Climate Vulnerability and Sovereign Debt Accumulation

A Panel Cointegration Study of Small Island Developing States

Jorge D. Ballestero

Columbia University | ECON GU4918 Senior Seminar in Econometrics

Spring 2026

The Puzzle

The facts

- SIDS contribute $<$**1%** of global GHG emissions
- Yet face disaster costs averaging **18% of GDP** annually (Saghir & Ijjasz-Vasquez 2025)
- Over **70%** of SIDS show signs of debt distress (UN OHRLLS 2024)
- Hurricane Maria: **226% of GDP** for Dominica (2017)

The system's response

- Concessional finance allocated by **GNI per capita**
- Middle-income SIDS are excluded despite structural exposure
- Top 10 funded SIDS receive **67%** of tracked adaptation finance (CPI 2025)
- Structural exposure goes **unpriced**

The countries *least* responsible for climate change are accumulating the most debt. The international finance system is not built to see why.

Research Question

Does **structural climate vulnerability** have a long-run cointegrating relationship with **sovereign debt accumulation** in SIDS, *independent of income and fiscal policy?*

Why SIDS?	Why long-run?	Why now?
Worst affected; most excluded from empirical panels	Structural exposure is persistent, not episodic	UN MVI adopted Aug. 2024; needs empirical foundation

Where This Paper Sits

Literature	What it does	Gap
Sovereign debt Edwards (1984); Uribe & Yue (2006)	Macro determinants of LDC borrowing costs	No climate
Climate-finance Buhr et al. (2018); Kling et al. (2021)	Vulnerability and cost of capital; spread responses	Short-run; SIDS excluded
SIDS policy UN OHRLLS; CPI	Debt distress, adaptation finance, MVI design	No panel econometrics

This paper's contribution

- First panel cointegration test of *structural* vulnerability and debt in a SIDS-centred sample
- Dependent variable: debt *stock*, not spread – no \$500m EMBI threshold required
- Tests for **asymmetric error correction** – a structural prediction derived before estimation

The Ratchet Hypothesis

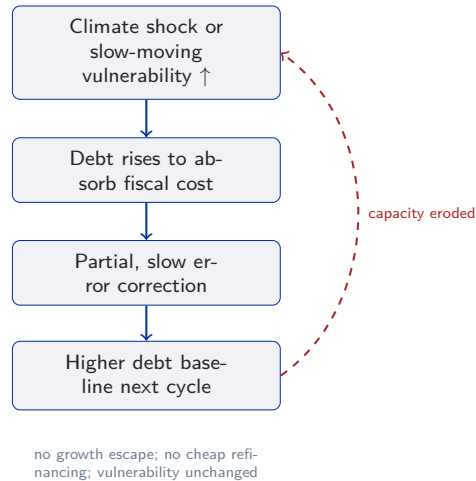
Standard cointegration assumes *symmetric* error correction. For SIDS, three structural features break that symmetry:

1. **Growth constraints** – small, open, tourism-dependent
2. **Capital market access** – terms worsen at worst times
3. **Vulnerability persistence** – the hurricane track does not move

Testable prediction

$\alpha_{\text{debt}} < 0$ debt error-corrects toward vulnerability-implied equilibrium

$\alpha_{\text{vuln}} > 0$ vulnerability adjusts *upward* – not down



Data

Sample

- **27 SIDS**, 2000–2023 ($N = 648$)
- 14 Caribbean 6 Pacific 7 AIS
- 12 excluded: ND-GAIN or DRS data gaps

Key variables

- **Debt:** WB IDS (21 countries) / IMF WEO (6 countries)
- **Vulnerability:** ND-GAIN sub-score
  exposure + sensitivity + adaptive capacity
- **Controls:** GDP growth, current account, inflation, fiscal balance, remittances

Summary statistics

	Mean	SD	Range
Debt (% GNI/GDP)	61.8	48.2	6.5 – 436
ND-GAIN vulnerability	0.50	0.06	0.38 – 0.65
Disaster damage (% GDP)	2.5	18.5	0 – 331
GDP pc PPP (000s USD)	13.6	9.5	2.0 – 49
GDP growth (%)	2.8	6.2	−33 – 63

Mean vulnerability gap SIDS vs. non-SIDS: **0.047 score units**, stable across all 24 years.

Empirical Strategy

Why cointegration?

Both debt and vulnerability are **I(1)**: shocks are permanent, not transitory. Standard panel regression risks spurious results. (Granger & Newbold 1974)

Long-run specification

$$\text{Debt}_{it} = \alpha_i + \beta_1 \,\text{Vulnerability}_{it} + \beta_2 \,\text{GDPpc}_{it} + \varepsilon_{it}$$

GDP per capita enters the cointegrating vector directly so that β_1 captures climate exposure, not a development-level story.

Panel VECM

$$\Delta X_{it} = \alpha\beta' X_{it-1} + \sum_{j=1}^{2} \Gamma_j \Delta X_{it-j} + \Phi Z_{it} + \varepsilon_{it}$$

$X = (\text{debt},\ \text{vulnerability},\ \text{GDPpc})'$; I(0) controls in Z; estimated via `tsDyn` in R.

Unit roots: Im-Pesaran-Shin (2003)
Debt, vulnerability, GDPpc confirmed I(1)

Rank: Johansen trace test (1991)
All three nulls rejected at 1%; VECM at $r = 1$

Pre-tests: Cointegration Confirmed

IPS Unit Root Tests

Variable	W-bar	Order
Debt	-1.08	I(1)
ND-GAIN vulnerability	-5.33^{***}	I(1)†
GDP per capita	-1.95^{**}	I(1)†
GDP growth	-14.0^{***}	I(0)
Current account	-5.82^{***}	I(0)
Fiscal balance	-8.07^{***}	I(0)
Δ Debt	-15.7^{***}	I(0) ✓
Δ Vulnerability	-22.4^{***}	I(0) ✓
Δ GDPpc	-13.0^{***}	I(0) ✓

† Borderline at levels; confirmed by first-difference test.

Johansen Trace Test

H_0	Trace	5% CV	1% CV
$r = 0$	89.2	42.4	48.5
$r \leq 1$	41.2	25.3	30.5
$r \leq 2$	19.8	12.3	16.3

All three nulls rejected at 1%. System is fully cointegrated. VECM estimated conservatively with $r = 1$.

Main Results: Cointegrating Vector

	(1) Baseline	(2) Enriched	(3) Breaks
Panel A: Cointegrating vector			
Vulnerability ($\hat{\beta}_1$)	-108.2	-105.2	-105.2
GDPpc ($\hat{\beta}_2$)	-0.00060	-0.00083	-0.00083
Panel B: Error correction – debt equation			
ECT ($\hat{\alpha}_{\text{debt}}$)	-0.156^{***}	-0.163^{***}	-0.164^{***}
	(0.021)	(0.022)	(0.022)
Panel C: Exogenous controls			
GDP growth	-0.634^{***}	-0.608^{***}	-0.576^{***}
Current acct	-0.206^{**}	-0.231^{**}	-0.230^{**}
Fiscal balance	—	-0.052	-0.019
Remittances	—	-0.143	-0.174
d_{GFC}	—	—	-1.14
$d_{\text{Commodity}}$	—	—	$+1.22$
d_{COVID}	—	—	$+5.42$
N	640	615	615

$^{*}p<.10$; $^{**}p<.05$; $^{***}p<.01$

Key results

- $\hat{\beta}_1 \approx -105$ pp – **stable** across specs (<3% movement)
- $\hat{\alpha}_{\text{debt}} \approx -0.163^{***}$ – debt corrects at **16%/yr**; half-life approx. 6 years
- Fiscal balance: **insignificant** in every specification
- All structural break dummies: **insignificant**

The debt accumulation is **structural before it is fiscal.**

The Ratchet in the Data

Asymmetric error correction

Equation	$\hat{\alpha}$	Sig.
Debt	-0.163	***
Vulnerability	$+0.000052$	*

When debt is below its vulnerability-implied equilibrium:

- Debt adjusts **upward** ✓
- Vulnerability also adjusts **upward** ✓

The long-run equilibrium is **itself drifting upward** as structural exposure increases.

What this means

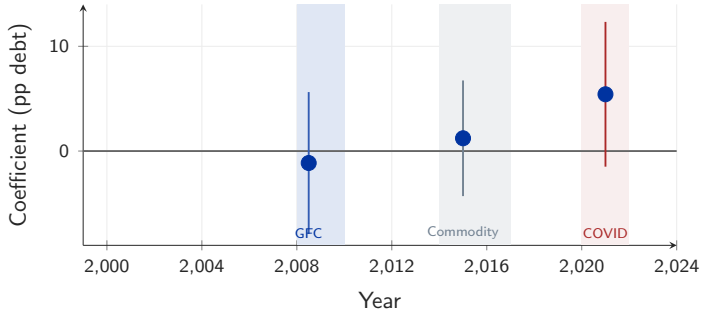
Mean reversion in residuals does not mean reversion to a fixed level. Debt tracks a drifting vulnerability-implied equilibrium.

The financing gap is not static. It is worsening.

Open question

How fast is the equilibrium drifting? A threshold VECM could formally bound the asymmetry.

A Continuous Relationship – Not an Episodic One



All three structural break dummies are statistically indistinguishable from zero. The vulnerability-debt relationship operated **before** the GFC, **through** the commodity shock, and **through** COVID-19. It does not require a disaster to activate it.

Regional Heterogeneity

Region	n	N	$\hat{\beta}_1$	$\hat{\alpha}_{\text{debt}}$
Caribbean	14	311	-120.3	-0.145^{***}
AIS	7	164	-163.9	-0.138
Pacific	6	142	-63.5	-0.119
Full panel	**27**	**617**	$\mathbf{-105.2}$	$\mathbf{-0.163}^{***}$

The Pacific deviation

Pacific SIDS receive a larger share of external financing as **grants**, not loans. The ratchet requires climate costs to be absorbed through debt. Where financing is grant-based, that transmission is **interrupted**.

The Pacific result is the **policy implication visible in the data**: appropriately structured financing breaks the mechanism this paper documents.

Open question

What grant-financing share fully decouples vulnerability from debt? Is there a threshold?

Robustness

Four checks, all consistent

Check	Change	Result
ND-GAIN decomposition	Replace composite with exposure + sensitivity only	$\hat{\beta}_1 = -127.2$ – stronger; physical dimensions drive result
Debt service (flow)	Replace debt stock with debt service / GNI	$\hat{\beta}_1 = -2.81^{***}$; ECT $= -0.179^{***}$; asymmetric adjustment absent (flow resets annually)
Trade openness	Add UNCTAD openness control; 2005–2023	Vulnerability coefficient stable
IDS subsample	Drop 6 WEO countries (different debt measure)	Consistent with full panel

Dropping adaptive capacity **strengthens** the result. The income-correlated component of vulnerability is not driving the long-run relationship.

Policy Implication: The Multidimensional Vulnerability Index

In August 2024, the UN General Assembly adopted **Resolution A/78/L.98**, establishing the MVI.

The MVI is designed to replace GNI per capita as the sole criterion for concessional finance access.

What this paper provides

- Vulnerability and debt: **long-run, independent of income**
- Fiscal policy: **not the driver**
- Ratchet: the financing gap is **worsening**, not static
- Pacific: grant financing **breaks the mechanism**

The core argument

Income-based criteria will *systematically exclude* the countries whose debt trajectories are driven by climate exposure – not fiscal mismanagement.

The debt is structural before it is fiscal. The MVI is designed to see it.

Open question

How should the MVI vulnerability weight be calibrated against the $\hat{\beta}_1 \approx 105$ estimate?

Open Questions and Next Steps

Geographic instruments

The cointegrating vector controls for income directly, but no instrumental variable strategy has been implemented yet.

Candidates: coastline-to-land ratio, proximity to hurricane tracks, distance from the equator.

Threshold VECM

Asymmetry is inferred from the sign of $\hat{\alpha}_{\text{vuln}}$, not formally tested.

A threshold VECM would identify: at what debt level does the ratchet lock in?

Panel extension

ND-GAIN data matures past 2023. A longer panel would narrow the IRF confidence bands, which are currently wide ($T = 24$).

Counterfactual: grant financing

Pacific SIDS show grant financing breaks the transmission from vulnerability to debt.

Can we estimate a counterfactual debt trajectory for Caribbean SIDS under a Pacific-style financing mix?

Synthetic control or DiD on financing structure shifts.

Conclusion

What was shown

- Structural climate vulnerability **cointegrates** with sovereign debt across 27 SIDS, 2000–2023
- A one-unit increase in ND-GAIN vulnerability score implies approx. **105 pp more debt** in the long run
- Result survives four nested specs, three break regimes, and four robustness checks
- Error correction is **asymmetric**: the ratchet is in the data
- Fiscal balance is **not significant** – the debt is structural, not a policy choice

Bottom line

The countries least responsible for climate change are accumulating debt as a structural consequence of their exposure.

The financing architecture was not designed to see this.

The MVI is.

Replication: can be found here

Jorge D. Ballestero jdb2250@columbia.edu Columbia University

Appendix: Country Sample

Caribbean (14)

Antigua & Barbuda (ATG)
Bahamas (BHS)
Belize (BLZ)
Barbados (BRB)
Dominica (DMA)
Dominican Republic (DOM)
Grenada (GRD)
Guyana (GUY)
Haiti (HTI)
Jamaica (JAM)
St. Lucia (LCA)
Suriname (SUR)
Trinidad & Tobago (TTO)
St. Vincent (VCT)

Pacific (6)

Fiji (FJI)
Papua New Guinea (PNG)
Solomon Islands (SLB)
Tonga (TON)
Vanuatu (VUT)
Samoa (WSM)

AIS (7)

Comoros (COM)
Cabo Verde (CPV)
Guinea-Bissau (GNB)
Maldives (MDV)
Mauritius (MUS)
Sao Tome & Principe (STP)
Seychelles (SYC)

Debt source: WB IDS for 21 countries; IMF WEO for ATG, BHS, BRB, SUR, SYC, TTO.

Appendix: Full VECM – Enriched Specification

Variable	Debt eq.	Vulnerability eq.	GDPpc eq.
ECT (α)	-0.163^{***} (0.022)	$+0.0001^{**}$ (0.000)	-1.805 (2.940)
Trend	-0.000 (0.004)	0.000 (0.000)	-0.821 (0.558)
Δdebt_{t-1}	0.095^{**} (0.040)	-0.000 (0.000)	-0.116 (5.463)
$\Delta\text{vulnerability}_{t-1}$	-13.47 (44.41)	0.002 (0.051)	-10164 (6052)
ΔGDPpc_{t-1}	-0.000 (0.000)	0.000 (0.000)	-0.142^{**} (0.048)
Δdebt_{t-2}	0.112^{**} (0.041)	-0.000 (0.000)	2.453 (5.518)
$\Delta\text{vulnerability}_{t-2}$	20.90 (44.46)	0.071 (0.051)	-15681^{**} (6059)
ΔGDPpc_{t-2}	0.000 (0.000)	0.000^{**} (0.000)	-0.195^{***} (0.048)
GDP growth	-0.608^{***} (0.145)	-0.000 (0.000)	169.9^{***} (19.7)
Current account	-0.231^{**} (0.084)	$+0.000^{**}$ (0.000)	-1.861 (11.46)
Inflation	0.080 (0.127)	-0.000 (0.000)	1.155 (17.28)
Fiscal balance	-0.052 (0.126)	-0.000^{**} (0.000)	13.72 (17.23)
Remittances	-0.143 (0.121)	$+0.000$ (0.000)	-24.05 (16.45)
N	615	615	615