Copula Approaches for the Assessment and Management of Critical Infrastructure Resilience

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Starting Point

• Critical Infrastructure concepts
• Current discussions similar to key-stone species concepts in Ecology
• Question about the connections and how to measure them
• Challenge I: Connections not always the same during extremes or failures
• Challenge II: Strength of connections not always the same in all situations
• One way to overcome this challenges is to use so-called copula approaches as a resilience indicator.
Interconnections between scales

Different Scales of Risk Bearers:

The ability to cope with extremes and failures is different for different risk bearers on different scales.

Strategies have to be dependent on their resilience to shocks and how a specific actor interacts with other stakeholders in times of disasters.

Dependent on the coping strategies for different levels of risks different instruments may be preferable.

Source: Hochrainer, S. (2013)
Critical infrastructure failure and consequences

Network dependencies

A network example: The flow $F$ represents the return. Investments can be made to increase the arc capacities $k_i$.

Source: Hochrainer und Pflug, 2009
Critical infrastructure failure and consequences

Left: The catastrophic event reduces for instance the capacity of only are 12. This network can be built with a budget of $B_0 - D$. Right: with the same amount of budget $B_0 - D$ a more effective network could be built as is shown here. The utility of this network is much higher than the one left over by the catastrophe.

Source: Hochrainer und Pflug, 2009
Critical infrastructure failure and consequences

Network utility as a resilience indicator

Kinked Utility calls for risk aversion as risk spreading options not feasible.

Arrow-Lind Theorem Fails: Government to behave risk averse and therefore need to act proactive

A catastrophe makes the return on investment drop below the historic return curve (The basic stock is $B_0 = 10$). The function $U(B)$ is shown as a dotted line, the function $\bar{U}(B)$ as a solid line.

Source: Hochrainer und Pflug, 2009
Geographical Dependencies: Flooding

Strong positive spatial correlations of flood events across Europe.

Source: Jongman et al. (2014)
New innovations based on so-called Copula approaches for determining non-linear dependencies to be used as critical indicators for the resilience of systems and critical infrastructures
Copulas are useful for modelling dependencies between continuous random variables:

Tightening of coupling in the case of extremes (large losses) or critical infrastructure failures.
Modelling dependent risk with copulas

Copyula model

Loss distribution of Node 1

Loss distribution of Node 2

Severity Node 1

Severity Node 2

Node 1

Extreme events

Tight connection

Node 1

Normal events

Loose connection

Node 2

Source: Hochrainer-Stigler et al. (2018)
Dependency of critical infrastructure on its connection strength.

Expected Losses on the System Level

Influence of a single-node failure on system-level losses given different dependency assumptions

Source: Hochrainer-Stigler et al. (2018)
Modularization to manage risk

<table>
<thead>
<tr>
<th>Network</th>
<th>Selected copula parameters</th>
<th>System level losses</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Network" /></td>
<td>( \rho = 0 )</td>
<td>( \text{VaR}_{0.95} = 90 )</td>
</tr>
<tr>
<td><img src="image2" alt="Network" /></td>
<td>( \rho = 0.8 )</td>
<td>( \text{VaR}_{0.95} = 129 )</td>
</tr>
<tr>
<td><img src="image3" alt="Network" /></td>
<td>( \rho = 0.33; \rho = 0; \rho = 0.8 )</td>
<td>( \text{VaR}_{0.95} = 101 )</td>
</tr>
<tr>
<td><img src="image4" alt="Network" /></td>
<td>( \rho = 0.33; \rho = 0.67; \rho = 0.8 )</td>
<td>( \text{VaR}_{0.95} = 103 )</td>
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</tbody>
</table>

Value of risk of total losses based on different clustering/schemes.

Source: Hochrainer-Stigler et al. (2018)
Dependency of risks highly important for risk management of extremes.

Increase in risk to financial instruments

EUSF under high risk of depletion due to large scale flood events. Would have also effects on lower levels, e.g. country and household.

Source: Jongman, Hochrainer et al. (2014), Hochrainer-Stigler et al. 2017
Direct flood risk in Austria

Risk information without copula approach

With the disentangled risk information available, a loss-scenario generator was built:
- Importance sampling algorithm
- Monte Carlo simulation

Risk information with copula approach

Hochrainer-Stigler et al. (2016)
From direct to indirect risk: ABM

Source: Poledna et al. (2018)
ABM results

Cumulative changes in GDP growth w.r.t. the BAU scenario as a function of initial damage as % of GDP. Results are shown for three different years after the disaster: 2014, 2015 and 2016.

Source: Poledna et al. (2018)
A risk-layering structure gives enough flexibility to be incorporated for each risk bearer separately and also for joint or interdependent risks.

Source: Mechler et al. (2018)
Summary

- Copula Model for nonlinear dependencies including critical infrastructure
- Can be used as a resilience indicator
- Risk-based approach to incorporate individual and systemic risk resilience indicators
- Integrated approach for different scales possible with this concept
- Risk-Layering for critical infrastructure
End of Presentation
Discussion