Macroeconomic Implications of Catastrophe Bond Adoption

Panit Wattanakoon and Wanissa Suanin
Faculty of Economics, Thammasat University

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Motivation

- **Climate change** is intensifying extreme weather, especially *floods*, which are increasingly frequent and damaging in *developing economies*
  - IPCC (2022): under high-emission scenarios, the risk of large-scale floods will rise significantly
- *Floods cause widespread macroeconomic disruption*:
  - Destroy capital and reduce output
  - Weaken household and firm balance sheets
  - Force governments into costly borrowing, raising debt and bond spreads
  - These shocks often reinforce each other, heightening default risk and causing financial instability
- CAT Bonds offer a solution:
  - Provide pre-arranged financing triggered by disaster events
  - Transfer risk to global investors
  - Help stabilize fiscal conditions and investor confidence when shocks hit

Key Takeaways

Objective

- Assess how sovereign CAT bonds (*Indemnity Loss* Vs *Parametric* Triggers) reduce flood-related macroeconomic and welfare losses using a calibrated small open economy model of the Thai economy

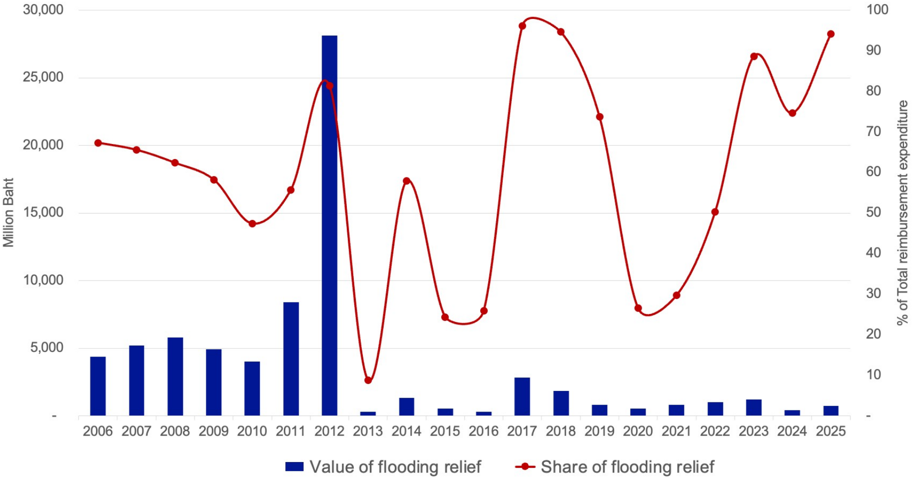
Key Findings

- Both triggers cushion capital, output, consumption, and gov. net worth
- Parametric CAT bonds dominate: faster payout $\rightarrow$ lower spreads and lifetime welfare losses
- Trade-off: CAT bonds increase public debt, which crowds out capital inflows

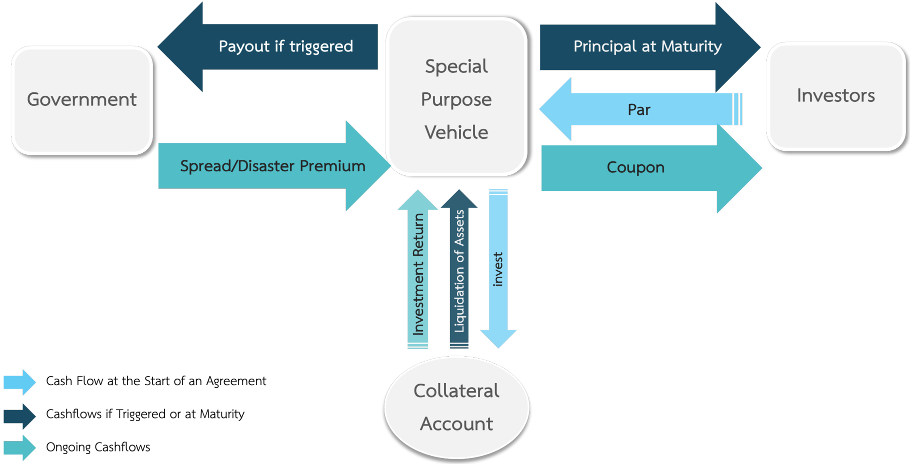
Why Thailand?

- High Flood Risk: Chronic exposure to flood events that are severe enough to cause economic disruptions but not large enough to cause humanitarian crisis.
- Fiscal Vulnerability: Limited fiscal space constrains post-disaster response, increasing reliance on debt and widening sovereign spreads
- Access to Capital Markets: Thailand has sufficient financial depth and creditworthiness to issue CAT bonds in global markets

High Flood Risk in Thailand



What is Catastrophe Bond?



Type of Triggers

Indemnity Trigger

- Payout based on actual losses exceeding a threshold
- Insurer compensates the issuer for the measured damage
- Advantage: High accuracy
- Drawback: Slow payout due to damage assessment

Parametric Trigger

- Payout based on physical indicators (e.g., rainfall, flood depth) exceeding a threshold
- Issuer receives a fixed amount regardless of actual losses
- Advantage: Rapid payout
- Drawback: Basis risk — payout may not match actual loss

Baseline Model

Consider a small open economy with a representative sovereign government à la Phan and Schwartzman (2024):

- A single consumption goods produced from capital K_t and L_t from

$$Y_t = (e^{-x_t d_t} K_t)^{\alpha} (A_t)^{1-\alpha}$$

where
$\alpha \in (0, 1)$: capital share
L_t: supplied inelastically

Shocks via TFP and weather:
A_t: a TFP, a random walk with i.i.d. growth shock g_t
$\log \frac{A_{t+1}}{A_t}$ from a distribution Φ_g.
$x_t = 1$ if a flood hits, and 0 otherwise.
$d_t \geq 0$: level of damage of flood toward the capital stock

Preferences

- The representative government maximizes Epstein and Zin (1989) recursive preferences

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

where
ι: the inverse intertemporal elasticity of substitution, bounded within 1
γ: the relative risk aversion coefficient
β: the discount factor
C_t: government consumption in the current period.

Sovereign Borrowing

- The government has access to one-period non-contingent bonds issued by risk-neutral international lenders with a promise to repay one unit of consumption good in the subsequent period.
- The country can decide either to repay the debt or default.
  - If default, bear deadweight loss of a fraction ℓ_t of the country's output
  - Immediately able to access the international credit market after default
  - The specification of a procyclical fractional loss $\ell_t = \ell(g_t)$ is defined as:

$$\ell(g') = \bar{\ell} e^{\psi g'}, \psi \geq 0, \bar{\ell} > 0,$$

where
g': next period growth shock
ψ: the responsiveness of the default to the loss fraction.

Optimization Problem

- After growth and weather shocks, the government chooses
  - to repay or to default on its outstanding debt,
  - the value of new bonds issued (b_n), and
  - new capital investment (k_n).
- All variables are detrended by the productivity A_t.
- The government's optimization problem with one state variable: the country's net worth m,

$$\nu(m)^{1-\iota} = \max_{k_n \geq 0, b_n} c^{1-\iota} + \beta E\left[\nu(\max\{m'_R, m'_D\})^{1-\gamma} e^{(1-\gamma)g'}\right]^{\frac{1-\iota}{1-\gamma}} \quad (1)$$

subject to budget constraint:

$$c = m - k_n + q(b_n, k_n)b_n$$

where $q(b_n, k_n)$: bond price schedule.

Next-Period Variables after Realized Shocks

- The detrended next-period debt (b') and capital stocks (k') after the realized subsequent-period shocks are as follows:

$$\begin{aligned} b' &= e^{-g'} b_n \\ k' &= e^{-x' d' - g'} k_n \end{aligned}$$

- The next-period country's net worth is defined as $m' = \max\{m'_R, m'_D\}$
  - m'_R if the government repays the debt,
  - m'_D if the government decides to default

$$m'_R = (k')^{\alpha} + (1-\delta)k' - b' \tag{2}$$

$$m'_D = (1 - \ell(g'))(k')^{\alpha} + (1-\delta)k', \tag{3}$$

where δ is depreciation rate.

Decisions to Default

- Default when
  - country's net worth if repayment is lower than that if default,
  - its debt over GDP is greater than the output lost fraction $\ell(g')$, or
  - the weather-adjusted growth term $\tilde{g}' = g' - \frac{\alpha}{1-\alpha+\psi} x' d'$ is less than an endogenous default threshold $\bar{g}(b_n, k_n) = \frac{\alpha}{1-\alpha+\psi} \ln \frac{b_n}{\bar{\ell} k_n^\alpha}$

$$
\begin{aligned}
m'_R &< m'_D \Leftrightarrow \\
\underbrace{\frac{b'}{k'^{\alpha}}}_{\text{debt to GDP}} &> \ell(g') \Leftrightarrow \\
\underbrace{g' - \frac{\alpha}{1-\alpha+\psi} x' d'}_{\tilde{g}'} &< \underbrace{\frac{\alpha}{1-\alpha+\psi} \ln \frac{b_n}{\bar{\ell} k_n^\alpha}}_{\bar{g}(b_n, k_n)} \qquad (4)
\end{aligned}
$$

- Default threshold $\bar{g}$ rises with b_n and falls with k_n
- When ψ increases, amplifying the responsiveness of default costs to the growth shock g', the sensitivity of the default threshold $\bar{g}$ to changes in debt and capital stock diminishes

Equilibrium Bond Price

- In a competitive credit market with risk-neutral lenders who account for the possibility of default, this schedule is determined by:

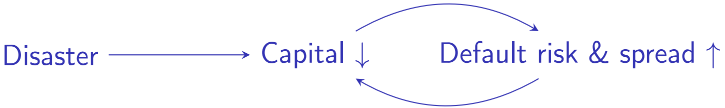
$$q(b_n, k_n) = \frac{1 - s(b_n, k_n)}{1 + r}, \forall b_n, k_n, \quad (5)$$

where
r is the world risk-free interest rate
s is the sovereign default spread defined as the probability of default with repayment and default net worth (m'_R and m'_D)

$$\begin{aligned} s(b_n, k_n) &= \Pr[m'_R < m'_D] \\ &= \Pr[\tilde{g}' < \bar{g}(b_n, k_n)] \\ &= (1 - p)\Phi_g(\bar{g}) + pE_{d'}\left[\Phi_g\left(\bar{g} + \frac{\alpha}{1 - \alpha + \psi} d'\right)\right] \end{aligned} \quad (6)$$

Vicious Feedback Loop

- **Spreads, Capital, and Disaster Risk**
  - The shape of the spread schedule s reflects how borrowing costs respond to disaster risk
  - Equilibrium spreads:
    - Increase with higher debt issuance b_n
    - Decrease with more next-period capital k_n
    - Reason: More capital raises the default threshold $\bar{b}$, shrinking the default region
- **Vicious Cycle of Capital and Spreads**



  - This feedback loop magnifies economic vulnerability
  - Key channel in the transmission of **weather shocks**

Government with CAT Bond Adoption

- The representative government decides the composition of debt issuance between regular and CAT bonds.
  - $\theta \in [0,1]$ as a fraction of CAT bond in total debt portfolio.

$$\nu(m)^{1-\iota} = \max_{k_n \geq 0, b_n, \theta} c^{1-\iota} + \beta E\left[\nu(\max\{m'_R, m'_D\})^{1-\gamma} e^{(1-\gamma)g'}\right]^{\frac{1-\iota}{1-\gamma}}$$

subject to

$$\begin{aligned} c =& m - k_n + q(b_n, k_n, \theta) b_n \\ b' =& (1 - T'\theta) e^{-g'} b_n \\ k' =& e^{-x'd' - g'} k_n \\ m'_R =& k'^{\alpha} + (1-\delta)k' - b' \\ m'_D =& (1 - \ell(g'))k'^{\alpha} + (1-\delta)k' \end{aligned}$$

  - q now represents the price of the entire bond portfolio as follows:

$$q(b_n, k_n) = \frac{1 - s(\bar{g}(b_n, k_n), \theta)}{1 + r}$$

Triggers

- Denote T' as the dummy for the CAT Bond trigger.
  - T'_d for indemnity loss trigger
  - T'_p for parametric trigger
- CAT bond is triggered ($T' = 1$) when the disaster hit ($x' = 1$), there are newly bond issued ($b_n > 0$) and
  - the damage is big enough ($d' > \bar{d}$) for indemnity loss trigger, or
  - the degree of disaster is large enough ($\omega' > \bar{\omega}$) for parametric trigger

$$T'_d = x' 1_{d' > \bar{d}} 1_{b^n \geq 0} \tag{7}$$

$$T'_p = x' 1_{\omega' > \bar{\omega}} 1_{b^n \geq 0} \tag{8}$$

Spread for Indemnity Loss

$$
\begin{aligned}
s(\bar{g}, \theta, \bar{d}) &= (1-p)\,\Phi_g(\bar{g}) \\
&+ p \int_0^{\bar{d}} \Phi_g\big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\, d'\big)\, f_{d'}(d')\, \mathrm{d}d' \\
&+ p(1-\theta) \int_{\bar{d}}^{\infty} \Phi_g\Big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\, d' + \underbrace{\tfrac{1}{1-\alpha+\psi}\, \ln\big(1-\theta\big)}_{<0,\ \text{reduced default risks.}}\Big)\, f_{d'}(d')\, \mathrm{d}d' \\
&+ \underbrace{p\,\theta \left[1 - \int_{\bar{d}}^{\infty} \Phi_g\Big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\, d' + \tfrac{1}{1-\alpha+\psi}\, \ln\big(1-\theta\big)\Big)\, f_{d'}(d')\, \mathrm{d}d'\right]}_{>0,\ \text{CAT bond premium}} \qquad (9)
\end{aligned}
$$

Spread for Parametric Trigger

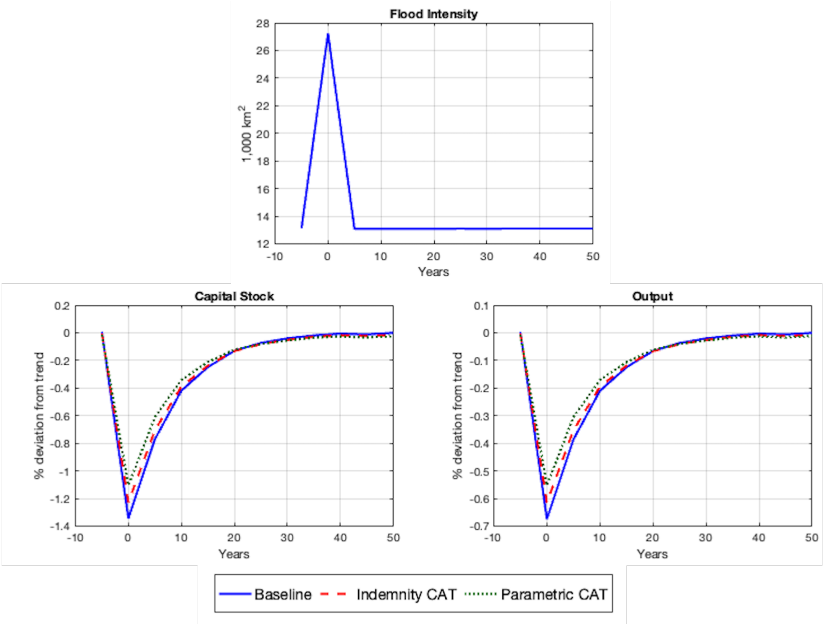
$$
\begin{aligned}
s(\bar{g},\theta,\bar{\omega}) \; = \; & (1-p)\,\Phi_g(\bar{g}) \\
& + \; p\int_0^{\bar{\omega}} \Phi_g\Big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\,\mu_p\,\omega'\Big)\, f_{\omega'}(\omega')\,\mathrm{d}\omega' \\
& + \; p(1-\theta)\int_{\bar{\omega}}^{\infty} \Phi_g\Big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\,\mu_p\,\omega' + \underbrace{\tfrac{1}{1-\alpha+\psi}\,\ln(1-\theta)}_{<0\text{, reduced default risks.}}\Big)\, f_{\omega'}(\omega')\,\mathrm{d}\omega' \\
& + \; \underbrace{p\,\theta\left[1 - \int_{\bar{\omega}}^{\infty} \Phi_g\Big(\bar{g} + \tfrac{\alpha}{1-\alpha+\psi}\,\mu_p\,\omega' + \tfrac{1}{1-\alpha+\psi}\,\ln(1-\theta)\Big)\, f_{\omega'}(\omega')\,\mathrm{d}\omega'\right]}_{>0\text{, CAT bond premium}}
\end{aligned}
\qquad (10)
$$

Calibrated Parameters

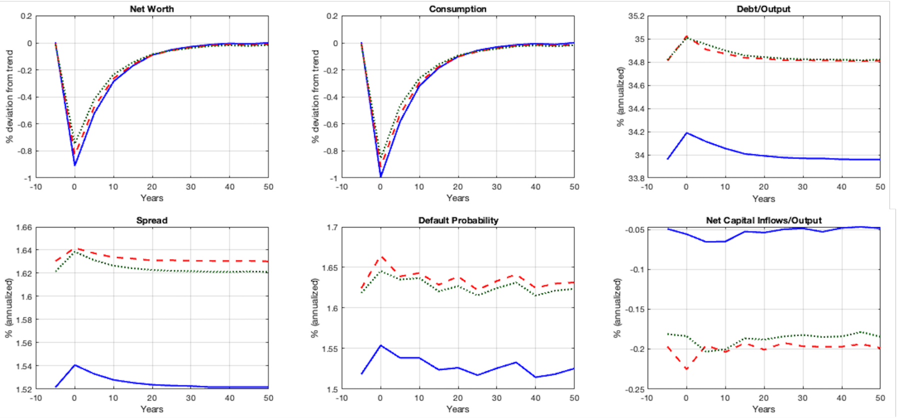
	Parameter	Value	Source
	period length	5 years	
α	capital share	$1/2$	Bank of Thailand
β	discount factor	0.96^5	Standard RBC values
δ	depreciation	$1 - 0.9^5$	
r	world interest rate	$1.01^5 - 1$	
ℓ	inverse elasticity of substitution	0.5	Gourio (2012)
γ	risk aversion	4	
μ_g	mean TFP growth	$1.006^{20} - 1$	Aguiar&Gopinath (2007)
σ_g	std of TFP growth	$0.0213\sqrt{20}$	
ℓ	default cost constant	0.07	Aguiar et al. (2016)
ψ	default cost curvature	7	
p	flood probability	0.30	Worawiwat et al. (2021)
μ	marginal output damage	0.0481	Tanoue et al. (2020)
Φ_d	shape of Gamma distribution	0.3391	S.&W. (2023)
	scale of Gamma distribution	148.7617	
$\bar{d}$	Indemnity Loss Trigger	90th percentile of d	Standard CAT Bond
$\bar{\omega}$	Parametric Trigger	90th percentile of ω	

Note: Payout for Parametrics (μ_p) = Coverage $\times$ Trigger Threshold $\times$ (1-basis risk)

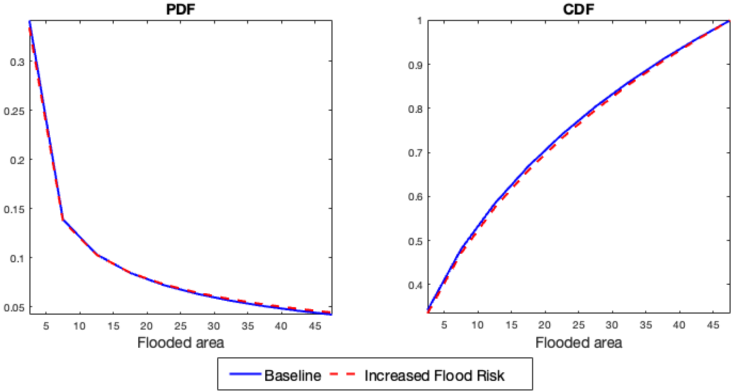
IRF on detrended capital and output



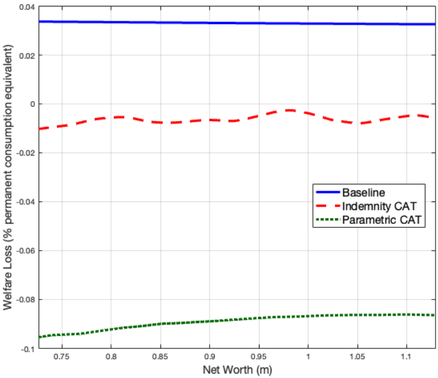
IRF on other detrended macro variables



Climate Shock: a rise in 30% of flood risk



Welfare Losses



- A change in welfare after the effect of climate change from $\Delta w = 1 - \frac{E_+[v_+(m)]}{E[v(m)]}$
  - $E[v(m)]$ as the lifetime utility for a given net worth level m
  - $E_+[v_+(m)]$ as those under the increased flood risk scenario

Conclusions

Key Findings

- Both indemnity and parametric CAT bonds cushion declines in capital, output, consumption, and gov. net worth after floods
- Parametric CAT bonds are more effective:
  - Provide immediate liquidity, reducing default risk
  - Lower sovereign spreads and lifetime welfare losses (via smoother consumption)
- Nonethelss, both increase public debt, temporarily crowding out capital inflows

Policy Takeaways

- Adopt a layered risk financing strategy: Parametric CAT bonds for extreme events, while budgetary buffers for moderate shocks

Future Plan

- Extend to mixed parametric&indemnity CAT bond, multi-period climate trends, household&firm heterogeneity, CAT Bond contract design
- Empirical data on CAT bond-capital flow dynamics