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Developing a model of disaster policies and the sovereign debt sustainability

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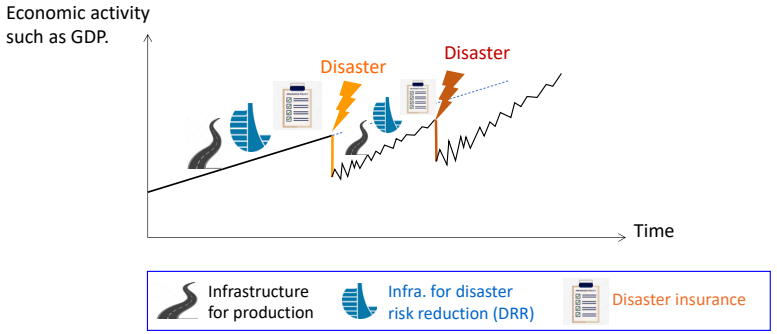
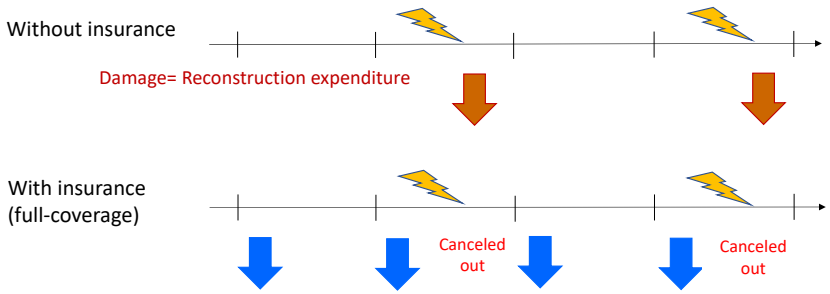
Focus 1: Allocation of resources between production and disaster risk reduction (DRR), and growth



Explore the resource allocation rule among investment in infrastructure for production (for growth) and DRR (for a decrease in potential damage at the next disaster), and financial contracts (for securing resources for recovery from the next disaster) under repeated and random arrivals of disasters.

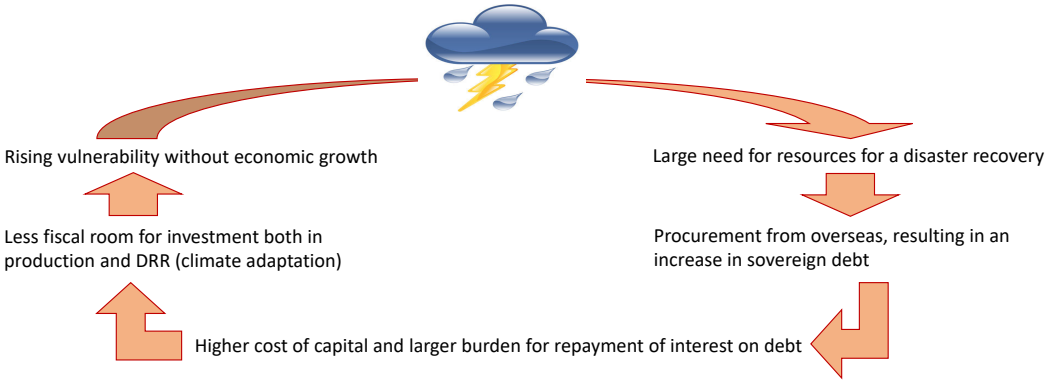
Focus 2: Role of sovereign insurance in a disaster-prone country

- Insurance premium = Claim x Probability x Mark-up rate (Probability: 1)
- E.g. If Probability=0.5 and Mark-up rate=2, then Insurance premium = Claim = Damage



Disaster occurs every year in terms of expenditure!

Focus 3: Fiscal sustainability and growth



The vicious cycle of economic stagnation, climate vulnerability, and debt crisis

Reference info.: On average, the poorest developing countries pay 14 per cent of revenue for interest on their debt, almost 4 times higher than developed countries, at 3.5 per cent. (UN (2022) "Financing for Sustainable Development Report 2022")

Purpose of study

- We are now developing a simple model of disaster policies and sovereign debt management for practical use in a small country in the Global South.

- This presentation will focus on the optimal coverage of insurance policies in response to the mark-up rates in the insurance market.

  Mark-up rate = Insurance premium / (Claim x Probability)

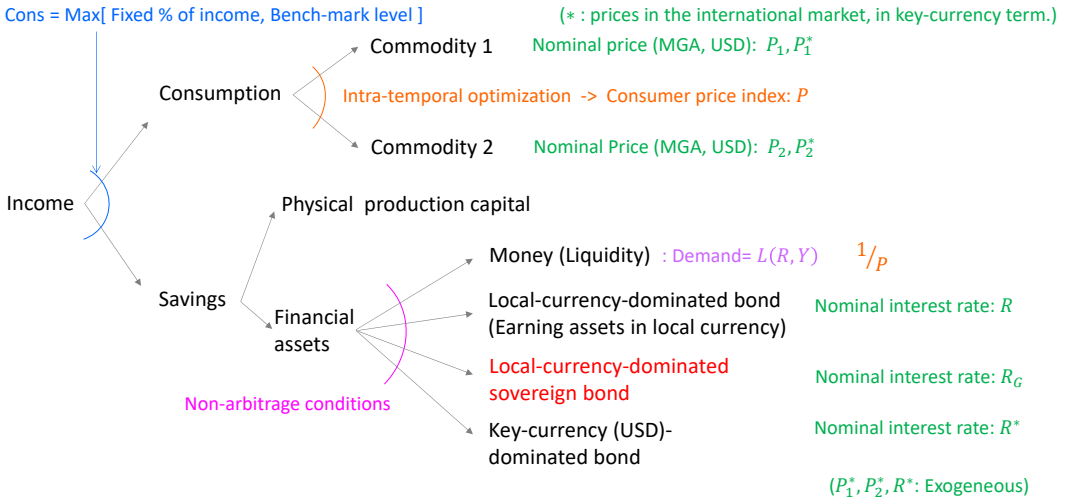
Related fields and frameworks (a few excerpts)

1. Strategic default of a government: Eaton and Gersovitz (1981): followed by many extensions; Ming (2019): on disaster risk on sovereign spread, and renegotiation and debt extension in a disaster state.
2. Credit risk and ruin theory: Series of Vasicek (2022) model; Cramer-Lundberg model
3. Natural disaster-resilient fiscal rule: Nakatani (2021): focus on the limited availability of information in small countries
4. Dynamic market models: Barro (2006), Barro et al.(2013), Gourio (2008, 2015): disaster and asset price evaluation; Coimbra (2020): Sovereign debt and banking leverage; Marto et al. (2018): Dynamic small-open economy models
5. Debt Sustainability Analysis (DSA); Applied by European Central Bank, EC, IMF, etc.: Bouabdallah et al. (2017), IMF (2021)
6. GDP-indexed bond: Borensztein and Mauro (2004)
7. Fiscal insurance theory: Bohn (1990), Angeletos (2002), Faraglia, Marcet and Scott (2008), etc.: the role of debt maturity

Model framework: market

- Small open economy
- Two commodities: Both traded. Home country specializes in the production of Commodity 1, while the rest of the world (ROW) produces both commodities.
- Closed labor market and no unemployment
- Closed physical capital markets; All firms are owned by domestic households.
- Open financial market: currency and bond
- Floating exchange rate system between the local currency (e.g., MGA: Malagasy Ariary of Madagascar) and the key currency (i.e., US dollar).
- Quasi-dynamic extension of Mundell–Fleming framework

Households' decisions and markets



Government budget and debt process

➢ Sovereign debt (Nominal, local-currency term), $D(t)$:
Formed by issuing Local-currency-dominated sovereign bond

➢ Expenditure (in each Period t)
Repayment of principal and interest of Sov bond, $D(t-1)$ (in case of No default),
Gov consumption, Investment in infrastructure for Prod and DRR, Insurance premium
At disaster time: Prompt reconstruction investment

➢ Income (in each Period t)
Tax, Grant from donor countries, Seigniorage, Issuance of Sov bond $D(t)$
At disaster time: Insurance claim

Market equilibrium

➢ Nominal exchange rate ε, and international relative price ω

$$\varepsilon = \frac{P}{P^*} = \frac{P_2}{P_2^*}, \qquad \omega \coloneqq \frac{\varepsilon P_2^*}{P_1} = \frac{P_2}{P_1} = \frac{p_2}{p_1} = \bar{\omega}$$

➢ Fisher equation

$$r = R - \pi^E, \qquad (r^* = R^* - \pi^*)$$

r, r^*: real interest rate, R, R^*: nominal interest rate, π^E: expected inflation rate of local currency

➢ Static expectation on the inflation rate: $\pi^E(t) = \pi(t-1)$

➢ No-arbitrage conditions

Local C dom bond, Key C (USD)-dominated bond, Sovereign bond

$$1 + R(t-1) = \frac{\varepsilon^E(t)}{\varepsilon(t-1)}\{1 + R^*(t-1)\} = \{1 - P_D(t)\eta_D\}\{1 + R_G(t-1)\}$$

ε_t^E: Expected Period-t nominal exchange rate as of Period t-1

$P_D(t)$: probability of Sov default in Period t, η_D: haircut (forfeiture rate)

Market equilibrium

➢ Real prices of Commodity 1, 2: From Consumer price index in Period t: $P = \left[\rho_1 P_1^{1-\varsigma} + \rho_2 P_2^{1-\varsigma}\right]^{\frac{1}{1-\varsigma}}$

$$p_1 = \frac{P_1}{P} = \left[\rho_1 + \rho_2 \bar{\omega}^{1-\varsigma}\right]^{-\frac{1}{1-\varsigma}}, \qquad p_2 = \frac{P_2}{P} = \left[\rho_1 \bar{\omega}^{-(1-\varsigma)} + \rho_2\right]^{-\frac{1}{1-\varsigma}}$$

➢ Market clearing of Commodity 1 (IS-curve)

$$\text{Prod: } Y = \text{Cons}(Y, p_1) + \text{Invest}(Y, p_1, r) + \text{Export}(\varepsilon) - \text{Import}(Y, p_1, r)$$

➢ Money market (LM-curve)

$$\text{Money demand } \big(R(t), Y(t)\big) = \frac{M(t)}{P(t)} \quad (\text{Nominal supply: } M(t) = \mu_M M(t-1))$$

➢ NOTE: Net export (nominal term)

$$\text{NX}(t) \coloneqq P_1 \cdot \text{Net Export}_1(Y, p_1, r, \varepsilon) - P_2 \cdot \text{Import}_2(Y, p_2, r)$$

Interest rate of Sovereign bond

➢ From the no-arbitrage condition

Local C-dominated bond, Key C (USD)-dominated bond, Sovereign bond

$$1 + R(t) = \frac{\varepsilon^E(t+1)}{\varepsilon(t)}\{1 + R^*(t)\} = \{1 - P_D(t+1)\eta_D\}\{1 + R_G(t)\}$$

Interest rate of Sovereign bond

$$\rightarrow \quad R_G(t) = \frac{1}{1 - P_D(t+1)\eta_D} \cdot \frac{\varepsilon^E(t+1)}{\varepsilon(t)}\{1 + R^*(t)\}$$

➢ Subjective probability of Sov default

$$P_D(t+1) = P_{Do}(t+1: \text{Sov Ins cov rate}) \cdot (1 - \text{A}_{\text{SI}} \times \text{Sov Ins cov rate})$$

$P_{Do}(\cdot)$: Objective default probability; reflecting an effect of Sov insurance.

$\text{A}_{\text{SI}} \times$ Sov Ins cov rate $(\text{A}_{\text{SI}} \geq 0)$: Additional (subjective) impact.

Criterion of Sovereign default

➢ Sovereign debt-GDP ratio

$$x_D(t) \coloneqq \frac{D(t)}{P(t)Y(t)} = \frac{\text{Sov Debt}}{\text{Nominal GDP}}$$

➢ Criterion of Sov default (i.e., the state where debt is no longer sustainable)

$x_D(t) > \bar{x}_D$: (Constant parameter) ⇒ Default at the end of Period t

(i.e., The repayment of the principal and interest in the next period t+1 will be defaulted.)

➢ Probability that Gov goes into default in the next period t+1

$$P_D(t+1) \coloneqq \text{Prob}(x_D^E(t) > \bar{x}_D \mid x_D(t-1) \leq \bar{x}_D)$$

Government's problem

➢ Constrained maximization problem

$\max_{\text{Policy}} F(\text{Policy})$ = Expected average annual GDP growth rate over T periods – ν x Its variance

subject to

(1) Probability of Sov default over the planning periods T $< \bar{P}_D$

(2) Expected average National Net External Debt (NNED)-GDP ratio $< \bar{x}_{DN}$

Intended to prevent Gov from imposing too heavy a tax on its citizens.

NOTE:

"Expectation" is given by the mean value of results of Monte-Carlo simulation.

"Average" is the mean over the planning periods T on each path of MC simulation.

Numerical example

➢ Used economic data of Madagascar. The probability of occurrence of disaster = 0.73.

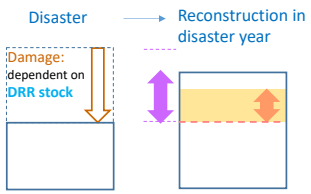
➢ Assumed values of a part of parameters by assumptions: to be refined by further data collection and better estimation. Please focus on the qualitative aspects of the results.

➢ Three policy variables: Constant throughout the planning periods.

1. The investment rate in DRR infrastructure; in terms of the GDP share: 1% – 5%.

2. The ratio of Government's prompt investment for reconstruction to the total destroyed physical capital within the disaster year: 0 – 100%.

3. The insurance-coverage rate against the total prompt needs of resources (= the total stock damage and the relief supply) : 0 – 100%.



Results of a basic case

More efficient insurance market

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0.4	0.2	0.2
Insurance coverage rate	1	0.8	0	0
Results				
Expect. ave. ann. growth rate of real GDP	5.40%	4.31%	3.50%	3.50%
Expected ave. ann. increase rate of variance of real GDP	0.00403	0.00443	0.00528	0.00528
Expect. Sov debt – GDP share (Year 10)	1.71	2.69	1.92	1.92
Variance of Sov debt (Year 10)	514	1270	762	762
Expect. Household asset – GDP share (Year 10)	0.108	0.173	0.0699	0.0699
Variance of HH debt (asset) (Year 10)	331	331	759	759

The smaller Mark-up rate of insurance is,
1) the larger the insurance coverage rate becomes, associated with larger Gov prompt reconstruction,
2) the larger the average growth rate of real GDP becomes, associated with smaller variance.

3) Sov insurance does not stabilize Sov debt.
4) Sov insurance increases Household assets and stabilizes its formation process.

Sovereign insurance contributes to GDP growth and stabilization of Household assets.

Sensitivity analysis

1. Impact of Sov Insu contract on the subjective default probability, A_{SI}

Subjective probability of Sov default

$$P_D(t+1) = P_{Do}(t+1\text{: Sov Ins cov rate}) \cdot (1 - A_{SI} \times \text{Sov Ins cov rate})$$

Objective default probability $P_{Do}(\cdot)$ includes an effect of Sov insurance.
"$A_{SI} \times$ Sov Ins cov rate" $(A_{SI} \geq 0)$ represents the additional (subjective) impact.

Higher (lower) the impact A_{SI}, larger (smaller) the contract rate.

Sensitivity analysis

2. Criterion of Sov default, $\bar{x}_D$ (Sov debt-GDP ratio $> \bar{x}_D \Rightarrow$ Sov default)

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies (Stricter criterion; by 22%)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0	0	0
Insurance coverage rate	1	0	0	0
Optimal set of policies (Basic case)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0.4	0.2	0.2
Insurance coverage rate	1	0.8	0	0
Optimal set of policies (Relaxed criterion; by 22%)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.8	0.6	0.6	0.6
Insurance coverage rate	0.4	0	0	0

The range of insurance and reconstruction is more limited.

Reconstruction investments will be more focused, but less insurance is needed to finance them.

The optimal combination of policies does not change in a monotonic way.

Sensitivity analysis

3. Constraint on National net foreign debt-GDP ratio, $\bar{x}_{DN}$ (Mean[Ave x_{DN}] $< \bar{x}_{DN}$)

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies (Stricter criterion; by 50%)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.4	0.2	0.2	0.2
Insurance coverage rate	0.6	0	0	0
Optimal set of policies (Basic case)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0.4	0.2	0.2
Insurance coverage rate	1	0.8	0	0
Optimal set of policies (Relaxed criterion; by 100%)				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.8	0.2	0.2	0.2
Insurance coverage rate	1	0	0	0

The environment in which insurance is needed is more limited.

Sensitivity analysis

4. Catastrophe (i.e., degree of low-frequency-and-high-impact)

The case that the probability is halved and the damage rate is doubled. (The expected damage rate is kept constant.)

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies (Basic case)				
Investment rate in DRR	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0.4	0.2	0.2
Insurance coverage rate	1	0.8	0	0
Optimal set of policies (lower probability by 50% and larger damage rate by 100%)				
Investment rate in DRR	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	1	1	1	0.4
Insurance coverage rate	0.4	0.6	0.8	0

Insurance works more broadly against events of low-frequency-and-high-impact.

Discussion (Issues to reconsider): Problem formulation

- The formulation of the optimization problem appears general. However, the impact of inequality conditions on the policy variables does not appear to be uniform. The difficulty in estimating the default criterion $\bar{x}_D$ (and market assessments of the default probabilities $P_D(t+1)$) makes these nonlinearities more troublesome for practice.

Constrained maximization problem

$\max_{\text{Policy}} F(\text{Policy}) =$ Expected average annual GDP growth rate $- v$ x Its variance

subject to

(1) Probability of Sov default over the planning periods $< \bar{P}_D$

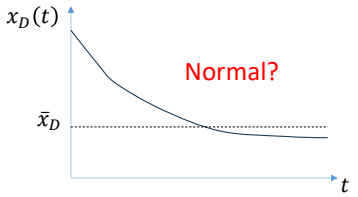
(2) Expected average National Net External Debt (NNED)-GDP ratio $< \bar{x}_{DN}$

Intended to prevent Gov from imposing too heavy a tax on its citizens.

Discussion: Static or dynamic default criterion

$$x_D(t) := \frac{\text{Sov Debt}}{\text{Nominal GDP}} > \bar{x}_D\text{: (Constant)} \Rightarrow \text{Default at the end of Period t}$$

- Normative path may allow a higher Sov debt-GDP ratio $x_D(t)$ on earlier stage of development. Is it too strict to assume a constant $\bar{x}_D$ for developing countries?
- On the other hand, in the real world, a part of developed countries are also increasing "Sovereign debt – GDP ratio".



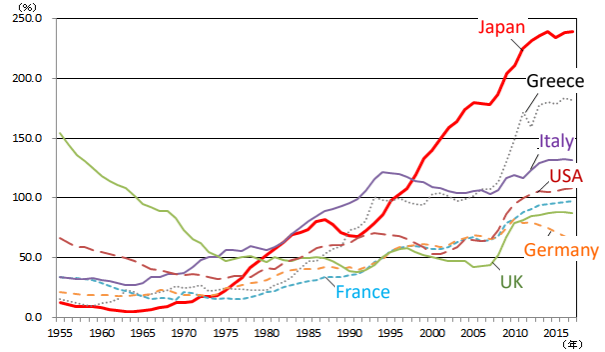
High and low "Sovereign debt –GDP ratio" countries in 2021

High	Country	SD/GDP(%)	Low	Country	SD/GDP(%)
1	Japan	259.43	1	Hong Kong	2.13
2	Sudan	200.35	2	Brunei	2.51
3	Greece	194.5	3	Afghanistan	7.4
4	Eritrea	179.66	4	Timor-Leste	9.43
5	Singapore	159.87	5	Turkmenistan	11.08
6	Maldives	154.39	6	Tuvalu	11.53
7	Lebanon	150.58	7	Kuwait	11.71
8	Italy	150.3	8	Solomon Islands	13.65

Source: World Population Review website

Discussion: Static or dynamic default criterion

The trend in "Sovereign debt –GDP ratio" in major developed countries



Source: https://www.nissay.co.jp/enjoy/keizai/102.html

Discussion: Static or dynamic default criterion

We tested the case where the constraint on the debt-GDP ratio is posed only in the first half of the planning periods.

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies **(Basic case)**				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	0.6	0.4	0.2	0.2
Insurance coverage rate	1	0.8	0	0
Results				
Expect. ave. ann. growth rate of real GDP	**5.40%**	**4.31%**	**3.50%**	**3.50%**
Expect. Sov debt – GDP share (Year 10)	1.71	2.69	1.92	1.92

Mark-up rate of the insurance	1	1.5	2	2.5
Optimal set of policies **(Default is judged only in the first half of the planning periods.)**				
Investment rate in DRR infra.	0.05	0.05	0.05	0.05
Rate of Gov prompt reconstruction invest.	1	0.6	0.4	0.4
Insurance coverage rate	0.6	0.4	0	0
Results				
Expect. ave. ann. growth rate of real GDP	**8.85%**	**6.74%**	**5.76%**	**5.76%**
Expect. Sov debt – GDP share (Year 10)	3.30	3.97	4.97	4.97

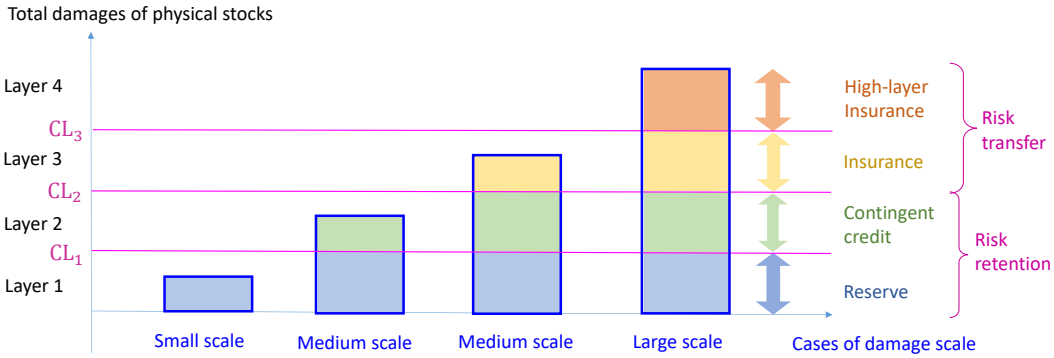
The expected growth rate is increased with an increase in the Sov debt-GDP ratio.

Discussion (Issues to reconsider):
Other roles and schemes of Sov insurance

Insurance premium = Claim x Probability x Mark-up rate

- The insurance associated with "Probability x Mark-up rate > 1" increases the expenditure "every period" from that in the case without insurance.
- What could be other roles of insurance? It may include a role in obtaining the key foreign currency in the event of a disaster.
- Excess-of-loss insurance contract (in a Risk-layering financial scheme) may work, which limits insured events to "low-frequency-and-high-impact" ones.

Risk-layering financial scheme:
Inclusive of Excess-of-loss insurance contract



CL_1, CL_2, CL_3: Ceiling of Layer 1,2,3

The probability of the insured events is limited.

Conclusion

- This study formulated the simple open-economy model for examining the sovereign debt sustainability of a country in the Global South.
- Sovereign insurance may be effective in decreasing the interest rate of the sovereign debt by decreasing the default probability.
- Future study includes further elaboration on the roles of insurance for a government in disaster-prone countries and statistical verification.

Thank You