Climate Defaults and Financial Adaptation

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2004 Hurricane Ivan & Grenada sovereign default

Asonuma et al (2018)

- Caused ∼200% GDP worth of damages
  - Mostly from housing stock (70% of which had no form of insurance)
- **Triggered a sovereign debt restructuring (2004-06)**
  - Followed by weak recovery & another debt restructuring (2013-15)
- 2015: Paris Club (major creditor countries) **introduced first-ever hurricane clause bonds** (to provide debt relief in future hurricanes)

Source: NOAA

Part of general pattern across world

- Large climate-related disasters can *cause large & lasting damages*
  - Cyclones' damage on income can approximate that from banking crisis, persistent up to 2 decades (Hsiang Jina 2014)
  - More severe in economies with less financial development (Bakkensen Barrage 2019)
- Disasters *raise probability of default crises* (Klomp 2015, 2017)
  - Vulnerable countries face higher bond yields (Kling et al 2018, Barnett et al 2020, Beirne et al 2020)

This paper

Tractable & quantifiable framework to analyze

- **Climate default risk**, i.e., interaction between
  - Physical risk of climate-related disasters
  - Financial risk of sovereign default
- **Financial adaptation** (different from physical adaptation)
  - Catastrophe bonds, disaster insurance
- Main findings:
  - Default risk significantly delays post-disaster recovery
  - Financial adaptation can significantly reduce welfare loss from increased disaster risk

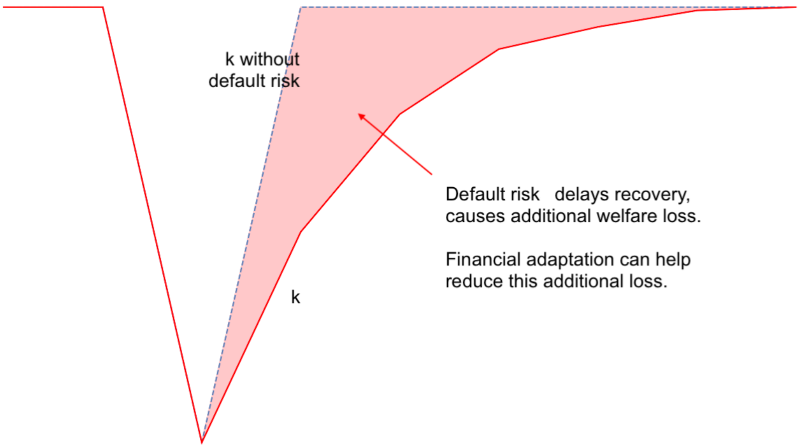


Figure: Response to a disaster shock

Related literatures

- **First model with disasters, sovereign default & capital**
- Climate macro/finance: Nordhaus Boyer (2007), Golosov Hassler Krusell Tsyvinski (2014), Lemoine Traeger (2014), Daniel Litterman Wagner (2018), Cai Lontzek (2019), Fried (2019), Bakkensen Barrage (2019), Bansal Kiku Ochoa (2019), Cantelmo Melina Papageorgiou (2020), Malluci (2020) ...
  - Contribution: **how financial frictions** (default risk) **amplify & propagate climate damages**
- Incorporate insights from
  - Sovereign default: Eaton Gersovitz (1981), Aguiar Gopinath (2006), Arellano (2008), Adam Grill (2017), Gordon Guerron-Quintana (2018), Asonuma Joo (2020), Rebelo Wang Yang (2019), ...
  - Rare disaster: Rietz (1988), Barro (2006), Gabaix (2011) Gourio (2012) ...

Baseline Model

- Output:

$$Y_t = \left(\overbrace{e^{-x_t d_t}}^{\text{disaster risk}} K_t \right)^{\alpha} A_t^{1-\alpha}$$

  - disaster onset: $x_t \in \{0, 1\}$, $\Pr(x_t = 1) = p$
  - disaster damage: $d_t \overset{\text{iid}}{\sim} \Phi_d$ over $\mathbb{R}_+$
  - for simplicity, TFP follows random walk: $\ln \frac{A_t}{A_{t-1}} = g_t \overset{\text{iid}}{\sim} \Phi_g$

- Epstein Zin preferences

$$V_t = \left(C_t^{1-\iota} + \beta E_t \left(V_{t+1}^{1-\gamma} \right)^{\frac{1-\iota}{1-\gamma}} \right)^{\frac{1}{1-\iota}}$$

  - Detrend variables by TFP $v_t := \frac{V_t}{A_t}, k_t := \frac{K_t}{A_t}, b_t := \frac{B_t}{A_t}$

Sovereign borrowing

- In each t, after shocks realize, country chooses: **repay or default**, **new debt issuance** b_n & new investment k_n
  - Debt instrument: non-contingent one-period bonds
  - Law of motion with shocks:

$$b' = e^{-g'} b_n$$
$$k' = e^{-x'd'-g'} k_n$$

- Country **cannot commit** to repay. Default cost: a fraction ℓ of output is lost. Default iff

$$\underbrace{k'^{\alpha} + (1-\delta)k' - b'}_{\text{net worth } m'_{Repay}} < \underbrace{(1-\ell)k'^{\alpha} + (1-\delta)k' - 0}_{m'_{Default}}$$

Recursive formulation

- *Very tractable* model: net worth is only state variable

$$v(m)^{1-\iota} = \max_{k_n, b_n} c^{1-\iota} + \beta E\left[v(\max\{m'_R, m'_D\})^{1-\gamma} e^{(1-\gamma)g'} \right]^{\frac{1-\iota}{1-\gamma}}$$

$$\text{s.t. } c = m - k_n + q(b_n, k_n) b_n$$

- Risk-neutral lenders' bond pricing:

$$q(b_n, k_n) = \frac{1}{1+r}\Big(1 - \overbrace{\Pr[\underbrace{\tfrac{b'}{y'}}_{\text{debt/gdp}} > \ell\,]}^{\text{default prob or spread } s(b_n, k_n)}\Big)$$

Proposition 1

Spread schedule decreases in investment

- Implication: propagation of disaster shock

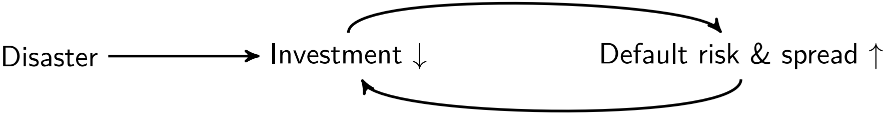


Figure: Vicious cycle

- This will leads to slow post-disaster recovery (more on this later)

Proposition 2 (Comparative statics in disaster risk)

Spread schedule increases in p and d

- Testable implication: EMs with more climate vulnerability face higher borrowing costs & higher prob of debt crises
- Consistent with empirics in Barnett et al (2020), Beirne et al (2020), Kling et al (2018)

Quantitative exercise (preliminary)

Calibration

	a period	5 years	medium-term focus
α	capital share	$1/3$	standard
β	discount factor	0.96^5	
δ	depreciation	$1-0.9^5$	
r	world interest rate	1.01^5-1	
ι	inverse elas subs	0.5	Gourio (2012)
γ	risk aversion	4	
μ_g	mean TFP growth	$1.006^{20}-1$	Aguiar Gopinath (2007)
σ_g	std growth shock	$.0213\sqrt{20}$	
ℓ	cost of default	0.1	50% average debt/annual GDP

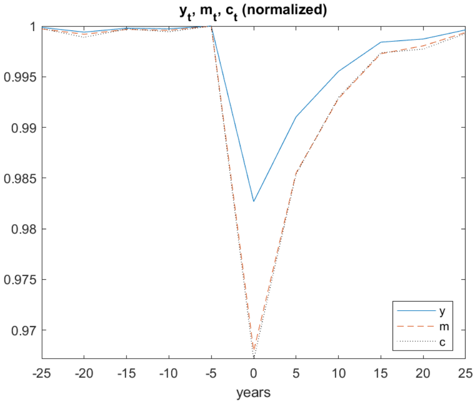
Calibration: disaster risk

- Focus on a particular disaster type: strong cyclones
  - Cyclones are relatively well studied in both climate sciences (e.g., Emmanuel et al 2008) and economics (e.g., Hsiang Jina 2014, Bakkensen Barrage 2019)
- Estimates from Hsiang Jina (2014):
  - Marginal GDP damage of 1m/s cyclone wind: 0.0895% cumulative over 5 years
  - 90th percentile cyclone: windspeed 19.5m/s, annual probability 5.8%

$$\Rightarrow p = 1 - (1 - 0.058)^5 = 0.2583$$
$$d = 0.0895\% \times 19.5/\alpha = 0.0524$$

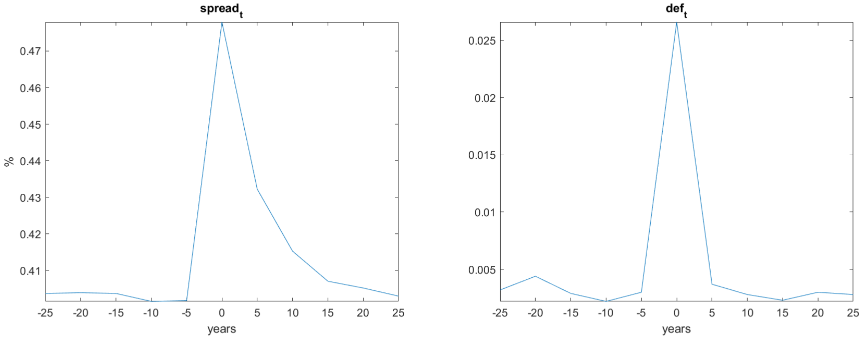
Slow recovery

Impulse response to disaster at $t = 0$



- Damages can be felt up to 20-25 years (consistent with empirics in Hsiang Jina 2014)
  - Recall: our calibration did not target duration of recovery

Spread & default



- Disaster raises spreads & likelihood of default
- Qualitatively consistent with empirics:
  - Climate-related disasters persistently increase spreads (Klomp 2015);
  - 90th percentile storm raises Pr(debt crisis) (Klomp 2017)

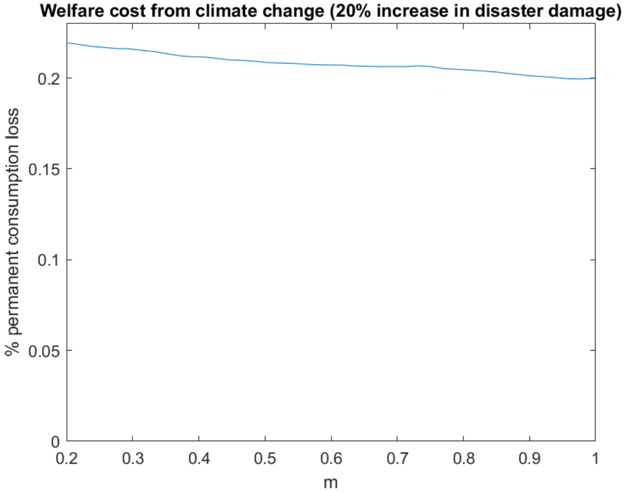
Climate change

- Projected to alter cyclone risk (Emmanuel et al 2008)
  - Under *business as usual*, by 2090 anthropogenic climate change will **increase cyclone activity in West Pacific basin by 19.1%**, North America by 10.3%, Oceania by -13.8%, North Indian by -5.8%
- Using estimate for West Pacific basin,[1] we assume **under business as usual, climate change will increase cyclone strength (windspeed) and hence** d **by** 20% ($d^{cc} = 1.20d$)
  - Result very similar if instead p increases by 20% ($p^{cc} = 1.20p$)

[1] Included emerging economies: China, Korea, Laos, Malaysia, Philippines, Thailand, Vietnam

- Measure welfare cost in consumption equivalence terms (Lucas 2003):

$$\tau(m) = 1 - \frac{v^{cc}(m)}{v^{baseline}(m)}$$



Financial adaptation
1. CAT bonds

Catastrophe (or act-of-God) bonds

- Additional instrument: bonds whose face value $\to 0$ if $x = 1$
- New portfolio choice: $\theta := \frac{B^{CAT'}}{B' + B^{CAT'}}$, fraction of bonds that are CAT
- **Tradeoff:**
  - Higher θ relieves debt burden in disaster, hence reduces default risk
  - But lenders will charge an insurance premium for this relief

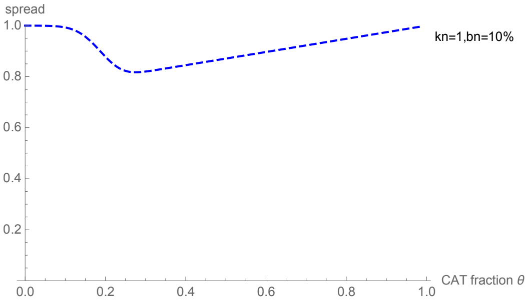
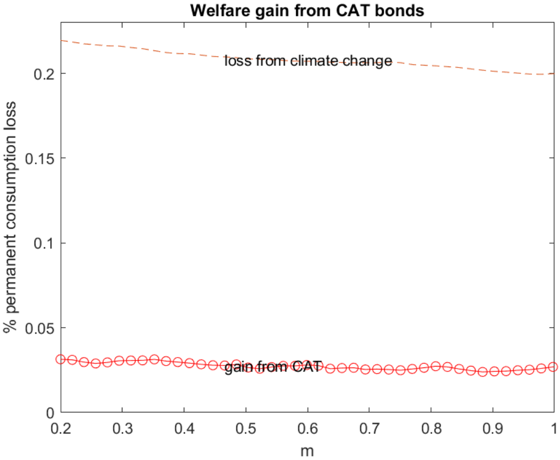


Figure: CAT Laffer curve



- Relatively small welfare gain from ability to issue CAT bonds

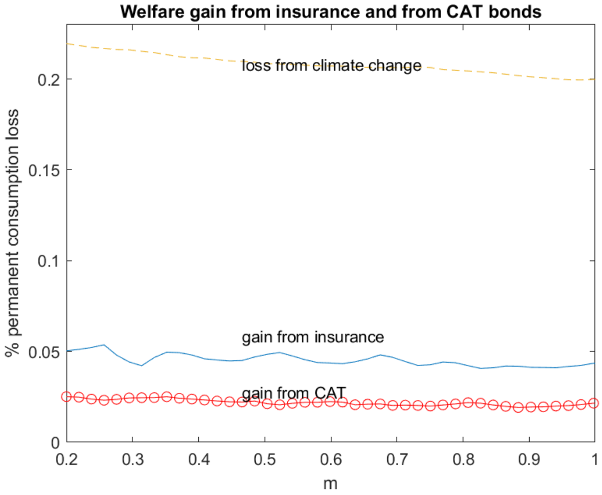
Financial adaptation
2. Disaster insurance

Recursive problem with disaster insurance

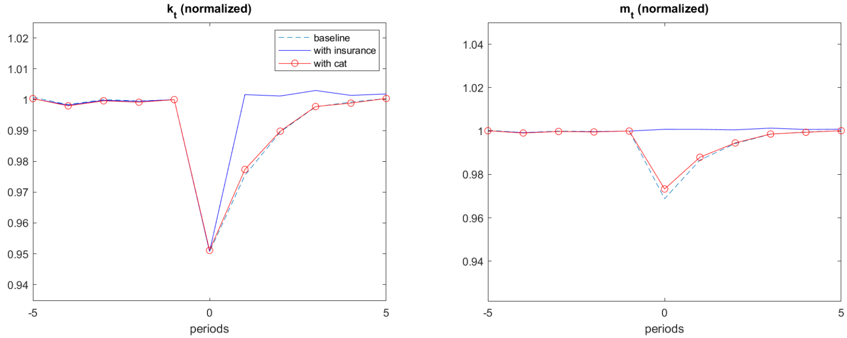
- Suppose country can hedge disaster risk with insurance contracts
  - At actuarily fair price
  - Insurance is *intra*temporal (chosen after g' is realized but before disaster or default decisions)
  - Country receives insurance payment even if it chooses to default

- Insurance smooths net worth across disaster & nondisaster states:

$$v(m)^{1-\iota} = \max_{k_n, b_n} c^{1-\iota} + \beta E_{g'} \left[v \left(E_{x'} [\max \{ m'_R, m'_D \}] \right)^{1-\gamma} e^{(1-\gamma)g'} \right]^{\frac{1-\iota}{1-\gamma}}$$

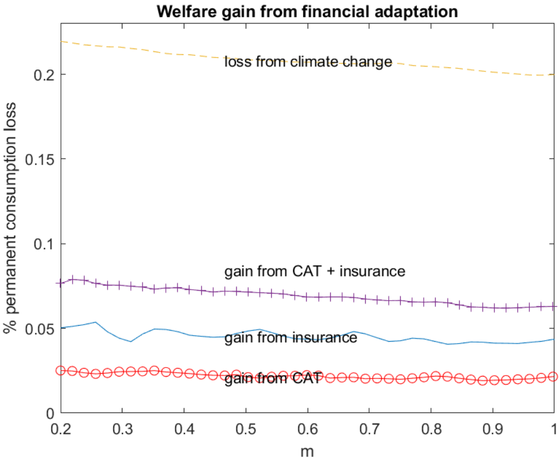


- Gain from disaster insurance ≈ nearly 1/4 of loss from increased disaster damage



- Intuitive, disaster insurance smooths out net worth m across disaster and nondisaster states
- This helps speed up recovery

Financial adaptation
3. CAT + Disaster insurance



- Gain from combo ≈ nearly 30% of loss from increased disaster
  - Intuitively, insurance smooths out recovery &
  - CAT bonds reduce default risk in disaster state, hence raise debt capacity

Conclusion

- Tractable & quantifiable framework to analyze
  - Climate default risk
  - Financial adaptation