDP. They are highly non-linear: fiscal damage is 152 per cent higher if the pre-shock fiscal space is below a Hansen (1999) threshold of 2.8 per cent of GDP. The impacts are highest for Small Island Developing States (CSI coefficient of -0.89), and parametric insurance penetration of more than 2 per cent of GDP reduces fiscal impacts by 67 per cent. The counterfactual scenarios demonstrate that a comprehensive policy bundle of fiscal buffers, parametric insurance, and concessional climate finance can prevent 60 to 80 percentage points of debt-to-GDP increases over 15 years compared to a baseline scenario without measures. The results have immediate policy implications for the debt sustainability assessment of the IMF, for the design of climate-contingent debt instruments, and for the visions of multilateral climate finance.

Keywords: Climate Shocks, Fiscal Space, Debt Sustainability, Small Emerging Markets, Small Island Developing States, Fiscal Trilemma, Parametric Insurance, Local Projections
JEL Classification: E62, F34, H63, O44, Q54

1. Introduction

1.1 Motivation and Research Context

The issue of climate change and sovereign debt sustainability has become one of the most urgent policy issues at the intersection of climate change and emerging and frontier market economies in the 2020s. Over the last 20 years, extreme weather events have become more frequent and more intense. Extreme weather events in developing countries have grown by about 83 percent during

2000-2019 (6681 events) compared to 1980-1999 (3656 events), according to economic damage estimates by the Centre for Research on the Epidemiology of Disasters (United Nations Office for Disaster Risk Reduction [UNDRR], 2020).

Nevertheless, literature on climate shocks and related fiscal responses in emerging markets is scarce. Up to now, most studies have either examined their long-run growth impacts (Dell et al., 2012; Burke et al., 2015) or estimated physical damages (Coronese et al., 2019), while relatively few analyze the fiscal transmission channel in depth through which climate shocks decrease tax revenues and raise emergency and reconstruction expenditures, putting upward pressure on public debt (Barrage, 2024; Fuje et al., 2023). This transmission mechanism is crucial in measuring debt sustainability and providing guidance on the policy decisions of international financial institutions.

This paper has three empirical regularities as motivation. Firstly, there are clear and lasting effects on the fiscal position of countries following major climate events, which exceed what can be explained by standard macroeconomic controls. Second, this fiscal deterioration is also unequal: countries with low fiscal buffers before the shock, low adaptive capacity, and limited access to external financing are more affected and for a longer duration. Third, the impact of the climate shocks on fiscal outcomes can be non-linear with threshold effects that set up self-reinforcing debt dynamics once fiscal space is squeezed below a critical threshold.

We call this combination of reinforcing vulnerabilities the Debt Sustainability Trilemma: countries highly vulnerable to climate change and, in parallel, with limited fiscal space and restricted access to external concessional financing cannot self-insure against climate shocks through only one policy lever. The three aspects of the trilemma reinforce each other. If there is no fiscal buffer, the high vulnerability will lead to procyclical fiscal adjustment. Lack of space in the budget, no outside finance, and limited external funding with non-climate-resilient fiscal policies result in sovereign stress. The trilemma can only be solved with a coordinated policy response across various pillars.

1.2 The Global Context: Fragmented Finance and Climate Vulnerability

Given that global economic fragmentation can lead to greater fiscal vulnerabilities and limited space for pro-development policies, the broader macroeconomic environment adds another important layer of context in understanding the climate-fiscal nexus (Aiyar et al., 2023). Multilateral climate finance mechanisms for vulnerable economies have been hindered by geopolitical conflicts (International Monetary Fund, 2023). Important, although still inadequate, responses to the scale of financing need are the Resilience and Sustainability Trust (RST) established by the IMF in 2022, and the World Bank's Climate Investment Funds (International Monetary Fund, 2022). Consequently, at a time when both adaptation and resilience needs are on the rise, geopolitical realignment can raise external borrowing costs for emerging markets—potentially squeezing fiscal space.

The Small Island Developing States can be seen as the most extreme example of the trilemma. Some countries like Dominica, Vanuatu, the Marshall Islands, and Barbados already have projected annual

natural disaster impact on their economy of more than 5 percent of their GDP, and owe on average over 80 percent of their GDP—with virtually no access to concessional climate financing at scale. The damage to Dominica was equivalent to 226 per cent of GDP in 2017 when it was struck by Cyclone Maria, an event that has yet to be fully overcome, even with Paris Agreement pledges by advanced economies. This is not an exception, but the most typical experience of SIDS in a warming world.

In this context, the paper offers four empirical contributions to the literature on macroeconomics of emerging markets:

- It builds a new composite Climate Shock Index (CSI) for 68 EMs for the period 2000-2024, using disaster frequency, economic damage, mortality, population exposure, and meteorological intensity, in a standardized index, calibrated to fiscal transmission.
- It provides the complete fiscal transmission channel by establishing the gravity magnitudes and demonstrates that the complete picture results in a measure of the fiscal transmission that is about 58 percent larger than standard OLS estimates due to the downward bias caused by measurement error in disaster data.
- Local projections around the Jorda (2005) pivot point are used to depict the complete impulse response path of fiscal balances and debt-to-GDP ratio over a five-year horizon following the climate shock, finding that hysteresis - rather than full recovery - is the rule.
- The paper estimates a threshold of fiscal space (2.8 percent of GDP) below which the effect of climate shocks is non-linearly amplified and simulates the debt sustainability consequences of various policy packages under different stochastic climate scenarios until 2040.

1.3 Situating This Paper in the Literature

In this paper, four different bodies of literature are discussed. The climate-macroeconomics literature (Dell et al., 2012, Burke et al., 2015, Kahn et al., 2021) sets the benchmark for growth impacts of temperature and precipitation shocks but tends to focus on long-run impacts and not so much on fiscal impacts in the short-to-medium run. The literature on EMs fiscal policy (Ilzetzki et al., 2013; Gavin and Perotti, 1997) shows that fiscal policy is pro-cyclical and hardly includes climate shocks as a specific factor.

The climate finance and debt sustainability literature is expanding, but it, for the most part, is normative in nature (Buhr et al., 2018; Volz et al., 2021; Moody's, 2022). Our paper provides the first systematic econometric panel evidence of the size of climate-fiscal effects across income levels and institutional contexts. The SIDS economic vulnerability literature (Briguglio, 1995; Easterly and Kraay, 2000; Becker and Mauro, 2006) captures this with the concept of small-state fragility but is earlier than the onset of the intensified climate events in the 2010s and does not connect fragility to fiscal space thresholds.

Most directly, this study extends Raddatz (2007), who investigated the output impact of external shocks such as natural disasters in low-income countries, and Noy (2009), who reported the heterogeneous output impact by income level. Extensions are attempted in four ways: (i) by developing a multi-dimensional climate shock measure, richer in dimensions than that used in previous studies; (ii) by making the discussion of fiscal outcomes rather than output outcomes explicit; (iii) by introducing threshold non-linearities to the fiscal space dimension; and (iv) by using local projections to capture the dynamic response profile.

2. Conceptual Framework: The Fiscal Trilemma

2.1 Transmission Channels from Climate Shocks to Fiscal Outcomes

Government fiscal positions are impacted by climate shocks in three key ways. The income channel works as follows: the destruction of physical capital, disruption of agriculture and services, and displacement of population decrease the taxable income base and result in a compression of the income taxes (VAT and trade). LICs that are very dependent on agricultural sector revenues, for which agricultural sector revenues are 20 to 35 percent of the revenues of the government, can see agricultural sector revenues decline by 2 to 4 percent of GDP during moderate droughts (Fuje et al., 2023).

The expenditure channel is generally bigger and quicker. Emergency response expenditures, evacuation operations, costs of providing temporary shelter, and funds for immediate reconstruction demands are immediate budget requirements. Emergency expenditures push the overall fiscal balance into deeply negative territory, within a matter of months of the shock, in SIDS economies with government spending already close to or at the limits of revenue capacity (Clayton & Rosenblatt, 2024). More importantly, reconstruction expenditures are much more likely to be front-loaded – governments can't indefinitely delay rebuilding critical infrastructure – so the expenditure spike is likely to happen in years zero through two after the event.

The financing channel reflects the second-order fiscal effects resulting from the necessity to borrow to meet the revenue shortfall and expenditure increase. For countries that already have high levels of debt, these interest payments mean that they will have to make higher payments, may experience credit rating downgrades, and sovereign spreads may widen at a time when financing is most expensive. This is a vicious cycle as the shock weakens fiscal position, lifting borrowing costs, which further weakens fiscal position as debt service rises, which reduces fiscal space to absorb the next shock, etc.

2.2 The Trilemma Structure

The three channels above are related in such a way that they form a structural trilemma for a small EM. Fiscal space is the gap between the current debt-to-GDP ratio and the debt ratio that is estimated to mark the point of debt distress for the income/institutional category. Climate Vulnerability

(Annual Expected Climate Damage in GDP) is the ratio of annual expected climate damage (calibrated from the ND-GAIN climate vulnerability sub-index and historical damage data from EM-DAT) to GDP. Access to external financing: availability and cost of external loans and credits, concessional or market rate, after the shock.

The trilemma arises because all three of these aspects are all interdependent upon each other at the same time. Limited fiscal space is associated with a higher sovereign risk premium, resulting in less external financing. Countries with limited access to external funding are unable to build up fiscal buffers and therefore have limited fiscal space. Those countries that have little fiscal space and little financing capacity can't invest in adaptive capacity measures, which would help reduce vulnerabilities to climate change. The end product is a stable but welfare-inferior equilibrium of high vulnerability, low space, and limited financing, which, in turn, feeds into greater vulnerability, lower space, and less financing and so on.

If the trilemma is to be broken, it must be addressed at least on two of its three aspects. This is the fundamental reason behind the policy scenario analysis in Section 7, which considers varying combinations of parametric insurance (financial channel), fiscal climate reserves (fiscal space dimension), and concessional multilateral climate finance (external financing channel).

2.3 Hypotheses

From the conceptual framework, we derive five testable hypotheses:

Hypothesis	Label	Testable Prediction
H1	Climate-Fiscal Channel	CSI is negatively associated with fiscal balance and positively with debt/GDP after controlling for standard macro fundamentals
H2	Adaptive Capacity Mitigates	Countries with higher ND-GAIN scores and insurance penetration face smaller fiscal effects per unit of CSI.
H3	Fiscal Space Amplifies	The fiscal impact of CSI is significantly larger (in absolute magnitude) when pre-shock fiscal space falls below the Hansen threshold.
H4	SIDS Burden	SIDS face disproportionately large fiscal effects relative to other EMs, controlling for CSI magnitude
H5	Debt Hysteresis	Following a climate shock, fiscal balances and debt/GDP ratios do not fully revert to pre-shock levels within five years.

3. Data and Measurement

3.1 Sample and Panel Structure

The core dataset is an unbalanced annual panel of 68 emerging and frontier market economies (with around 1,700 country-year observations) between 2000 and 2024. The sample is defined as the set of countries that satisfy three conditions: (i) country must be classified as an emerging and/or developing economy at least in one of the years in the sample period according to IMF World

Economic Outlook; (ii) EM-DAT disaster data is available for at least five years for the country; and (iii) IMF WEO fiscal data (fiscal balance and public debt series) is available for at least ten years for the country. Countries where the number of missing years in some key variables is high (>5 consecutive) are excluded.

Sixty-eight countries are included in the sample, across six major geographic clusters: South and Southeast Asia (15 countries), Sub-Saharan Africa (20 countries), Latin America and the Caribbean (18 countries including 5 SIDS and 5 Central American economies), Middle East and North Africa (5 countries), Eastern Europe and Central Asia (8 countries), and Pacific SIDS (2 countries with extended coverage). This spatial scale is crucial to capture exposure to climate change, income, and institutional capacity at the cross-section.

3.2 Climate Shock Index Construction

The main explanatory variable is a new Climate Shock Index (CSI) which is built for every country-year observation. EM-DAT's existing disaster measures have well-known drawbacks: the raw damage variable is highly skewed, there is reporting heterogeneity across countries and across decades, and the monetary value assigned to the disaster is an amalgamation of multiple dimensions of disaster severity which may not capture the fiscal impact on the government. The CSI has been created to overcome these limitations by integrating five distinct and complementary dimensions of shock intensity of the climate impacts:

Component	Raw Variable	Source	Weight	Rationale
Physical Damage	Disaster damage (% GDP), winsorized at 99th pct	EM-DAT / World Bank	**35%**	Primary fiscal channel; reconstruction costs drive expenditure surge
Frequency	# Disaster events, log(1+N) normalized	EM-DAT	**25%**	Repeated smaller events erode resilience even without a single catastrophic loss.
Mortality	Deaths per 100,000 population, log-normalized	EM-DAT / UN Population	**20%**	Human capital destruction and labor supply shock with fiscal implications
Population Affected	Persons affected / total population	EM-DAT	**10%**	Captures indirect economic disruption beyond immediate physical damage
Meteorological Intensity	Wind speed/flood depth Z-score	ERA5 Reanalysis	**10%**	Physical intensity independent of exposure; measures hazard severity

The different components are min-max scaled between 0 and 1 for the entire panel. The five components are then combined with the weights indicated above, and the combined index is rescaled between [0,10] to be more interpretable. Observations of country-years with CSI >=7.0 belong to

the category of "Major Shock Years". Major Shock Years make up about 12 percent of all the observations in the full sample, and are heavily concentrated in SIDS (28 percent of observations) and the lowest income quartile of the sample (19 percent of observations).

The CSI validation is accomplished in three stages. First, we check that the index reflects the 20 most devastating events in the literature (e.g., the earthquake in Haiti (2010) has a CSI of 9.85, Hurricane Maria in Dominica (2017) has a CSI of 9.38, and Pakistan floods (2022) have a CSI of 8.88). Second, we show that the CSI is positively and significantly correlated with each of the five component measures separately, thus reflecting good internal consistency. Third, we perform parallel regressions with the CSI replaced by alternative indexes: the INFORM Risk Index, OCHA, the ND-GAIN's vulnerability sub-index, and the World Risk Index, and validate that the results are qualitatively similar (see Robustness section).

3.3 Fiscal and Macroeconomic Variables

The main fiscal indicators that are of interest are (i) the overall fiscal balance (revenue minus expenditure, including interest payments, percent of GDP); (ii) primary fiscal balance (fiscal balance excluding interest payments, percent of GDP); and (iii) public debt-to-GDP (general government gross debt, percent of GDP). All three series were taken from the IMF World Economic Outlook (WEO) database (April 2025 vintage), with additional data from the IMF Fiscal Monitor and individual country Article IV consultation reports for those years in which the data are not available in the WEO.

The set of macroeconomic control variables is based on the standard literature on fiscal reaction functions (Bohn, 1998; Fatas and Mihov, 2003). Lagged debt-to-GDP embodies the debt stabilisation motive and the existing fiscal pressures. The fiscal balance is adjusted for the cyclical component using real GDP growth (one period lagged). The proportion of government revenue to GDP is an indicator of the structural capacity of the state to mobilize government revenues. As a proxy for economic stability conditions, inflation is included. These variables are taken from the IMF WEO and World Bank World Development Indicators (WDI).

3.4 Climate Resilience and Adaptive Capacity Variables

A core prediction of our framework is that adaptive capacity will introduce as a moderator the fiscal impacts of climate shocks. We measure the latter with two complementary measures. ND-GAIN Country Index (Notre Dame Global Adaptation Initiative) is an annual country-level score that is based on a vulnerability sub-index (which measures exposure, sensitivity, and adaptive capacity to climate hazards) and a readiness sub-index (which measures economic, governance, and social readiness to implement adaptation). For this analysis, we rely on a summary measure of adaptive capacity, represented by the overall ND-GAIN score, and use sub-components of the ND-GAIN score in some specifications.

The second resilience variable is insurance market penetration, which is the total insurance premiums as a share of GDP, and is obtained from the World Bank FINDEX database and the Swiss Re Institute sigma reports. This variable is especially relevant for the SIDS and Caribbean sub-sample as parametric insurance schemes like the Caribbean Catastrophe Risk Insurance Facility (CCRIF) have been demonstrated to provide liquidity provision in the aftermath of a disaster. The policy scenario analysis is motivated by the fact that countries in the sample with high insurance penetration (i.e., above the sample median, around 1.0 percent of GDP) have fiscal CSI that are around 40-50 percent lower than for the remaining countries.

3.5 Descriptive Overview

The important variables are summarized in Table 3.1. The full sample has a mean CSI of 4.22 (SD = 2.18), indicating that the sample exhibits a high level of climate exposure with a high level of variation across the sample. The average fiscal balance is -3.80 percent of GDP (standard deviation 3.20) — from -18.0 percent (severe post-disaster fiscal deterioration) to +5.2 percent. The level of public debt is 62.4 percent of GDP, well above the generally accepted 60 percent ceiling for emerging markets, which highlights that the sample countries have limited fiscal space to begin with. The mean score for ND-GAIN is 44.5 (SD = 9.8) on a 0-100 scale, suggesting that on average the sample has moderate adaptive capacity, with SIDS (mean = 35.8) and LICs (mean = 38.2) below the average.

The income-group distribution shows a very sharp gradient both in terms of climate exposure and fiscal impact. As compared to high-income frontier markets in the sample, with a mean CSI of 2.15 and an estimated fiscal coefficient of -0.180 per CSI unit, SIDS' mean CSI is 6.45 with an estimated fiscal coefficient of -0.885 per CSI unit. This is in line with the trilemma hypothesis: the most climate-exposed are the least fiscally space constrained and, thus, the least able to access concessional financing.

4. Estimation Strategy

4.1 Baseline Panel Regressions

The empirical baseline specification estimates fiscal outcomes as a function of the Climate Shock Index and a common set of macroeconomic controls using a panel regression. The formally written baseline equation is:

$$Y_{it} = \alpha + \beta_1 CSI_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \qquad (1)$$

where Y_{it} is the fiscal outcome of country i in year t (either fiscal balance, debt/ GDP or primary balance); CSI_{it} is the Climate Shock Index; X_{it} is a vector of macroeconomic controls (lagged debt/GDP, GDP growth, government revenue, inflation); μ_i is a country fixed effect; λ_t is a year

fixed effect; and ε_{it} is an idiosyncratic error term. Within-country serial correlation is accounted for by the clustering of standard errors throughout.

We estimate the equation (1) in 5 increasingly rich columns: (1) pooled OLS without fixed effects, as a baseline; (2) country fixed effects only; (3) two-way fixed effects (country and year); (4) two-way FE model with addition of product of CSI and dummy variables for low fiscal space and SIDS status; (5) two-way FE model with instrumental variables (as described in Section 4.2). The evolution over time of the climate-fiscal coefficient across columns is a way of disentangling the impact of country-specific heterogeneity and common time effects from the estimated climate-fiscal coefficient, and testing the sensitivity of beta1 to the inclusion of these controls.

4.2 Instrumental Variable Strategy

One of the critical identification issues is that the CSI could be related to other country characteristics that also affect fiscal outcomes and that the researcher cannot observe. For example, a country with poor governance institutions could be more vulnerable to the effects of climate shocks (because of its low level of preparedness for such shocks) and also have more procyclical fiscal policies, which creates an upward bias in the OLS estimates of the actual causal effect of climate shocks. On the other hand, the under-recording of climate damage in countries with lower capabilities in statistical recording by EM-DAT will dampen the measured CSI towards the zero value and lead to an underestimation of the OLS coefficient.

To overcome these endogeneity issues, we instrument for the CSI, based on the log kilometers distance between the country's capital city and the nearest weather monitoring station in the Global Historical Climatology Network (GHCN). The intuition is simple: countries with less sophisticated meteorological monitoring infrastructure (measured in terms of distances to the closest monitoring station with good quality meteorological data) tend to exhibit more frequent and less predictable climate events in the EM-DAT disaster database, which serve as a quasi-random source of variation in measured disaster intensity that plausibly remains exogenous to fiscal policy choice.

The exclusion restriction must be satisfied for the fiscal outcomes to be affected by the distance to monitoring stations only indirectly, via the climate shock channel. This is a reasonable assumption to make, as the location of weather stations is based on historical geographical and colonial considerations (e.g., near airports, administrative centers, early development of the meteorological network) and not on current budgetary policy. We add geographic characteristics - coastline length and agricultural land share - as additional sources of exogenous climate exposure variation, creating an overidentified 2SLS model for which tests for overidentification are possible (Sargan-Hansen J-statistic).

The first-stage F-statistics are all well above the Stock-Yogo (2005) critical value for weak instrument rejection at the 10 percent significance level, and the statistics confirm that the instruments are relevant. Heteroskedasticity-robust inference confirms relevance with a Kleibergen-

Paap rk Wald F-statistic of 52.1. The magnitude of the coefficient on the CSI (-0.612) in the 2SLS model is considerably larger than the OLS estimate (-0.388), as hypothesized in the downward attenuation bias scenario: EM-DAT under-records the disaster damage in countries with a lower number of monitoring stations, which results in the downward bias in the OLS estimate.

4.3 Local Projection Impulse Response Functions

The baseline regression reflects the fiscal impact of climate shocks at the same time, but doesn't measure the response profile. To estimate the complete time horizon of fiscal adjustment after a climate shock, we use the local projections method of Jorda (2005) as the standard method of the macro-fiscal literature for estimating impulse response functions (IRFs) in panel environments.

That is, we estimate the following sequence of regressions for each horizon (h = 0, 1, 2, 3, 4, 5):

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_h + \beta_h CSI_{it} + \gamma_h X_{it} + \mu_i + \lambda_t + \varepsilon_{i,\,t+h}$$

The coefficients β_h for h = 0, ..., 5 are the cumulative impulse response of the fiscal balance (or debt) to a one-unit CSI shock measured in terms of the deviation from the pre-shock level $Y_{i,t-1}$. Several advantages of the local projection approach are that it is robust to the misspecification of the dynamics at horizons outside of the estimated horizon, avoids the smoothness restrictions imposed by VAR systems, and is directly interpretable as regression coefficients at each horizon.

We present 90% and 95% confidence bands around the IRF point estimates as outlined in Ramey (2016) and Stock and Watson (2018) and use the Newey-West heteroskedasticity and autocorrelation consistent (HAC) estimator with a bandwidth of the square root of the panel size. The fiscal balance IRF shows a maximum fiscal impact at horizon h=1 (the year after the shock), and a gradual but incomplete recovery, in line with debt hysteresis (H5). The five-year fiscal cost of a one-unit CSI shock is -1.77 percentage points of GDP, and the value of the corresponding debt accumulation is +10.8 percentage points, which would imply an existential debt crisis for a typical SIDS economy affected by a major cyclone (CSI ~ 8-9).

4.4 Threshold Regression

To formally test the non-linearity predicted by the trilemma framework (H3), we use the threshold regression model of Hansen (1999) to estimate both the threshold parameter and the slope coefficients of both regimes in one shot, applying least squares. The fiscal space in year t-1 (the year before the shock) is used as the threshold variable because it is a measure of the fiscal space that would be available to address the impact of the shock.

The Hansen model determines whether the null hypothesis of the constancy of the parameters (no threshold) is accepted or the alternative hypothesis of a single discrete threshold is accepted. We estimate the threshold to be gamma-hat = 2.8 per cent of GDP (bootstrap 90 per cent confidence interval [2.1 per cent, 3.5 per cent]), with a bootstrap p-value of 0.001, which strongly rejects the

null of parameter constancy. Countries at or below this threshold (36 percent of the sample) have a CSI coefficient of -0.618 on the fiscal balance, compared with -0.245 for countries above the threshold, which is 152 percent different from the sample below the threshold and statistically significant at the one percent level.

The threshold level is of economic significance. It suggests that climate shocks do not only generate linear fiscal effects but rather that a shock above a certain threshold level of fiscal space would produce a qualitatively different, non-linear fiscal response. This is because the borrowing needs of the government in the state of emergency exceed its ability to remain even at primary balance when the level of economic debt is below the threshold. When it is above the threshold, the same shock leads to a more limited and reversible fiscal deterioration.

4.5 Heterogeneity and Robustness

We carry out heterogeneity analysis on three dimensions. We start by dividing the sample into income groups (LIC, LMC, UMC, and HIC frontier) and estimate the baseline specification separately for each group, testing for a systematic variation in the climate-fiscal coefficient across the different income groups. Second, a geographic split (Sub-Saharan Africa, South/Southeast Asia, Latin America and Caribbean, MENA, Central Asia) was used to investigate whether the estimated effects are region-specific due to institutional or geographic factors. Third, we divided the sample into high and low insurance penetration (above/below 1.0 percent of GDP) as well as IMF program and non-IMF program in order to test the H2 prediction that adaptive institutional structures moderate climate fiscal impacts.

The robustness analysis uses 18 different versions of the climate shocks (Panel A), 4 different versions of the fiscal outcome variables (Panel B), and 3 placebo and outlier controls (Panel C: Pre-shock placebo (h=-1), randomly shuffled CSI, outlier exclusion (Haiti), winsorization (95th percentile), and outlier exclusion (COVID-affected years 2020-2021). All 18 tests support the empirical evidence, and both the placebo specifications (h=-1 horizon and random shuffle) show statistically insignificant coefficients, which indicate that the estimated effects are indeed due to true post-shock fiscal responses, and not to pre-existing trends.

5. Empirical Results

5.1 Baseline OLS and Fixed Effects: The Climate-Fiscal Channel

Table 1 reports the baseline regression results for six increasingly specific specifications that use the fiscal balance (as a percentage of GDP) as the dependent variable. Three main conclusions are immediately apparent.

Table 1. Baseline OLS and Fixed Effects: Fiscal Balance as Dependent Variable

Dep. Var: Fiscal Balance (% GDP) | Six progressive specifications | Clustered SEs at country level | N = 1,700

Variable	(1) OLS No FE	(2) Country FE	(3) Two-Way FE	(4) FE + Interact.	(5) IV-2SLS	(6) Local Proj.h=1
Panel A — Climate Shock Variable						
Climate Shock Index (CSI)	−0.485*** (0.065)	−0.412*** (0.058)	−0.388*** (0.055)	−0.362*** (0.052)	−0.612*** (0.125)	−0.425*** (0.068)
CSI × Low Fiscal Space	—	—	—	−0.218*** (0.048)	—	—
CSI × SIDS Dummy	—	—	—	−0.312*** (0.065)	—	—
Panel B — Macro Controls						
Debt / GDP (%, lagged)	−0.028*** (0.005)	−0.022*** (0.005)	−0.020*** (0.005)	−0.019*** (0.004)	−0.021*** (0.005)	−0.020*** (0.005)
GDP Growth (%, lagged)	0.185*** (0.025)	0.162*** (0.022)	0.158*** (0.022)	0.155*** (0.021)	0.160*** (0.023)	0.155*** (0.022)
Govt Revenue (% GDP)	0.152*** (0.028)	0.138*** (0.025)	0.135*** (0.025)	0.132*** (0.024)	0.140*** (0.026)	0.132*** (0.025)
Inflation (%)	−0.042** (0.018)	−0.038** (0.018)	−0.036** (0.017)	−0.035** (0.017)	−0.038** (0.018)	−0.035** (0.017)
Panel C — Adaptive Capacity & Insurance						
ND-GAIN Score	0.065*** (0.018)	0.058*** (0.016)	0.055*** (0.016)	0.052*** (0.015)	0.060*** (0.017)	0.052*** (0.015)
Insurance Penetration (% GDP)	0.182*** (0.042)	0.165*** (0.038)	0.158*** (0.037)	0.152*** (0.036)	0.172*** (0.040)	0.155*** (0.037)
Constant	−3.520*** (0.385)	−2.980*** (0.352)	—	—	−3.120*** (0.408)	—
Model Fit Statistics						
Observations	1,700	1,700	1,700	1,700	1,700	1,700
R^2 / Within R^2	0.328	0.382	0.415	0.438	—	0.401
Country FE	No	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	Yes	Yes
F-statistic	42.5***	51.8***	58.2***	62.5***	38.8***	—

*Note: Clustered SEs at the country level in parentheses. *** p<0.01, ** p<0.05, * p<0.10. CSI = Climate Shock Index (0–10). ND-GAIN Score and Insurance Penetration are adaptive capacity moderators. Column (5) uses GHCN weather-station distance as IV. Column (6) is a Local Projection at horizon h=1. Country and year FE in cols (2)–(6), suppressed for brevity. Low Fiscal Space dummy = 1 when pre-shock fiscal space ≤ 2.8% GDP.*

First, macro fundamentals do not change their expected signs in between (Panel B). Lagged debt-to-GDP is negatively related to the fiscal balance, in line with the automatic debt stabilization motive. The fiscal balance is positively related to GDP growth and government revenues, which are both cyclical and structural. Inflation has been found to have a negative association, which agrees with the fact that inflation ultimately leads to higher expenditure pressures during high inflation periods. All fundamental controls are at the 5 percent level of significance or less for all six columns.

Second, the Climate Shock Index (CSI) is a very large and significant quantitative determinant of the fiscal balance (Panel A). The pooled OLS results in column (1) show an estimate of −0.485 (SE = 0.065), meaning that a one-unit increase in the CSI leads to a 0.49 percentage point of GDP decline in the fiscal balance in the same year. When country fixed effects (column 2), two-way fixed effects

(column 3), and interactions (column 4) are introduced, this coefficient does not change and remains significant, suggesting that the result is not due to cross-country selection or common global shocks. The preferred two-way FE estimate is −0.388 (SE = 0.055, $p < 0.001$), confirming Hypothesis H1.

Third, fiscally, the impact is moderated by adaptive capacity and insurance (Panel C). In the FE specification, the ND-GAIN score enters positively and significantly (0.055, $p < 0.001$), suggesting that the fiscal deterioration is smaller for a given CSI for countries with a higher score on the adaptive-institutions dimension. Insurance penetration is also positive and significant (0.158, $p < 0.001$), indicating that parametric insurance can provide "fast money" after disaster, which can be used as a substitute for emergency government spending. In line with hypotheses H3 and H4, the interaction specifications in column (4) indicate that the CSI effect is much stronger for low fiscal space countries (interaction coefficient: −0.218, $p < 0.001$) than for others, and, similarly, for SIDS (interaction: −0.312, $p < 0.001$).

5.2 Instrumental Variable Estimation: Addressing Attenuation Bias

The IV-2SLS results are shown in two panels in Table 2. Panel A (Table 2a) presents first-stage results of the CSI regressed on the set of instruments, followed by second-stage results (Panel B) and OLS reference estimates as well as the implied bias ratio.

Table 2a. First Stage: Climate Shock Index on Weather Station Distance Instrument
Dep. Var: Climate Shock Index (CSI, 0–10) | Country & Year FE | Clustered SEs at country level

Variable	(1) First Stage	(2) First Stage + Controls
Dep. Var: Climate Shock Index (CSI) | Instrument: Distance to GHCN Station		
ln(Distance to weather station)	0.185*** (0.032)	0.178*** (0.031)
Climate Vulnerability (ND-GAIN)	0.088*** (0.022)	0.085*** (0.021)
Coastline length (ln km)	0.042*** (0.012)	0.040*** (0.012)
Agriculture share of GDP (%)	0.032*** (0.010)	0.030*** (0.010)
GDP per capita (ln)	—	−0.058*** (0.018)
Urbanisation rate (%)	—	−0.022** (0.010)
Constant	1.485*** (0.285)	2.158*** (0.348)
First-Stage Diagnostics		
First-Stage F-statistic	58.4***	55.2***
Partial R^2	0.185	0.198
Kleibergen-Paap rk Wald F	52.1	48.8
Stock-Yogo 10% critical value	16.38	16.38
Instrument relevance	Strong ✓	Strong ✓

*Note: *** p<0.01, ** p<0.05, * p<0.10. Clustered SEs at country level. Instrument is log distance (km) from country capital to nearest GHCN Level-3 monitoring station. KP F-stat = Kleibergen-Paap rk Wald F-statistic, robust to heteroskedasticity. Country and year FE included but not reported.*

First-stage strength. The first stage has a coefficient of 0.185 (SE = 0.032, $p < 0.001$) for the primary instrument (log distance between country's capital city and nearest Global Historical Climatology Network (GHCN) weather monitoring station), meaning that countries further away from the quality monitoring stations show higher measured CSI values, which is consistent with the idea that under-reporting bias is present in more easily monitored locations. The F-statistic for the first-stage regression is 58.4, well above the Stock-Yogo (2005) criterion of 16.38, indicating that

the instruments are relevant. This can be supported by the Kleibergen-Paap rk Wald F of 52.1 under heteroskedasticity-robust inference. The Sargan-Hansen J-statistic is not significant (J = 2.14, p = 0.34 in the overidentified specification), so instrument validity is not rejected.

Table 2b. Second Stage: Fiscal and Debt Outcomes on Instrumented Climate Shock Index

Dep. Var: As labelled | 2SLS with Country & Year FE | Clustered SEs | OLS reference in col (4)

Variable	Fiscal Bal. (% GDP) 2SLS	Debt/GDP (%) 2SLS	Primary Bal. (% GDP) 2SLS	Fiscal Bal. (OLS ref)	Bias Ratio
Dep. Var: As labelled in column header | 2SLS with Country & Year FE					
CSI (instrumented)	−0.612*** (0.125)	2.485*** (0.482)	−0.428*** (0.108)	−0.388*** (0.055)	1.58×
Debt / GDP (%, lagged)	−0.020*** (0.005)	0.445*** (0.088)	−0.015*** (0.005)	−0.020*** (0.005)	—
GDP Growth (%, lagged)	0.158*** (0.022)	−0.628*** (0.118)	0.110*** (0.020)	0.158*** (0.022)	—
ND-GAIN Score	0.055*** (0.016)	−0.215*** (0.062)	0.038*** (0.014)	0.055*** (0.016)	—
Insurance Penetration	0.158*** (0.037)	−0.625*** (0.142)	0.110*** (0.032)	0.158*** (0.037)	—
Model Fit					
Observations	1,700	1,700	1,700	1,700	—
Country + Year FE	Yes	Yes	Yes	Yes	—
Sargan-Hansen J	χ^2=2.14 (p=0.34)	χ^2=2.05 (p=0.36)	χ^2=1.98 (p=0.37)	—	—

*Note: *** p<0.01, ** p<0.05, * p<0.10. Clustered SEs at the country level. Bias Ratio = |2SLS coeff| / |OLS coeff| — values >1 indicate downward attenuation bias in OLS. Sargan-Hansen J-statistic tests overidentification using station distance + coastline length + agriculture share as instruments. Country and year FE in all specifications.*

The second-stage results and attenuation bias: The instrumental variable that is used in the 2SLS empirical model of the fiscal balance and CSI is −0.612 (SE = 0.125), while the OLS estimate is −0.388, a 58 percent increase in absolute value. This validates the downward attenuation bias hypothesis that EM-DAT will under-record disaster damage in countries with lower-quality meteorological infrastructure, and thus OLS estimates of fiscal damage from climate shocks will underestimate the true fiscal damage. The 2SLS debt/GDP coefficient (+2.485 pp per CSI unit) is also larger than the OLS coefficient (1.842 pp), with a bias ratio of 1.35. These results suggest that the fiscal cost of climate shocks – as generally calculated in the literature based on EM-DAT data using OLS – is underestimated materially, with implications for climate finance adequacy assessments.

5.3 Local Projections: The Temporal Profile of Fiscal Adjustment

Table 3 shows the impulse response function (IRF) estimates for horizons h = 0, 1, 2, 3, 4 and 5 from the Jordà (2005) local projections framework. This analysis follows the entire dynamic sequence of fiscal and debt consequences from a positive CSI shock of one unit, and offers evidence on the persistence and reversibility of fiscal damage due to climate change.

Table 3. Local Projection Impulse Response Functions — Jordà (2005)

Dynamic fiscal balance & debt/GDP responses to a +1 CSI unit shock | Horizons h=0 to 5 | Country & Year FE | 90% CI reported

Outcome	h	Coeff.	Lower 90% CI	Upper 90% CI	Sig.	Cumul. Effect	Interpretation
Panel A — Fiscal Balance (% GDP) Response per +1 CSI Unit Shock							
Fiscal Balance (% GDP)	**0**	−0.388	−0.478	−0.298	***	−0.388	*Impact yr: immediate hit*
	1	−0.412	−0.511	−0.313	***	−0.800	*Yr 1: reconstruction peak*
	2	−0.358	−0.465	−0.251	***	−1.158	*Yr 2: spending sustained*
	3	−0.285	−0.397	−0.173	***	−1.443	*Yr 3: partial recovery*
	4	−0.198	−0.316	−0.080	***	−1.641	*Yr 4: normalisation starts*
	5	−0.125	−0.253	0.003	*	−1.766	*Yr 5: partial, not full recovery*
Panel B — Debt/GDP (pp) Response per +1 CSI Unit Shock							
Debt / GDP (pp)	**0**	1.842	1.140	2.544	***	1.842	*Emergency borrowing begins*
	1	2.485	1.736	3.234	***	4.327	*Yr 1: reconstruction accumulation*
	2	2.218	1.424	3.012	***	6.545	*Yr 2: debt still rising*
	3	1.852	1.013	2.691	***	8.397	*Yr 3: growth offsets partially*
	4	1.425	0.553	2.297	***	9.822	*Yr 4: stabilisation begins*
	5	0.985	0.079	1.891	**	10.807	*Yr 5: partial debt reduction*

*Note: *** p<0.01, ** p<0.05, * p<0.10. Newey-West HAC standard errors with bandwidth = √N. Confidence intervals computed at 90% significance level. Cumulative Effect = sum of coefficients from h=0 through stated horizon. Country and year FE included in all LP regressions. Controls: lagged debt/GDP, GDP growth, govt revenue, inflation (all lagged one period).*

The dynamics of fiscal balances (Panel A): The fiscal impact is highest at horizon h=1 (coefficient: −0.412), one year after the shock, which is the combination of the immediate loss of revenue and the rise in expenditure commitments to reconstruct, materialised in the budget year following the disaster. This effect then dissipates somewhat for horizons h=2 to h=5, but remains negative and statistically significant even at h=5 (coefficient: −0.125, marginally significant at 10 percent). Hypothesis H5 (debt hysteresis) is supported: The cumulative cost over five years of a one-unit CSI shock is −1.77 percentage points of GDP. A major climate event (CSI ~ 8) would cause a cumulative fiscal impact over 5 years of around −14.2 pp GDP, from which many SIDS economies have never recovered.

Debt dynamics (Panel B): In contrast, the debt accumulation after a climate shock has a more enduring pattern than the fiscal balance deterioration, as the new debt incurred to support reconstruction remains on the fiscal balance even as the primary balance improves somewhat. The

debt response peaks at h=1 (+2.485 pp GDP) and remains large and significant through h=5 (+0.985 pp, $p < 0.05$). These cumulative debt accumulation effects of +10.8 pp of GDP for a one-unit CSI shock over five years suggest that a major cyclone occurring in a SIDS economy (CSI ~ 8–9) would result in 86–97 pp of GDP of cumulative debt accumulation, which would exceed or be very close to standard debt distress thresholds for most frontier market economies. The debt sustainability trilemma is the hallmark of the asymmetry between the slower recovery of fiscal balances and the faster build-up of debt liabilities.

5.4 Threshold Regression: Non-Linearity and the Fiscal Trilemma

The threshold regression results of Hansen (1999) are given in Table 4, using pre-shock fiscal space as the threshold variable. This analysis tests Hypothesis H3 directly, the non-linear amplification of the fiscal impact of climate shocks when fiscal space is below a critical threshold, and offers the empirical underpinning to the trilemma interpretation.

Threshold identification: By using the Hansen bootstrap procedure, we find an estimated threshold of $\hat{\gamma} = 2.8$ percent of GDP in fiscal space in the pre-shock period (90% bootstrap confidence interval: [2.1%, 3.5%]), and a bootstrap p-value of 0.001, which strongly rejects the null of parameter constancy. There are 612 low fiscal space observations (36 percent of the sample) and 1,088 high fiscal space observations (64 percent).

Table 4. Threshold Regression — Fiscal Space Regime Analysis

Hansen (1999) Threshold Model | Threshold Var: Pre-shock Fiscal Space (% GDP) | $\hat{\gamma}$ = 2.8% GDP | Bootstrap p = 0.001

Variable	Low FS Fiscal Bal.	High FS Fiscal Bal.	Difference	Low FS Debt/GDP	High FS Debt/GDP	Diff.
Threshold: Fiscal Space $\hat{\gamma}$ = 2.8% GDP | Low FS: N=612 (36%) | High FS: N=1,088 (64%) | Hansen (1999) bootstrap p=0.001						
Climate Shock Index (CSI)	−0.618*** (0.095)	−0.245*** (0.062)	−0.373*** p<0.001	2.852*** (0.498)	1.285*** (0.342)	1.567***
Debt / GDP (%, lagged)	−0.025*** (0.006)	−0.018*** (0.005)	−0.007 p=0.18	0.502*** (0.102)	0.398*** (0.085)	0.104
GDP Growth (%, lagged)	0.145*** (0.028)	0.168*** (0.024)	−0.023 p=0.36	−0.582*** (0.128)	−0.658*** (0.112)	0.076
ND-GAIN Score	0.048*** (0.022)	0.062*** (0.018)	−0.014 p=0.32	−0.188*** (0.082)	−0.238*** (0.068)	0.050
Insurance Penetration	0.125*** (0.048)	0.182*** (0.040)	−0.057 p=0.18	−0.485*** (0.185)	−0.712*** (0.158)	0.227*
Model Fit						
Observations	612	1,088	—	612	1,088	—
Within R^2	0.448	0.402	—	0.385	0.352	—
Country + Year FE	Yes	Yes	—	Yes	Yes	—

*Note: *** p<0.01, ** p<0.05, * p<0.10. Clustered SEs at the country level in parentheses. Low FS = fiscal space ≤ 2.8% GDP (N=612, 36%); High FS = fiscal space > 2.8% GDP (N=1,088, 64%). Fiscal space is defined as the distance from the estimated debt-distress threshold. Difference column reports coefficient difference (Low − High) with associated p-value from Wald test. Country and year FE in all specifications.*

Regime-specific CSI effects: The bottom line is clear: in the low fiscal space regime, the CSI coefficient on fiscal balance is −0.618, which is 152 percent lower than in the high fiscal space regime, where the coefficient is only −0.245, and the difference is significant at the 1 percent level. The same applies to the CSI debt coefficient, which is 2.21 times as high in the low-space regime (2.852 pp) as in the high-space regime (1.285 pp). This is a non-linearity that is an empirical fact, and that is nothing but the trilemma: fiscal space is the threshold below which governments do not have the fiscal capacity to absorb climate shocks proportionately, and where, as a result, the fiscal-debt deterioration is disproportionate and accumulates over time.

The threshold results suggest an important asymmetry in the role of adaptive capacity, as the ND-GAIN coefficient is larger in the high-fiscal space regime, while the insurance penetration coefficient is larger as well. This balance of fiscal space and adaptive capacity is an inherent part of the trilemma, and fiscal buffers are a precondition to climate resilience investments to reap their full protective benefit.

5.5 Heterogeneity and Robustness

Table 5 presents the results of the heterogeneity and robustness tests for five panels (income groups, geographic regions, institutional characteristics, and specification alternatives).

Panel A: Gradient of income group. Based on the SIDS sub-sample, the fiscal balance's CSI coefficient is the largest of all groups, equal to −0.885 (SE = 0.142), whereas the debt/GDP CSI coefficient is equal to +3.185 pp (SE = 0.625), resulting in a five-year cumulative fiscal cost of −4.42 percent of GDP per one-unit CSI shock. Upper-middle-income economies have the lowest fiscal exposure, with a coefficient of −0.285, which is less than one-third of the value of the SIDS. The monotonic gradient in income strongly suggests that standard panel estimates, which average across income groups, greatly underestimate the burden that is borne by the most vulnerable economies and strongly supports Hypothesis H4.

Table 5. Heterogeneity Analysis and Robustness Checks

CSI Coeffs from Two-Way FE Regressions | Dep. Var: Fiscal Balance (% GDP) and Debt/GDP (%) | Clustered SEs

Sub-Group	N	CSI Coeff. (Fiscal Bal.)	CSI Coeff. (Debt/GDP)	5-yr Cumul. Fiscal Cost	Mean ND-GAIN	Assessment
Panel A — Income Group						
SIDS	136	−0.885*** (0.142)	3.185*** (0.625)	−4.42% GDP	35.8	*Most vulnerable — existential risk*
Low-Income (LIC)	425	−0.618*** (0.095)	2.852*** (0.498)	−3.09% GDP	38.2	*High vuln., no buffer*
Lower-Middle (LMC)	510	−0.452*** (0.078)	1.985*** (0.385)	−2.26% GDP	44.8	*Significant, limited space*
Upper-Middle (UMC)	425	−0.285*** (0.062)	1.142*** (0.298)	−1.43% GDP	53.2	*Meaningful but manageable*

Panel B — Geographic Region						
Sub-Saharan Africa	385	−0.615*** (0.098)	2.785*** (0.515)	−3.08% GDP	38.5	*Highest regional vulnerability*
South & SE Asia	320	−0.525*** (0.085)	2.248*** (0.428)	−2.63% GDP	43.2	*High exposure, mixed capacity*
Latin America & Caribbean	280	−0.388*** (0.075)	1.652*** (0.348)	−1.94% GDP	48.5	*Moderate — some resilience*
MENA & Eastern Europe	215	−0.242*** (0.068)	0.985*** (0.278)	−1.21% GDP	51.2	*Lower exposure*
Panel C — Institutional Characteristics						
High Insurance (>2% GDP)	245	−0.228*** (0.065)	0.882*** (0.265)	−1.14% GDP	50.5	*Insurance buffers the shock ✓*
Low Insurance (<0.5% GDP)	380	−0.682*** (0.108)	3.125*** (0.548)	−3.41% GDP	39.5	*Uninsured = amplified cost*
Countries with IMF Program	285	−0.312*** (0.072)	1.285*** (0.318)	−1.56% GDP	46.2	*Conditionality limits spending*
Countries without IMF access	415	−0.528*** (0.092)	2.215*** (0.448)	−2.64% GDP	44.8	*No backstop — worse outcomes*
Panel D — Robustness Checks						
Baseline CSI (benchmark)	1,700	−0.388*** (0.055)	1.842*** (0.358)	−1.77% GDP	46.5	*Benchmark*
INFORM Risk Index (OCHA)	1,700	−0.412*** (0.060)	1.958*** (0.385)	—	—	*Consistent ✓*
ERA5 Met. Intensity only	1,700	−0.328*** (0.058)	1.548*** (0.325)	—	—	*Consistent ✓*
Excl. Haiti (outlier)	1,658	−0.372*** (0.055)	1.778*** (0.352)	—	—	*Consistent ✓*
Placebo: CSI shuffled	1,700	−0.015 (0.052)	0.062 (0.205)	—	—	*Placebo fails ✓*

*Note: *** p<0.01, ** p<0.05, * p<0.10. Clustered SEs at country level. All specifications include country FE, year FE, and the full set of macro controls. 5-yr Cumulative Fiscal Cost = sum of local projection coefficients h=0 to 5 multiplied by the sub-group mean CSI (4.22 for full sample). Placebo test uses CSI randomly re-assigned within each country across years.*

Insurance as a mitigating mechanism (Panel C). The most dramatic heterogeneity finding is the insurance penetration split, with countries having above 2 percent insurance penetration having a CSI fiscal coefficient of −0.228, which is 67 percent less than the fiscal coefficient of −0.682 for countries with less than 0.5 percent insurance penetration. This difference is significant at the 1 percent level and is unaffected by the inclusion of all macro controls and fixed effects. The result constitutes the best available evidence in the paper about the effectiveness of parametric insurance as a risk management instrument for the fiscal budget, and directly feeds into the policy scenario analysis which reveals that the cumulative five-year fiscal cost of climate shocks can be cut by around 40 percent if insurance coverage is scaled up to 2 percent of GDP.

Robustness checks (Panel D). All three alternative CSI measures (INFORM Risk Index, ERA5 meteorological intensity only, and the World Risk Index) result in negative and significant coefficients, which are very close to the baseline. The coefficient is only slightly affected by the extreme outlier in the data set, Haiti, as it moves from −0.388 to −0.372 when Haiti is excluded. Most importantly, coefficients for the placebo test based on a randomly permuted CSI (within country) are insignificant, at −0.015 (p = 0.77), ruling out the possibility that the baseline results are spurious panel correlation.

5.6 Economic Magnitude: From Statistics to Policy Stakes

To convert the regression coefficients to magnitudes that can be used to make policy decisions, we assume the benchmark case of a SIDS economy with an initial debt/GDP ratio of 75 percent and an average annual CSI exposure of 6.5 units (the SIDS sub-sample average). On the basis of the two-way FE estimates, it means that climate shocks alone (no policy response) can be expected to cause a loss in fiscal performance of 2.5 percentage points of GDP on average per year. The cumulative fiscal cost over five years of two major shock events (as observed in the Pacific and Caribbean) would be about 22 per cent of GDP, while the debt increases due to climate shocks would be about 70 per cent of GDP. For most SIDS economies, this path suggests that they will cross thresholds of debt distress during a decade under the no-buffer baseline.

The counterfactual policy scenario analysis (shown in the accompanying Excel file, sheet 11) estimates the debt-savings potential of alternative policy packages. A comprehensive policy package, with parametric insurance coverage for 2 percent of GDP, a dedicated climate fiscal reserve of 4 percent of GDP, and a concessional climate finance of 2 percent of GDP per year is expected to lower debt/GDP in 2040 by around 60 to 80 percent of GDP compared to the no-buffer baseline, allowing debt to stay on a sustainable path under repeated major shock scenarios. This quantification highlights that the fiscal trilemma is not a structural constraint, but a policy challenge – one that can be overcome if the multilateral climate finance system scales up in response to the scope of climate vulnerability in the most vulnerable economies.

6. Policy Implications

The empirical findings of this paper lead to three propositions, each of which is important and together transformative for climate finance policy. First, fiscal costs from climate shocks are 58 per cent higher than standard OLS estimates, which are based on EM-DAT data and lack any adjustment for attenuation bias. Second, these costs are non-linearly amplified when fiscal space is below 2.8 percent of GDP, and thus the most vulnerable economies are caught in a vicious deterioration spiral. Third, a multi-pillar response – with a coordinated mix of parametric insurance, fiscal buffer and concessional financing – can lower 15-year debt levels by 60–80 pp of GDP compared to a baseline without a buffer.

6.1 The Trilemma in Practice: Why Single-Pillar Responses Fail

However, it is important to understand that single-pillar solutions to climate-related fiscal risk can often fail to deliver before making policy recommendations. Climate vulnerability, fiscal space, and access to external financing are deeply linked, as limited fiscal space increases climate vulnerabilities and climate vulnerabilities limit external financing.

The first challenge is high climate vulnerability, with the mean Climate Stress Index (CSI) ranging from 5.8 to 6.5 for LICs and SIDS, and annual disaster damages reaching up to 3 percent of GDP. Recurrent climate shocks come at high fiscal cost from emergency spending, reconstruction needs, and loss of revenues. The second challenge is the lack of funds. The estimated threshold $\gamma \hat{} = 2.8\%$ of GDP indicates that the countries with values below this threshold (around 36 percent of the sample) are especially vulnerable to climate shocks. Small buffers can lead governments to further borrow, raise debt levels and thus limit their fiscal capacity. Limited access to outside financing is the third dimension. Under less favorable financing conditions, access to IMF support, concessional finance or international capital markets is restricted, in which case the negative fiscal impact of climate stress increases significantly to -0.528, against -0.312 under more favorable financing conditions.

Together, these are a self-reinforcing 'climate–fiscal trilemma'. High vulnerability erodes fiscal buffers, limited fiscal space reduces investment in resilience, and restricted financing affects governments' response and recovery. Thus, even if insurance is paid out, it might not be effective if debt-service obligations increase, or because fiscal reserves could be quickly depleted by repeated shocks, and external financing could also generate new debt-service requirements or simply fail to materialize due to the lack of implementation capacity.

Thus, there is a clear policy implication: no one instrument can solve the problem. However, breaking the vicious cycle needs a coordinated multi-pillar approach which can address climate vulnerability, build fiscal capacity, and enhance access to cheap and readily available external financing.

6.2 Implications for IMF Debt Sustainability Analysis

6.2.1 Climate-Adjusted Baseline Projections

DSA baseline projections should include a climate-adjusted fiscal and debt path that considers the annual fiscal cost from the country's distribution of CSI. A two-way FE estimate of the CSI's impact on fiscal health is −0.388 per CSI unit, implying that an economy with a mean CSI of 5.0 would experience an additional climate-induced fiscal deterioration of around −1.94 pp of GDP per year, which is not included in any existing DSA baselines. This neglect systematically overestimates fiscal space and underestimates the accumulation of debt for climate-vulnerable economies.

6.2.2 Fiscal Space Threshold as a DSA Warning Indicator

The empirically estimated threshold of 2.8 per cent of GDP should be made a part of the DSA by formalizing it as a Climate Fiscal Vulnerability Indicator (CFVI). Countries in this band should have increased DSA review modelling, similar to the non-linear shock amplification, risk of a debt trap spiral, and financing gap needed to maintain sustainability in the context of climate stress scenarios.

6.2.3 Insurance and Reserves as DSA Credit Enhancements

Parametric insurance and dedicated climate fiscal reserves should be acknowledged as DSA credit enhancements, as they boost a country's absorptive capacity to climate shocks. Reserve buffers, like external sustainability assessments, serve to lessen the fiscal impact of bad outcomes and curtail the need for extra loans.

The proposed framework would implement an enhanced (climate-adjusted) DSA protocol for countries with a pre-shock fiscal space at or below 2.8 percent of GDP. This assessment would include an estimate of the impact of climate stress on the fiscal baseline, the more pronounced non-linear effects observed below the fiscal-space threshold, and the projected 5-year debt path after a large climate stress (CSI $\geq$7.0).

Importantly, specific pre-arranged risk-financing instruments should be explicitly included in the stress assessment. Parametric insurance coverage of more than 2% GDP and climate reserves of more than 4% GDP can each provide a 20% reduction in the climate stress scenario, for a maximum of 40% reduction. This would create more incentives for countries to commit to ex-ante financial protection and make debt sustainability assessment more representative of countries' underlying capacity to absorb shocks to their fiscal space from climate change.

6.3 Implications for the Climate Finance Architecture

6.3.1 Scaling Parametric Insurance to SIDS and LICs

The 67 percent reduction in fiscal impact for countries with insurance penetration of more than 2 percent of GDP, the strongest single heterogeneity result in the paper, gives strong evidence for the scaling up of CCRIF-style parametric insurance to all LICs and SIDS. We estimate the cost of donor-financed premiums at around $8–12 billion per year, with the fiscal benefit from avoiding fiscal damage expected to be $35–45 billion per year, representing a benefit-cost ratio of 3-4 X, making insurance premium financing one of the highest-return investment vehicles in the climate finance toolkit.

6.3.2 A Climate Fiscal Recovery Facility (CFRF)

The existing multilateral instruments are geared towards either investment in adaptation or emergency response. At horizons h=2-5, where governments have above-normal expenditure while emergency finance is depleted, there is a critical medium-term financing gap. A new Climate Fiscal

Recovery Facility should be set up to automatically disburse five-year program financing, based on CSI ≧7.0 events, according to the impulse response path h=1–h=5 in this paper. Target capitalization: $50 billion in MDB balance sheet expansion and from donors.

6.3.3 Debt-for-Climate Swaps at Scale

Parametric insurance and reserves will not be able to solve the debt-overhang problem for countries that are already below the fiscal space threshold. Debt-for-climate swaps that involve a reduction in face value or service burden of a debt in exchange for verifiable adaptation investment commitments are most direct in addressing the debt and the vulnerability dimensions. Based on our estimates, a 10–15 pp of GDP debt relief could return fiscal space above the 2.8 percent threshold for most countries in our sample that are in the sub-threshold zone, allowing them to benefit from the non-linear resilience gains shown in Table 4.

6.4 Implications for National Climate Fiscal Frameworks

6.4.1 Dedicated Climate Fiscal Reserves

The policy scenario analysis indicates that the creation of a dedicated climate buffer of 4 per cent of GDP at 0.5 pp/year in non-shock years and 0.1 per cent of GDP if there is a climate shock (CSI ≥ 7.0) decreases 2040 debt/GDP by 25-30 pp compared to the no-buffer baseline scenario. The reserve should also be set aside from general budget funds, be subject to clear draw-down rules, and be part of the proposed IMF CFVI credit enhancement facility.

6.4.2 Climate Risk in Medium-Term Fiscal Frameworks

Finance ministries should include climate-adjusted fiscal projections in national MTFFs, and should use country-specific CSI distributions to derive fiscal cost estimates (central case) and estimates for years with major shocks (stress case). This allows legislatures, rating agencies, and multilateral creditors to make a truthful assessment of fiscal sustainability that takes into account the uncertain but significant climate event liability.

6.4.3 Adaptive Capacity as Fiscal Risk Management

The positive coefficient on ND-GAIN of 0.055 per increment on the fiscal balance highlights the fiscal dividend that comes from investing in adaptive capacity: each increment in ND-GAIN – which can be achieved over the course of a decade – leads to a corresponding reduction in annual climate-induced fiscal deterioration around 0.28 pp of GDP. Governments should categorize investments in adaptive capacity as fiscal risk management, measured and quantified, and not as a development or humanitarian investment.

7. Policy Recommendations

Building on the empirical results, seven policy recommendations are proposed, focusing on their key institutional audience and potential for enhancing climate–fiscal resilience.

First, the IMF needs to incorporate a Climate Fiscal Vulnerability Indicator (CFVI) in the LIC and MAC Debt Sustainability Analysis (DSA) frameworks. If the pre-shock fiscal space reduces to/equals 2.8 per cent of GDP, then the enhanced DSA review may be activated. The assessment should include a climate-adjusted fiscal baseline as well as try to capture non-linear impacts of climate stress beyond the fiscal-space threshold and consider the five-year debt path after major climate shocks (CSI $\geq$ 7.0). DSA credit enhancements could be applied to those countries with parametric insurance coverage of more than 2 percent of GDP and climate reserves of more than 4 percent of GDP.

Secondly, there is a need for multilateral donors and the G7+ to invest in parametric insurance coverage for LICs and SIDS. Around USD 8–12 billion per year is estimated to be required for providing coverage equivalent to about 2 percent of GDP in the 68 eligible LIC and SIDS economies, and this could lead to potential fiscal benefits of between USD 35–45 billion per year. Scale-up coverage could be achieved through existing regional risk-pooling mechanisms such as CCRIF, African Risk Capacity and PCRAFI. International financial commitments to support climate action could also be centered on premium financing.

Third, there should be a Climate Fiscal Recovery Facility (CFRF) of the World Bank and other multilateral development banks. The facility could offer a five-year financing program with an automatic on, once a major climate event (CSI $\geq$7.0) occurs. Disbursements need to show the best guess of fiscal recovery, with more support in the first two years, and then a downward trend in the next three years. The capitalization of the facility could be between USD 50 and 55 billion, initially for IDA-eligible countries and SIDS, with a target of USD 50 billion via balance-sheet expansion of MDBs and donor contributions.

Fourth, bilateral creditors should launch debt-for-climate swap programs for countries whose fiscal space is below the estimated threshold. The potential of such programs is to offer debt relief of 10–15 percent of GDP for verified climate adaptation and resilience investments. Relief may involve principal reductions and interest concessions spread over 10 years implementation period, with independent assessment of the quality of adaptation and technical assistance on how to design the program.

Fifth, emerging-market finance ministries should create specific climate fiscal reserves – the medium-term goal being 4 percent of GDP. Such reserves could be established in non-shock years via annual contribution of ~0.5 percent of GDP and be utilized after major climate events. Making such reserves part of national medium-term fiscal planning would help enhance fiscal preparedness

and make it more likely that governments will see adaptation spending as an investment in fiscal risk management, not just a development or environmental investment.

Sixth, the UNFCCC and its COP climate-finance framework should shift from traditional disaster damage estimates to IV-calibrated fiscal cost estimates. These findings indicate that the fiscal impacts of climate change, based on the IV estimation approach, are on average around 58 percent higher than those based on the traditional approach using the EM-DAT database and the OLS estimation approach. The estimated expected fiscal cost of climate shocks with the domestic buffers deducted could therefore be used as a measure of country-level climate finance needs. Such a strategy would support overcoming the possible optimism bias in the current climate-finance sufficiency evaluations.

Last but not least, the research community should broaden the Climate Stress Index (CSI) approach to subnational, sectoral and cross-country political economy analysis. Subnational applications could focus on differential fiscal vulnerability to climate within the country, and sectoral extensions could target differential effects on agriculture, energy and infrastructure. It could be beneficial to further examine how political positioning, as identified in the geopolitical alignment study accompanying this one, might interact with climate vulnerability and access to concessional climate finance, and to build up a broader understanding of the combined climate – fiscal – financing trilemma.

8. Conclusion

This study develops a new Climate Shock Index (CSI) for the 68 emerging and frontier market (EFM) economies during 2000–2024 and discusses the results of fixed-effects, IV-2SLS, local projections, and threshold regression analyses to detect the fiscal effects of climate shocks.

Overall, results indicate that climate shocks significantly and persistently impact budget outcomes. The baseline estimates show that a one-unit rise in the CSI leads to a 0.388 percentage point decline in the fiscal balance as a share of GDP, while the results obtained from the IV-2SLS are 0.612 percentage points. The difference between the two is about 58 percentage points, with the OLS understating the causal effect. The fiscal impact is highest in the first year and lasts for at least five years, and there is a cumulative 10.8 percentage-point increase in public debt over five years from climate shocks. The impact is far more pronounced in the event of fiscal space below 2.8 percent of GDP, where the fiscal space coefficient is estimated to increase approximately by 152 percent. The burden is also greatly asymmetric, with SIDS feeling a fiscal impact of −0.885 while the UMICs feel a fiscal impact of −0.285.

Fortunately, however, parametric insurance can greatly help to reduce these impacts. The fiscal impact of countries with coverage above 2 percent of GDP is −0.228, whereas the impact for countries with coverage below 0.5 percent of GDP is −0.682, which is about 67 percent less.

Simulations of policy options also indicate that a package of insurance, fiscal reserves, and climate finance can lead to cumulative fiscal savings of 60–80 percentage points of GDP by 2040.

The key conceptual contribution of this paper is the Debt Sustainability Trilemma in small emerging markets that are highly vulnerable to climate change, with low fiscal capacity and limited external financing, and are stuck in a vicious downward cycle, where no single policy option offers an easy way out. The threshold regression provides an estimate of the exact level of fiscal space (2.8 percent of GDP) where the effects of climate shocks shift in nature and increase all three aspects of the trilemma simultaneously. The heterogeneity analysis corroborates the fact that SIDS and low-income countries are the most climate-exposed and the least fiscally capable and thus face the highest trilemma.

The trilemma framework is of a descriptive and prescriptive nature. Descriptively, it depicts why these individual-instrument interventions (debt relief without resilience investment, resilience investment without fiscal space, and insurance without liquidity backstops) have not proven to be effective in creating lasting enhancements in fiscal sustainability. Prescriptively, it suggests that at least two trilemma dimensions will need to be tackled by effective interventions, and all three dimensions – insurance, fiscal reserves, and concessional finance – are necessary for transformative impact.

In summary, the countries most vulnerable to the growing physical shocks and stresses of climate change are the countries with the least fiscal space to face those shocks. This paper introduces a crucial additional layer to this observation: The relation is not just additive but multiplicative, and this relationship does not just work through a linear threshold but rather through a non-linear one that defines a boundary of fiscal space at 2.8 percent of GDP.

However, a significant percentage of the world's most climate-vulnerable economies will fall below this threshold within the decade without deliberate multilateral interventions – not due to fiscal mismanagement, but due to repeated climate shocks taking their toll on buffers which cannot be replenished quickly enough. Geophysical forces and institutional failures that they and their governments did not select will contract the trilemma, endanger debt sustainability, and rule out the development aspirations of hundreds of millions of people.

The positive aspect is that the trilemma can be resolved. Even highly exposed SIDS economies can be maintained on sustainable debt trajectories with a full package of policies, if they are applied on a large scale and over a long period of time. It is financially achievable: $8-$12 billion each year in financing of insurance premiums alone provides a 3-4 times fiscal return. The mismatch between the present and the future that this analysis suggests is not so much one of resources as of institutional design, political will, and analytical clarity as to how exactly climate vulnerability turns into fiscal fragility. This paper has aimed to provide such analytical clarity.

Connection to the Conference Theme: Fragmented Global Economy

The results are related to the theme of the NBER conference in three ways. The companion paper (Topic 1) has shown that geopolitically non-aligned EMs pay 130-190 bps more in sovereign bond markets. This represents a double burden of financing for the climate-vulnerable economies that are non-aligned (a significant overlap): increases in financing costs at a time when fiscal deterioration is most severe due to climate. Second, the financing pillar of the trilemma is being undermined at the very time it is needed, as geopolitical fragmentation has hampered MDB recapitalization and replenishment of climate funds windows. Third, the second-round effects through trade: export revenues also decline as a result of fragmentation of supply chains, while reconstruction imports become more expensive due to climate effects, which adds to the fiscal deterioration found in the IRF analysis.

Limitations and Extensions

First, despite the IV correction, the CSI is still controlled by reporting heterogeneity. More objective exposure data would be afforded by satellite-based damage assessment data (UNOSAT, USGS ShakeMap). Second, the five-year IRF time horizon does not adequately reflect changes to the frequency and intensity of disasters as a result of climate change that occur on a 10-year scale. If the historical panels were longer or the climate models projected for 10 to 20 years, then the analysis could be done for that time frame. Third, the analysis does not account for the interaction between the climate shocks, monetary policy, dynamics of the exchange rate, or financial sector stability, all of which tend to magnify each fiscal channel examined here, and are frequently found in SIDS.

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