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**


  - Contribution: **how financial frictions** (default risk) **amplify & propagate climate damages**

- Incorporate insights from

  
  - Rare disaster: Rietz (1998), Barro (2006), Gabai (2011) Gourio (2012) ...
Baseline Model
Output:

\[ Y_t = \left( e^{-x_t d_t} K_t \right)^\alpha A_t^{1-\alpha} \]

- 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

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

- 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 \( \ell \) of output is lost. Default iff
  \[
  k'\alpha + (1 - \delta)k' - b' < (1 - \ell)k'\alpha + (1 - \delta)k' - 0
  \]
  net worth \( m'_{\text{Repay}} \) < \( m'_{\text{Default}} \)
Recursive formulation

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

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

s.t. \( c = m - k_n + q(b_n, k_n)b_n \)

- Risk-neutral lenders’ bond pricing:

\[ q(b_n, k_n) = \frac{1}{1+r} (1 - \Pr\left[ \frac{b'}{y'} > \ell \right]) \]
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
Quantitative exercise
(preliminary)
## Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>capital share</td>
<td>$1/3$</td>
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<tr>
<td>$\beta$</td>
<td>discount factor</td>
<td>0.96$^5$</td>
<td>standard</td>
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<tr>
<td>$\delta$</td>
<td>depreciation</td>
<td>$1 - 0.9^5$</td>
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<tr>
<td>$r$</td>
<td>world interest rate</td>
<td>$1.01^5 - 1$</td>
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<tr>
<td>$i$</td>
<td>inverse elas subs</td>
<td>0.5</td>
<td>Gourio (2012)</td>
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<tr>
<td>$\gamma$</td>
<td>risk aversion</td>
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<td></td>
</tr>
<tr>
<td>$\mu_g$</td>
<td>mean TFP growth</td>
<td>$1.006^{20} - 1$</td>
<td>Aguiar Gopinath (2007)</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>std growth shock</td>
<td>$0.0213\sqrt{20}$</td>
<td></td>
</tr>
<tr>
<td>$\ell$</td>
<td>cost of default</td>
<td>0.1</td>
<td>50% average debt/annual GDP</td>
</tr>
</tbody>
</table>
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%

\[
p = 1 - (1 - 0.058)^5 = 0.2583
\]

\[
d = 0.0895\% \times \frac{19.5}{\alpha} = 0.0524
\]
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*)

¹Included emerging economies: China, Korea, Laos, Malaysia, Philippines, Thailand, Vietnam
Measure welfare cost in consumption equivalence terms (Lucas 2003):

\[ \tau(m) = 1 - \frac{\nu^{cc}(m)}{\nu^{baseline}(m)} \]
Financial adaptation

1. CAT bonds
Catastrophe (or act-of-God) bonds

- Additional instrument: bonds whose face value $\rightarrow 0$ if $x = 1$
- New portfolio choice: $\theta := \frac{B^{\text{CAT}^i}}{B^i + B^{\text{CAT}^i}}$, fraction of bonds that are CAT

**Tradeoff:**
- Higher $\theta$ relieves debt burden in disaster, hence reduces default risk
- But lenders will charge an insurance premium for this relief

![Figure: CAT Laffer curve](image-url)
• 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 actuarially fair price
  - Insurance is *intratemporal* (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:

\[
v(m)^{1-t} = \max_{k_n, b_n} c^{1-t} + \beta E_g' \left[ v \left( E_{x', \max \{ m'_R, m'_D \}} \right)^{1-\gamma} e^{(1-\gamma)g'} \right]^{\frac{1-\gamma}{1-t}}
\]
- Gain from disaster insurance $\approx$ 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 $\approx$ 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