Real Options as a Tool for Valuing Investments in Adaptation to Climate Change

Conference on Economics of Adaptation to Climate Change in Low-Income Countries
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Motivation

- IPCC2007: Inevitability of adaptation
- Multiple challenges relevant to adaptation investments in low-income countries
- Is there an optimal investment strategy?
Context: Pervasive Uncertainty

- **Sources of uncertainty**
  - GHG Emissions = \( f(\text{Economic Activity, Technology Choices, Policy Regimes}) \)
  - Science: Emissions + Sinks \( \Rightarrow \) Warming \( \Rightarrow \) Impacts
  - Adaptation: Autonomous choices, global funding

- **Reductions in uncertainty over time**
  - Research-Driven: IPCC1990 \( \Rightarrow \) IPCC2007 \( \Rightarrow \) IPCC20xx
  - Calendar-Driven: Estimates of future \( \Rightarrow \) Observations of present
Core Research Question

- Invest *now* to adapt to *potential* climate change versus …
- Invest *later* to adapt to *actual* climate change versus …
- Steer a middle course by creating options *today* that can be exercised as needed in the *future*?
Approach to Decisions under Uncertainty

- Framed adaptation as a minimization problem

\[
A = \sum_{i=1}^{n} \frac{C_i + O_i + E(D_i)}{(1 + r)^i}
\]

- \(n\) = duration of analysis period
- \(c\) = capital investment
- \(o\) = recurring investment
- \(E(D)\) = expected value of residual damages
- \(r\) = discount rate

- Assumed risk-neutrality
Our Study: Sea Level Rise (SLR)

- Multiple uncertainties
  - Global sea level rise trajectory
  - Local storm surge frequency & intensity
  - Evolving value of vulnerable land-side assets

- Potential for significant impacts
  - Concentration of vulnerable cities in low-income countries
  - 11 million residents in vulnerable port cities in low-income countries

- Caveat: Not all coastal risks originate in climate change
  - 1900 Galveston Flood; 1953 North Sea Flood
Adaptation to SLR as a “One-Off” Decision

Chose Height of Defense In Year 1

- High
  - High SLR
    - High Asset Value
      - Protected
    - Low Asset Value
      - Protected
  - Low SLR
    - High Asset Value
      - Over-Protected
    - Low Asset Value
      - Over-Protected

- Low
  - High SLR
    - High Asset Value
      - Inundation: High Loss
    - Low Asset Value
      - Inundation: Low Loss
  - Low SLR
    - High Asset Value
      - Protected
    - Low Asset Value
      - Protected

- None
  - High SLR
    - High Asset Value
      - Inundation: High Loss
    - Low Asset Value
      - Inundation: Low Loss
  - Low SLR
    - High Asset Value
      - Inundation: High Loss
    - Low Asset Value
      - Inundation: Low Loss
Adaptation to SLR as Sequential Decisions

Year 1: Select Height of Defense

Year 1+x: Decide whether to Raise Defense

Year 1+2x: Decide whether to Raise Defense

Year 1+3x: Decide whether to Raise Defense

Year 1+4x: Decide whether to Raise Defense

Ongoing Reduction in Uncertainty About Sea Level Rise & Value of Vulnerable Assets

X = Number of years between periodic planning decisions.
Methodology: Evaluate Two Strategies

- **Inflexible Strategy**: Select height of coastal defense once, at Time 0
- **Real Option Strategy**: Adjust height of coastal defense once every 20 years, by re-solving minimization problem, based on then-available data
Methodology: Two Cases
Methodology: Monte Carlo Simulation

- SOURCE
  - Sea Levels
  - Sea Level Rise
  - Storm Surges

- PATHWAY
  - Inundation
  - Mediation by coastal defenses

- RECEPTORS
  - Vulnerable economic assets
  - Vulnerable populations

- IMPACTS
  - Fatalities
  - Displaced Persons
  - Lost Economic Assets

- ADAPTATION
  - Evacuation
  - Re-location
  - Investments in defenses

- Not meant to be prescriptive for simulated cities
Simulation: Annual Maximum Sea

1. Global Sea Level Rise
   - 100-Year GSLR Trend: \( T \sim N(3\text{mm}, 2\text{mm}) \)
   - \( \text{GSLR}_i \sim U(.5T, 1.5T) \)

2. Local Sea Level Rise
   - Dar-es-Salaam: -1.58mm/year
   - Dhaka: 0.65mm/year

3. Annual Maximum Storm Surge …
Annual Maximum Surge: Dar-es-Salaam
Annual Maximum Surge: Dhaka
Simulation: Coastal Defenses

- Population & Economic Assets
- Natural Freeboard
- "Baseline" Sea Level
- Coastal Defense
- Sea Level w SLR & Storm Surge
## Simulation: Vulnerabilities to Inundation

Vulnerability as a Function of Vertical Quantity (Q) of Over-Topping of Defenses

<table>
<thead>
<tr>
<th>Q (meters)</th>
<th>1.0</th>
<th>2.0</th>
<th>3.0</th>
<th>4.0</th>
<th>5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dar-es-Salaam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Assets (US$m)</td>
<td>134</td>
<td>169</td>
<td>278</td>
<td>469</td>
<td>835</td>
</tr>
<tr>
<td>Population (thousands)</td>
<td>20</td>
<td>25</td>
<td>41</td>
<td>69</td>
<td>123</td>
</tr>
<tr>
<td><strong>Dhaka</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Assets (US$m)</td>
<td>1,153</td>
<td>1,564</td>
<td>1,975</td>
<td>3,598</td>
<td>8,149</td>
</tr>
<tr>
<td>Population (thousands)</td>
<td>163</td>
<td>221</td>
<td>279</td>
<td>508</td>
<td>1,151</td>
</tr>
</tbody>
</table>
Simulation: Changes in Vulnerability

- Stochastic simulation of:
  - Population Growth
  - Asset Growth

- Correlation of Population and Asset Growth
  - $\sigma = 0.75$

- No behavioral response to investments in coastal defenses
Compilation of Results

- 10,000 iterations
- Calculate NPV of total cost over 100 yrs, $r = 3\%$
- Compute mean value of total cost
  - Investments in defenses
  - Damage to economic assets
  - Monetary value of fatalities (~US$170,000)
  - Monetary value of displaced persons (~US$4,200)
Sensitivity to Intensified Climate Change

- GSLR: $N(3,2) \Rightarrow N(5,4)$
- Gumbel extreme value distribution – Scale increased 5x
  - Dar-es-Salaam
    - 100-Year Surge: 3.1m $\Rightarrow$ 4.6m
    - 1-Year Surge: 2.8m $\Rightarrow$ 2.8m
    - Mean Surge: 2.8m $\Rightarrow$ 3.0m
  - Dhaka
    - 100-Year Surge: 4.7m $\Rightarrow$ 8.9m
    - 1-Year Surge: 3.7m $\Rightarrow$ 3.7m
    - Mean Surge: 3.8m $\Rightarrow$ 4.3m
## Results: Base Case

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Cost (US$ billion)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Dar-es-Salaam</td>
</tr>
<tr>
<td>Inflexible Strategy</td>
<td>$7.9</td>
</tr>
<tr>
<td>Real Option: Predict &amp; Respond Strategy</td>
<td>$7.9</td>
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</tbody>
</table>
# Results: Climate Sensitivity Case

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<tbody>
<tr>
<td></td>
<td>Dar-es-Salaam</td>
</tr>
<tr>
<td>Inflexible Strategy</td>
<td>$14.2</td>
</tr>
<tr>
<td>Real Option: Predict &amp; Respond Strategy</td>
<td>$9.5</td>
</tr>
</tbody>
</table>
## Results: Value of Flexibility

<table>
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<tr>
<th>Scenario</th>
<th>Total Cost (US$ billion)</th>
<th>Dar-es-Salaam</th>
<th>Dhaka</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Base Case</td>
<td>Greater Climate Change</td>
</tr>
<tr>
<td><strong>Inflexible Strategy</strong></td>
<td></td>
<td>$7.9</td>
<td>$14.2</td>
</tr>
<tr>
<td><strong>Real Option: Predict &amp; Respond Strategy</strong></td>
<td></td>
<td>$7.9</td>
<td>$9.5</td>
</tr>
<tr>
<td><strong>Value of Flexibility</strong></td>
<td></td>
<td>$0.0</td>
<td>$4.6</td>
</tr>
</tbody>
</table>
Option Strategies May Save Resources

- **Sources of value**
  - Building later postpones costs: time value of money
  - Delay of investment creates possibility that never build
  - Netted against possibility of inundation & consequent costs

- **Parallel to financial options**
  - Value of underlying asset ↑ ⇒ Value of option ↑
  - Volatility ↑ ⇒ Value of option ↑
Quality of Information Matters

- Time frame
  - Inflexible Strategy: 50-100 years
  - Real Option: 20-30 years

- Distribution of uncertain parameters, not point estimates, to solve for E(D)

\[
A = \sum_{i=1}^{n} \frac{C_i + O_i + E(D_i)}{(1 + r)^i}
\]

- Local SLR: 0.65m/yr vs. -1.52m/yr
Capacity to Manage Option Matters

- **Inflexible Strategy**: “Once-and-forget-it” character
- **Option Strategy**: Decision to exercise
  - Financial Asset: Compare stock price to option strike price
  - Real Asset (Coastal Protection): Re-solve minimization problem
- **Sequential decision-making requires ...**
  - Monitoring sea conditions, scientific research, land-side assets
  - Timely decisions: asset valuations & risk assessments
  - Ability to implement sequential decisions (design, procure, build)
Uncertainty of Resources to Exercise

- Implications for multilateral development assistance
  - Inflexible Strategy: One-time capital investment
  - Option Strategy
    - Potential for ongoing capital investments
    - Level & timing of funding needs uncertain

- Global adaptation funding likely to come in tranches
  - If option exercise date beyond end of current tranche, recipient countries may be reluctant to pursue option strategy
  - Use current tranche to fund escrow account for option exercise??
Key Question: Re-visited

- Can real option techniques be used to improve use of resources for adaptation to rising sea levels?
  - Qualified yes

- Implications of such techniques for investment decisions?
  - Smaller investments needed if SLR less than expected
  - Investments pushed into future
  - Initial investment in less robust defense raises risk of inundation

- What policy & technical issues require further study?
  - Ability to manage option
  - Resources to exercise option
  - Research agenda focused on drivers of option value
  - Risk neutrality
  - Behavioral response
  - Coastal risk not originating in climate change
Questions?

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- Paper
  - http://www.gwu.edu/~iiep/adaptation