Climate Change, Adaptation, and Sovereign Risk

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Adaptation and Sovereign Risk

Climate change is projected to increase the frequency and severity of natural disasters

- Climate Policy attention turning towards adaptation: adjusting to this 'new normal'
- e.g. seawalls, reefs, early warning systems
- Adaptation can limit damages, but it is costly

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- e.g. Cyclone activity concentrated around tropics
- Climate change likely to increase borrowing costs further: climate defaults?
- Calls for 'debt relief for climate resilience'

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This paper:

1. How does sovereign risk affect adaptation? climate-related losses?
2. Could debt relief help?

Takeaways

- Analytical Model: Sovereign default + natural disasters, endogenous adaptation
  - Default risk constrains adaptation of emerging markets: Adaptation Trap

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- Data: Novel adaptation measure from government budgets
  - Adaptation increasing in exposure + ratings
  - Hurricane causes CDS spreads and default probs $\uparrow$, driven by low adaptation countries

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    - Default risk constrains adaptation of emerging markets: Adaptation Trap
- Data: Novel adaptation measure from government budgets
    - Adaptation increasing in exposure + ratings
    - Hurricane causes CDS spreads and default probs $\uparrow$, driven by low adaptation countries
- Quantitative Model: long term debt, adaptation capital
    - Adaptation investment / GDP in Caribbean is 13% lower due to default risk
    - GDP effects of hurricanes are 10% higher - increases with climate change
    - Debt relief can help: interest free loan, adaptation bond

Relation to the Literature

Climate Change and Sovereign Risk

- Climate Change exacerbates fiscal vulnerabilities (Mallucci, 2022; Phan + Schwartzmann, 2023)

Contribution: Endogenous Adaptation

Climate Change and Adaptation

- Macro: (Hong et al, 2023; Fried, 2021). Micro: access to finance matters (e.g. Lane, 2024)

Contribution: Default risk affecting aggregate adaptation

Adaptation: Measurement

- Macro: Latent variable approach (e.g. Burke et al, 2024)

Contribution: Direct measure of aggregate adaptation

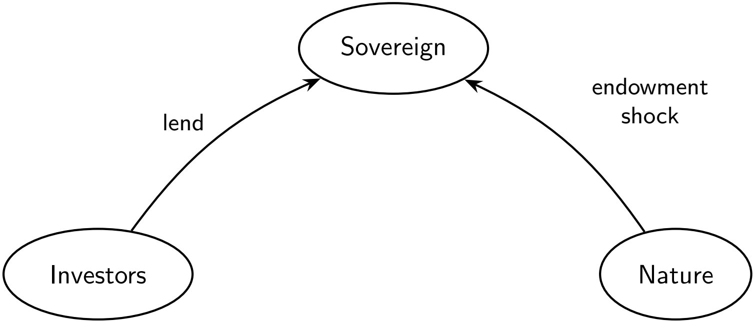
Disaster Risk

- Matters for asset prices (e.g. Barro 2009, Gourio 2012)

Contribution: Additional feedback: protective capital

A Model of Sovereign Default

Objective: max U
choices: default, borrowing



$q = \frac{1-s}{1+r}$

$s = \Pr(\text{default}_{t+1})$

Sovereign Risk and Climate Risk

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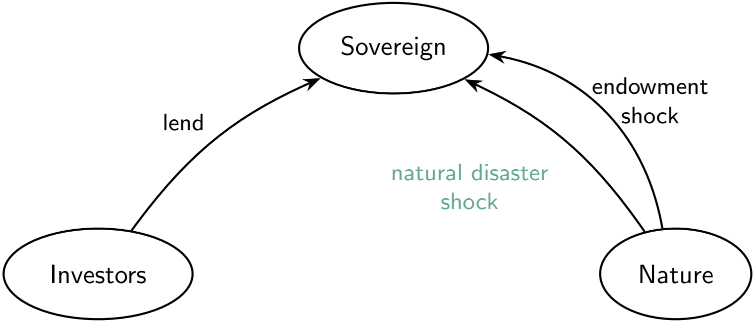

$q = \frac{1-s}{1+r}$

$s = \Pr(\text{default}_{t+1})$

$y_t = y_{t-1}^{\rho}(1 - x_t d_t F(\Lambda_t))\epsilon_t$

▸ model equations

Model Analytics: Adaptation Trap

The spread increases with

1. Borrowing
2. Climate Change

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Additionally, spread *falling* in adaptation.

▸ proofs

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Adaptation *declining* in sovereign risk

- Default risk restricts consumption smoothing
- and reduces lifetime income
- therefore increases the marginal cost of adaptation

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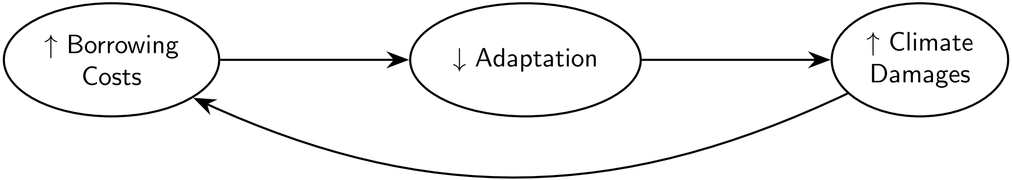


Measuring Adaptation

No existing data on aggregate adaptation across countries

Build a measure of adaptation expenditure utilising data from government budgets

NLP Approach: transfer learning

1. Start with a list of keywords describing adaptation
2. 'Learn' related terms from an auxilliary corpus $\rightarrow$ adaptation dictionary
3. Search for terms from adaptation dictionary
4. Record corresponding monetary amounts

Sample: Rated economies in Latin America and the Caribbean with

- English or Spanish budgets
- Machine readable budgets

▸ sample

Measuring Adaptation

Spend on average **0.31%** (1.1%) of GDP (Total expenditure) on adaptation.

	N	Mean	St. Dev.	Min	Max
Adaptation Total / GDP	163	0.31%	0.0021	0.001	0.0187
Adaptation Total / Expenditure	163	1.1%	0.0080	0.0038	0.0538

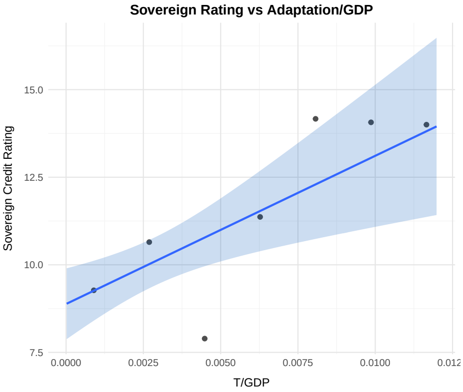
Table: Panel of 19 Latin American and Caribbean countries 2014-2025.

Adaptation Expenditure is:

1. Increasing in disaster exposure ▸ exposure
2. Trending upwards over time ▸ trend

Possible to disaggregate measure by action ▸ disaggregate ▸ line items

Adaptation Expenditure is Increasing in Rating



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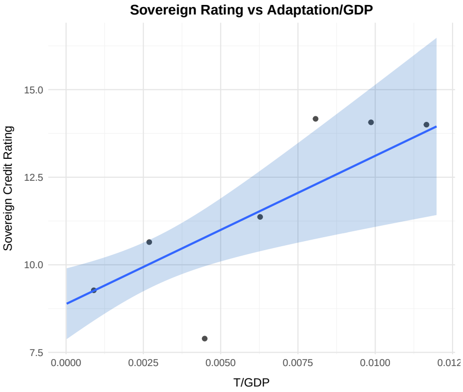

	adapt	
sovrate	67,554,921***	30,964,525***
	(16,647,312)	(9,241,031)
gdp	0.0022***	0.0069***
	(0.0002)	(0.0018)
exposure	143,757,032**	
	(62,519,154)	
government effectiveness	121,350,937**	
	(48,299,257)	
Country Fixed Effects	No	Yes
Year Fixed Effects	Yes	Yes
Observations	98	105
R-squared	0.95	0.84
Note:	*p<0.1; **p<0.05; ***p<0.01	

▸ data ▸ robustness

Cyclones and Sovereign Risk

Data:

- International Best Track Archive: hurricane location at 6-hourly intervals
- Map to country units:
- $D_{it} = 1$ if country i experiences at least category 1 hurricane in year t
- CDS spreads (36 countries)
- Default indicators (80 countries)

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Contribution:

- Local projection with cyclone shock
- Previous empirical literature on disasters + sovereign risk uses EMDAT
- Disaster incidence data collated from news articles + insurance claims $\rightarrow$ selection bias
- Combine with adaptation data

Cyclones cause sovereign risk to increase

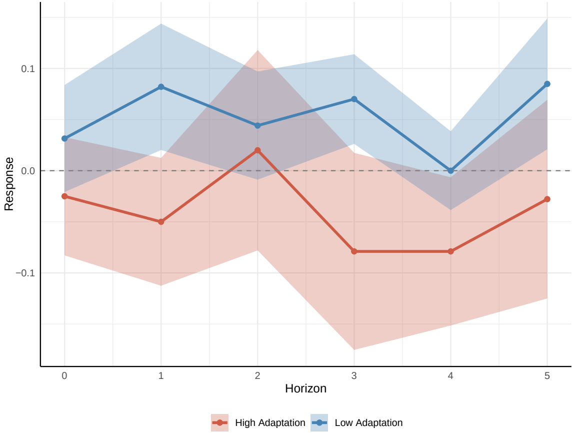

Figure: IRFs from local projections. Shocks are storms at least category 1 strength from IBTrACS geolocated to country coordinates. Outcome: sovereign crisis dummy from Global Macro Database.

aggregate irf

Simple Model and Empirical Evidence: Summary

1. Adaptation is declining in sovereign risk
2. Natural disasters increase sovereign risk
3. Adaptation attenuates that affect

Simple Model and Empirical Evidence: Summary

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How quantitatively important is this sovereign risk - adaptation channel?

- What does it mean for the welfare effects of disasters? and climate change?
- Could debt relief help?

Extend the two period model: infinite horizon ▸ details

- Long term debt
- Adaptation investment cumulates into capital
- Quadratic default costs
- Estimated to match moments ▸ details

Sovereign Risk Restricts Adaptation

Simulated Moments: Caribbean		
Moment	Model	No-Default Counterfactual
Adaptation Investment/GDP	0.003	$+13\%$
GDP loss per Hurricane	0.05	-10%
Welfare loss from Hurricanes	5.02%	4.62%

- GDP loss from a hurricane is 10% larger due to the sovereign risk- adaptation channel
- This gap increases to 13% with a projected increase in frequency and severity by end of century

Debt Relief can Help

1. Interest Free Loan
   - Motivated by IMF Resilience and Sustainability Trust
   - 'Default free' due to seniority structure $\rightarrow$ risk free rate
   - 10% of pre-loan output with a 3 year grace period
   - 5% increase in λ/GDP

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2. Adaptation Bond
   - Sustainability linked bonds: lower coupon payment if reach environmental target
   - Consider an *adaptation* linked bond
   - 2.5% coupon reduction if adaptation capital 5% larger
   - 11% increase in λ/GDP

Conclusion

Sovereign Risk restricts adaptation and increases the costs of disasters

- Theory: adaptation trap
- Data: robust negative correlation between sovereign risk and adaptation
- Quantitative: default risk is a quantitatively important driver of climate losses due to restricted adaptation.

Questions and suggestions very welcome!

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Model Equations

The sovereign's lifetime value is:

$$v_0 = \sum_{t=0}^{\infty} \beta^t \mathbb{E}\left(u\left(c_t\right)\right),$$

where $u(c_t)$ is the household's utility from consumption.

The income process is given by:

$$y_t = y_{t-1}^{\rho}(1 - x_t d_t F\left(\Lambda_t\right))\,\epsilon_t^y,$$

where ρ allows for persistence in the endowment process and x_t is an indicator variable for the natural disaster shock with

$$\mathbb{P}(x_t = 1) = p_t.$$

Disaster damage is given by the continuous variable d_t which is iid distributed according to the distribution $F(d)$ with support $[0, 1)$. The endowment shock $log(\epsilon^y)$ is normally distributed with mean zero.

back

Model Equations

$$\Lambda_t = (1-\delta)\Lambda_{t-1} + \lambda_{t-1},$$

where λ_t is investment in adaptation. Consumption is:

$$c_t = (1-D_t)y_t + D_t\,(y_t - \phi(y_t)) + (1-D_t)q_t(b_{t+1} - (1-\psi)b_t) - (1-D_t)b_t - \lambda_t,$$

where the bond price accounts for default risk:

$$q_t = \frac{1}{1+r}\mathbb{E}\left((1-D_{t+1}) + (1-\psi)(1-D_{t+1})q_{t+1}\right).$$

back

Model Equations

$$V = \max_{D} \left\{ (1-D)V_{nd} + DV_d \right\}, \tag{1}$$

$$V_{nd}(y,b,\Lambda) = \max_{b',\Lambda'} u(c) + \beta \mathbb{E}[V(y',b',\Lambda')], \tag{2}$$

$$V_d(y,0,\Lambda) = \max_{\Lambda'} u(c) + \beta \mathbb{E}[(1-\eta)V_d(y',0,\Lambda') + \eta V(y',b',\Lambda')], \tag{3}$$

▸ back

Details: two period model

Assume:

- $T = 2$
- $\Lambda_1 = 0$, $y_1 = 1$
- log utility
- Simple pro-cyclical default costs: $\phi(y_t) = \left(1 - \bar{l}e^{\psi g}\right)$

Default if $C_2(D = 1) > C_2(D = 0)$, i.e. if:

$$\underbrace{g + \frac{1}{1+\psi}\ln(1 - x_t d_t(1 - \lambda_t))}_{\tilde{g}} < \underbrace{\frac{1}{1+\psi}\ln\left(\frac{B}{\bar{l}y_1^{\rho}}\right)}_{\bar{g}(B)}$$

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Analytical results

$$s(b,\lambda) = \Pr\left[\tilde{g}' < \bar{g}(b)\right]$$
$$= (1-p)\Phi_g(\bar{g}) + pE_{d'}\left[\Phi_g\left(\bar{g} - \frac{1}{1+\psi} ln(1 - d_t(F(\lambda_t))\right)\right]$$

$$\frac{\partial s}{\partial p} = -\Phi_g(\bar{g}) + E_{d'}\Phi_g\left(\bar{g} - \frac{1}{1+\psi} ln(1 - d_t F(\lambda_t)\right) > 0.$$

$$\hat{\Phi}_d \overset{fosd}{\geq} \bar{\Phi}_d \Rightarrow s(\cdot,\cdot|\hat{\Phi}_d) \geq s(\cdot,\cdot|\bar{\Phi}_d).$$

$$\frac{\partial s}{\partial \lambda} = pE_{d'}\left[\phi_g\left(\bar{g} - \frac{1}{1+\psi}\ln(1 - d\cdot F(\lambda)\right)\cdot\frac{d\cdot F(\lambda)}{(1+\psi)(1-d\cdot F(\lambda))}\right] < 0$$

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Analytical results

$$\underbrace{\frac{1}{c_1}}_{MC} = \underbrace{\beta \mathbb{E}\left(\frac{y_2'(\lambda)}{c_R} - s(\lambda)\frac{y_2'(\lambda)b}{y_2 c_R}\right)}_{\text{MB damage reduction}} + \underbrace{\beta \mathbb{E}\left(s'(\lambda)(u(c_D) - u(c_R))\right)}_{\text{MB reduced default prob}} \underbrace{-\frac{\frac{1}{1+r}s'(\lambda)b}{c_1}}_{\text{MB lower spread}}$$

▸ back

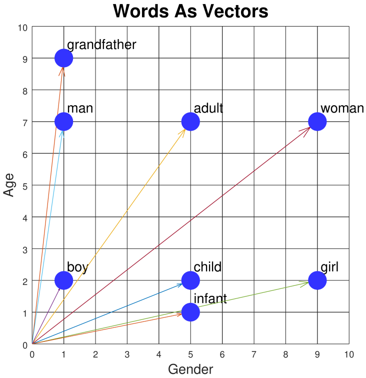
Initial Keywords

- adaptation
- climate_adaptation
- coastal_protection
- seawall
- shoreline_management
- coral_reef_restoration
- stormwater_management
- mangrove_plantation
- coastal_management
- urban_green_area
- air_conditioning_system
- shading
- drainage
- flood_insurance
- agricultural_insurance
- irrigation
- water_management
- natural_disaster_management
- national_disaster_management
- drought_management
- flood_management
- hazard_mapping
- cyclone_shelter
- storm_management
- wastewater_management
- managed_retreat
- ecosystem_restoration
- watershed_management
- wetlands_management

Word Embeddings

Word embedding: real-valued vector representation of a word

- Words closer in the vector space are expected to be similar in meaning
- Use GloVe model from Stanford NLP group trained on my adaptation corpus



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Keyword Discovery

	Initial Term: sea wall
Output Term	**Cosine Similarity**
sea defense	0.89
groyne	0.86
tidal barrier	0.81
dune restor	0.79
waterfront protec	0.78
gullies	0.72
breakwater	0.71

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Sample

- Latin America: 18 sovereigns. Caribbean: 13 sovereigns
- Lose 2 due to language
  - Haiti, Brazil
- Lose 3 due to lack of rating
  - Saint Lucia, Antigua + Barbuda, Dominica
- Lose 7 due to lack of machine readability
  - Trinidad and Tobago, Cuba, Bolivia, El Salvador, Nicaragua, Paraguay, Venezuela
- Lose 74 country-year observations due to lack of availability

Final sample: Unbalanced panel of 19 economies 2014-2025

- 163 country-year observations

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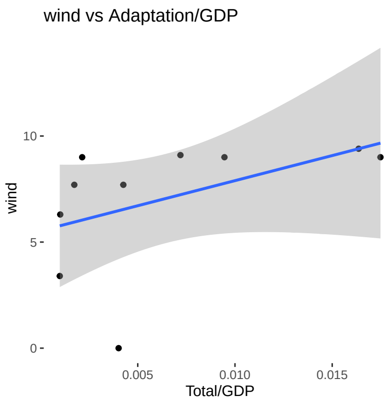
Exposure



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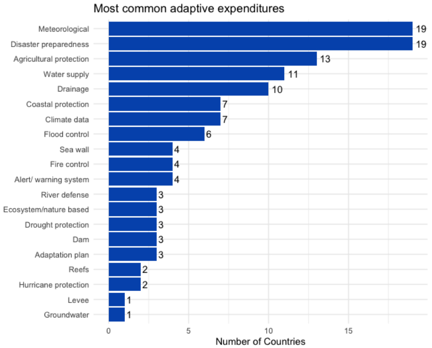
Adaptation Measure: Disaggregated

How are governments adapting?



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Line Items: Descriptive Statistics

	N	Mean	St. Dev.	Min	Max
Line Items (country x year)	163	17.7	23.3	3	126
Line Items (country average)	19	20.33	23.4	4.9	75.4

	N	Corr	p-value
(Line Items, T/GDP)	163	-0.0967	0.2489
(avg Line Items, avg T/GDP)	19	-0.131	0.589

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Expenditure Comparisons

	Mean
Adaptation/GDP	0.31%
Agriculture/GDP	1.3%
Health/GDP	3.4%

Table: Source: ELAC

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Official Debt: Share of Total

Country	Share of Official Debt (%)
Argentina	7
The Bahamas	3
Barbados	20
Chile	3
Colombia	14
Costa Rica	7
Dominican Republic	16
Ecuador	29
Guatemala	26
Jamaica	22
Mexico	4
Panama	25
Peru	8
Uruguay	7
Average	14

Table: Share of Official Debt in Total Public Debt (2018)

Data

1. sovrate:
   - Index from 0-21
   - From World Bank
2. exposure:
   - average maximum monthly windspeed scaled by land area from GeoMet or:
   - climate vulnerability index from INFORM RISK
   - Constructed by the EU commission
3. government effectiveness:
   - World Bank Index

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Robustness

- Narrower measures of adaptation: disaster preparedness, meteorological services
- Validation with hand read budgets
- English and Spanish subsamples
- Drop 10% of sample
- EMBI or CDS rather than sovrate
- alternative indices of exposure
- regulatory quality rather than government effectiveness
- Stricter word embedding cutoffs
- Instrument for ratings with a global factor

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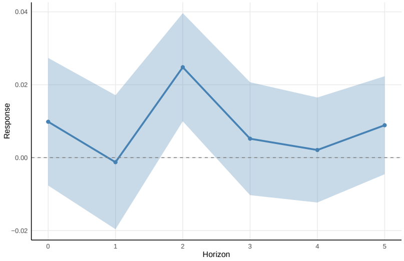
Aggregate irf



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Calibration Strategy

1. External parameters: η, γ, δ
2. Calibrated directly from data: r, ψ, p, ρ, μ_ϵ, σ_ϵ^2, σ_d^2
   - Estimate:
   $$\log(y_t) = \rho \log(y_{t-1}) - \xi x_t + \varepsilon$$
   - Model counterpart:
   $$\xi_t = F(\Lambda_t) d_t$$
3. Jointly calibrated to target moments:
   - μ_d: mean GDP loss from disaster, ξ
   - α: adaptation investment to GDP ratio
   - β: debt to GDP ratio
   - κ: mean spread

Solution Algorithm

Discretize output, debt, adaptation.

Iterative algorithm:

1. Initial guesses for the unconditional debt price function and for the value functions
2. Update the value function V_{nd} by solving the maximization problem in the market access case
   - Each possible choice of debt and adaptation is associated with an additive taste shock.
   - The sovereign chooses b' conditional on having chosen a particular Λ' subject to taste shocks, and that Λ' is chosen subject to taste shocks for a fixed b'.
   - Probability of choosing a given discrete value is given by the multinomial logit formula.
3. Update the value function V by solving the discrete choice default problem.
   - Introduce extreme value shocks to the default problem.
4. Update the default value function V_d making use of the update values of V and V_{nd}.
5. Repeat (2-4) until value functions have converged.
6. Update the unconditional debt price function by imposing the default policy and the average equilibrium price function.
7. Repeat (2-6) until convergence of the unconditional debt price function.

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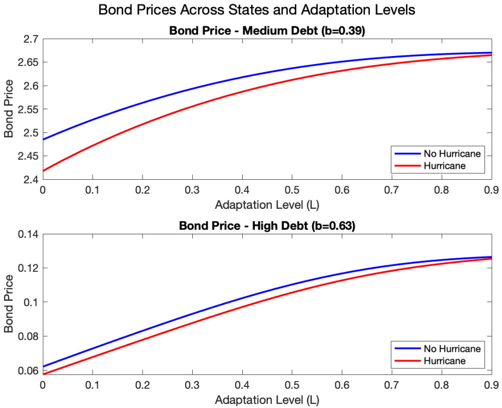
Calibration: Caribbean

Parameter		Value	Source/Target statistic
Parameters set Externally:			
Relative risk aversion	γ	2	Standard
Readmission probability	η	0.33	Standard
Depreciation	δ	0.1	Standard
Parameters Estimated Externally:			
Risk free rate	r	0.0451	US T-Bill
Duration	ψ	0.0564	Average Maturity
Hurricane Frequency	p	0.103	NOAA
Endowment autocorr	ρ	0.95	Data
Endowment st dev	σ_ϵ	0.021	Data
Disaster st dev	σ_d	0.031	Data
Parameters Set Internally:			
Discount factor	β	0.92	Debt/GDP
Default cost	d_0	0.621	Mean Spread
Default cost	d_1	0.978	Std. dev Spread
Hurricane intensity	μ_d	0.096	Mean hurricane loss
Adaptation benefit	α	2.496	Adaptation investment/ GDP

Model Performance

	Model	Data
Targeted		
Adaptation Investment/GDP	0.003	0.003
Debt/GDP	0.401	0.414
GDP loss — Cyclone	0.052	0.050
Mean Spread	502	526
Std. dev Spread	352	374
Untargeted		
Default Frequency	0.048	0.051
Spread Increase — Cyclone	0.015	0.01
Untargeted		
Adaptation Capital/GDP	0.029	
Percent Damages Avoided	0.45	
Market Value Debt/GDP	0.37	
Median Spread	121	

Bond Price



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