Welcome to the Climate Casino!

$ \times 10 = 1 \times \$$

\[ \text{dice} \times \text{crop damage} \]
A Climate Casino

\[
\begin{align*}
\text{dice} & = \text{leaf} + 1 \\
\text{dice} & = \text{leaf} - 2 \\
\text{dice} & = \text{leaf} - \text{all}
\end{align*}
\]
A Climate Casino

\[
\begin{align*}
&\text{\small icon} = 1 \times \$ \\
&1 \times \text{\small icon} \quad \checkmark \quad \text{\small dice} \\
&3 \times \text{\small icon} \quad \checkmark \quad \text{\small dice}
\end{align*}
\]
Game starts

Round 1: 🌾 × 9 🏡 × 1

Dice : 🎲

Token: 💰 × 10
Game starts

Round 2: Wheat × 9  House × 1

Dice:

Token: $ × 10
Game starts

Round 3: 🌾 × 9 🔑 × 1

Dice: □

Token: $ × 10
What if?

$ \times 3$

= -all
Effects of climate disaster reduction measures

**Society A**
- Economic activity such as GDP.
- Disaster
- Biased investment in infrastructure for production
- Large damage resulting in delayed growth due to lack of infra. for DRR

**Society B**
- Disaster
- Smaller damage but slow recovery of the economy
- Infrastructure for production
- Infra. for disaster risk reduction

Title of presentation goes here
Integrating risk reduction and risk finance

Economic activity such as GDP.

Society C

Society D

A large number of resources for reconstruction but large destruction at disaster time

Balanced investment among infrastructure for production and DRR, and financial contracts

Infrastructure for production

Infra. for disaster risk reduction (DRR)

Disaster insurance
SMART-SUPPORT FOR GOVERNMENTS IN DEVELOPING COUNTRIES FOR ADDRESSING PHYSICAL AND FISCAL RISKS OF CLIMATE CHANGE

Qinhan Zhu
Muneta Yokomatsu
Stefan Hochrainer-Stigler
Reinhard Mechler

INTERNATIONAL INSTITUTE OF APPLIED SYSTEMS ANALYSIS
Analyse multi-hazard risks under different scenarios

- Model: CLIMADA
- Case study: Madagascar
- Covered hazards: tropical cyclones, riverine flood, coastal flood

- Resilience measures (for example: prevention, spatial planning, building codes ...)
- Climate scenarios
- Development scenarios
- Vulnerability
- Impact
- Outputs:
  - Risk analysis
  - High-res risk mapping
  - Impact warnings...
  - Example: Economic impact
  - Appraisal of resilience measures / options (effectiveness of options, cost/benefit ...)
  - Quantification of uncertainty

Title of presentation goes here
Physical risks in Madagascar

- Average Annual Losses considering cyclones and flood:
  - General assets: 30 million $
  - Public assets: 16.8 million $
  - Agriculture: 4.6 million $
- 50-year compound event: 521 million $ (2.7% of total assets, 3.8% of GDP)
Risk Reduction

- Physical: Storm-reinforced Housing (wood and unreinforced masonry housings make up 78% of all residential land area (Madagascar evidence)
- Natural: Bamboo T-fence (global evidence)

<table>
<thead>
<tr>
<th>Option for retrofitting</th>
<th>AAL after retrofitting (AAL2)</th>
<th>Benefit of retrofitting (AAL1-AAL2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood only</td>
<td>48.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Unreinforced</td>
<td>42.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Masonry (UM) only</td>
<td>33.0</td>
<td>24.4</td>
</tr>
<tr>
<td>Both wood and UM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Estimated benefits of enforcing higher building code, unit: million $
Effects of disaster risk reduction measures:

Exceedance probability
(=1 – “Value of distribution function of damage”)

Original (without-DRR) risk curve

After risk reduction risk distribution

Damage scale
Stock formation process: Production capital and DRR stock

At the beginning of Year t

Production capital

In Year t

Without a disaster hit

Invest. by Government
Invest. by Private sector

Depreciation

With a disaster hit

Invest. by Government
Invest. by Private sector

Disaster damage

Prompt reconstruction based on financial preparedness

Mitigation effect brought by DRR stock

→ Year t+1
Layered strategy: combining risk reduction and risk finance

Exceedance probability

Original (without-DRR) risk curve

Approximated after-DRR curve

Reserve

Contingent credit

Insurance

ART (e.g. CAT bond)

Stock damage
## CatSim: Fiscal-centered macroeconomic modelling

<table>
<thead>
<tr>
<th></th>
<th>Independent of disaster occurrence</th>
<th>At disaster time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenue</strong></td>
<td>Tax, Grant from donor countries, Other revenues (including dividends from state companies),</td>
<td>Income from Disaster finance contracts:</td>
</tr>
<tr>
<td></td>
<td>Seigniorage (i.e., income from printing money, technically by the central bank)</td>
<td>1) Withdrawal from Reserve fund</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Contingent credit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) Insurance claim</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4) Income of ART</td>
</tr>
<tr>
<td><strong>Expenditure</strong></td>
<td>Gov. consumption, Investment in Prod. capital and DRR stocks, Interest payment of debt,</td>
<td>Prompt reconstruction of Prod. capital and DRR stocks,</td>
</tr>
<tr>
<td></td>
<td>Annual expenditure for Disaster finance:</td>
<td>Relief good supply</td>
</tr>
<tr>
<td></td>
<td>1) Transfer to Dis. Reserve stock,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Fee for credit line contract,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) Insurance premium,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4) payments for alternative risk transfer (ART)</td>
<td></td>
</tr>
</tbody>
</table>
Debt sustainability and default

➢ Process of government’s financial position: in terms of sovereign debt
   Debt (Year t+1) = Debt (Year t) + Expenditure (t) - Revenue (t)

➢ Index that serves as the criterion
   Debt-GDP ratio

\[
x_D(t) := \frac{\text{Debt}(t)}{\text{Nominal GDP}(t)}
\]

Assumption: national government is subjected to

\[
x_D(t) < \bar{x}_D.
\]

\[
\bar{x}_D : \text{Constant value of the limitation of the debt-GDP ratio}
\]
Index focused for policy evaluation

➢ GDP growth rate

\( \gamma_{YAT} \): The average annual real-GDP growth rate over the planning period (T years)

Example)

➢ Expected growth rate and its variance

In the numerical simulation, run the model many times with many disaster scenarios over the planning period (i.e., “Monte-Carlo simulation”), and obtain

[Expected level of \( \gamma_{YAT} \)]: the mean over the tested disaster scenarios,

[Variance of \( \gamma_{YAT} \)]: the size of distribution, which reflects uncertainty of growth.
Policy evaluation

➢ Evaluation function

\[ F (\text{Policy}) = [\text{Expected level of } \gamma_{YAT}] - [\text{Weight}] \times [\text{Variance of } \gamma_{YAT}] \]

✓ \( \gamma_{YAT} \): The average annual real-GDP growth rate over the planning period (T years)

✓ Each set of Policy is input to be evaluated by the function.

✓ Degree of risk aversion is represented by the value of [Weight].

✓ NOTE: In stead of focusing on the growth rate, the objective function could also be

\[ \max_{\text{Policy}} F_{\text{GDP}}(\text{Policy}) = E[\text{GDP}(t)] - \nu_{\text{GDP}} \cdot \text{Var}[\text{GDP}(t)]. \]

➢ Problem formulation

Maximize \( F (\text{Policy}) \) with respect to Policy,

Subject to

“Net external debts (at the national level) must be smaller than the certain level.”
Sample of the results

- Data collection is ongoing in Madagascar
- Policy variables
  - $\theta_S$: Investment rate in DRR (disaster mitigation) infrastructure; in terms of the GDP share
  - $\xi_{KS}$: The ratio of Government’s prompt investment for reconstruction to the total destroyed physical capital within the disaster year
  - $\omega_I$: The insurance-coverage rate against the total prompt needs of resources (= the total stock damage and the relief supply)
Sample of the results (Cont’d)

➢ Environment

Mark-up rate of the insurance: MUR=1.0,1.5,2.0,2.5

<table>
<thead>
<tr>
<th>MUR</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal set of policies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inv. rate in DRR</td>
<td>0.0371</td>
<td>0.0457</td>
<td>0.0457</td>
<td>0.0371</td>
</tr>
<tr>
<td>Gov. recovery rate</td>
<td>1</td>
<td>0.6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Insurance cov. rate</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Results

<table>
<thead>
<tr>
<th></th>
<th>MUR 1.0</th>
<th>MUR 1.5</th>
<th>MUR 2.0</th>
<th>MUR 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Eva. function</td>
<td>0.0786</td>
<td>0.0468</td>
<td>0.0448</td>
<td>0.0382</td>
</tr>
<tr>
<td>Expected average growth rate</td>
<td>0.0898</td>
<td>0.0715</td>
<td>0.0701</td>
<td>0.0534</td>
</tr>
<tr>
<td>Variance of growth rate</td>
<td>0.000112</td>
<td>0.000247</td>
<td>0.000253</td>
<td>0.000152</td>
</tr>
</tbody>
</table>

Policy variables

✓ \( \theta_S \): Investment rate in DRR (disaster mitigation) infrastructure; in terms of the GDP share
✓ \( \xi_{KS} \): The ratio of Government’s prompt investment for reconstruction to the total destroyed physical capital within the disaster year
✓ \( \omega_I \): The insurance-coverage rate against the total prompt needs of resources (= the total stock damage and the relief supply)
Sample of the results (Cont’d)

➢ Sample path (under one process of random arrivals of disasters) of the case MUR=2.0 and the optimal policy set

![Diagram showing sample path](image)

- Damage rate of physical stocks
- Real GDP, standardized as the ratio to R-GDP (20)
- Sovereign debt-GDP ratio
Sample of the results (Cont’d)

➢ Sensitivity analyses

<table>
<thead>
<tr>
<th>MUR</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal set of policies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inv. rate in DRR</td>
<td>0.0371</td>
<td>0.0457</td>
<td>0.0457</td>
<td>0.0371</td>
</tr>
<tr>
<td>Gov. recovery rate</td>
<td>1</td>
<td>0.6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Insurance cov. rate</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Eva. function</td>
<td>0.0786</td>
<td>0.0468</td>
<td>0.0448</td>
<td>0.0382</td>
</tr>
<tr>
<td>Expected average growth rate</td>
<td>0.0898</td>
<td>0.0715</td>
<td>0.0701</td>
<td>0.0534</td>
</tr>
<tr>
<td>Variance of growth rate</td>
<td>0.000112</td>
<td>0.000247</td>
<td>0.000253</td>
<td>0.000152</td>
</tr>
</tbody>
</table>

Basic case

1. More strict default threshold: 0.8 -> 0.5

<table>
<thead>
<tr>
<th>MUR</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal set of policies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inv. rate in DRR</td>
<td>0.0500</td>
<td>0.0414</td>
<td>0.0329</td>
<td>0.0371</td>
</tr>
<tr>
<td>Gov. recovery rate</td>
<td>0.8</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Insurance cov. rate</td>
<td>0.8</td>
<td>0.6</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Eva. function</td>
<td>0.0490</td>
<td>0.0252</td>
<td>0.0268</td>
<td>0.0160</td>
</tr>
<tr>
<td>Expected average growth rate</td>
<td>0.0778</td>
<td>0.0507</td>
<td>0.0527</td>
<td>0.0447</td>
</tr>
<tr>
<td>Variance of growth rate</td>
<td>0.000288</td>
<td>0.000255</td>
<td>0.00026</td>
<td>0.000287</td>
</tr>
</tbody>
</table>

2. Increasing damage rate due to climate change

<table>
<thead>
<tr>
<th>MUR</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal set of policies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inv. rate in DRR</td>
<td>0.0329</td>
<td>0.0500</td>
<td>0.0500</td>
<td>0.0457</td>
</tr>
<tr>
<td>Gov. recovery rate</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>Insurance cov. rate</td>
<td>1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Eva. function</td>
<td>0.0596</td>
<td>0.0423</td>
<td>0.0469</td>
<td>0.0218</td>
</tr>
<tr>
<td>Expected average growth rate</td>
<td>0.0802</td>
<td>0.0713</td>
<td>0.0729</td>
<td>0.0435</td>
</tr>
<tr>
<td>Variance of growth rate</td>
<td>0.000206</td>
<td>0.000250</td>
<td>0.000260</td>
<td>0.000217</td>
</tr>
</tbody>
</table>
Most critical component: Estimation of the interest rate function

- Interest rate function

\[ i(x_D(t), \Omega_{hl}(t) | \text{for all } h, P(t)Y(t)) = \begin{cases} 
  r(t) & \text{if } x_D(t) \leq x_r \\
  r(t) \cdot \{1 + a_{i1} \bar{x}_D(t) + a_{i2} \bar{x}_D(t)^2 + a_{i3} \varepsilon_i(t)\} & \text{if } x_D(t) > x_r
\end{cases} \]

where

\[ \bar{x}_D(t) := x_D(t) - a_{i0} \sum_h \Omega_{hl}(t) \frac{D(t) - a_{i0} \sum_h \Omega_{hl}(t)}{P(t)Y(t)} \]

\( r(t) \): risk free interest rate in market, \( x_D(t) \): the sovereign debt-GDP ratio, \( x_r \): threshold value

\( \sum_h \Omega_{hl}(t) \): sum of insurance claims, representing the total scale of insurance contract

\( \varepsilon_i(t) \): truncated standard normal random variable: \( 0 \leq \varepsilon_i(t) \leq 1 \)

\( \bar{x}_r, a_{i0}, a_{i1}, a_{i2}, a_{i3} \): parameters to be estimated by data.

In the numerical examples, it was found that giving a small positive value to \( a_{i2} \) results in explosion of the interest rate and the sovereign debt-GDP ratio.
Milefa ny fossa, tojo ny kary?

To escape from the fossa but meet a wild cat
THANK YOU!

QINHAN ZHU
MUNETA YOKOMATSU
STEFAN HOCHRAINER-STIGLER
REINHARD MECHLER

INTERNATIONAL INSTITUTE OF APPLIED SYSTEMS ANALYSIS