Insurance Data Science

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University of London
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Vine Copulas for Systemic Cyber Risk Modelling

What makes modelling cyber risk accumulation so challenging?

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Cyber Insurance Landscape – An Overview

Cybersecurity Stakeholders are Vulnerable, Insurance Firms are Exposed

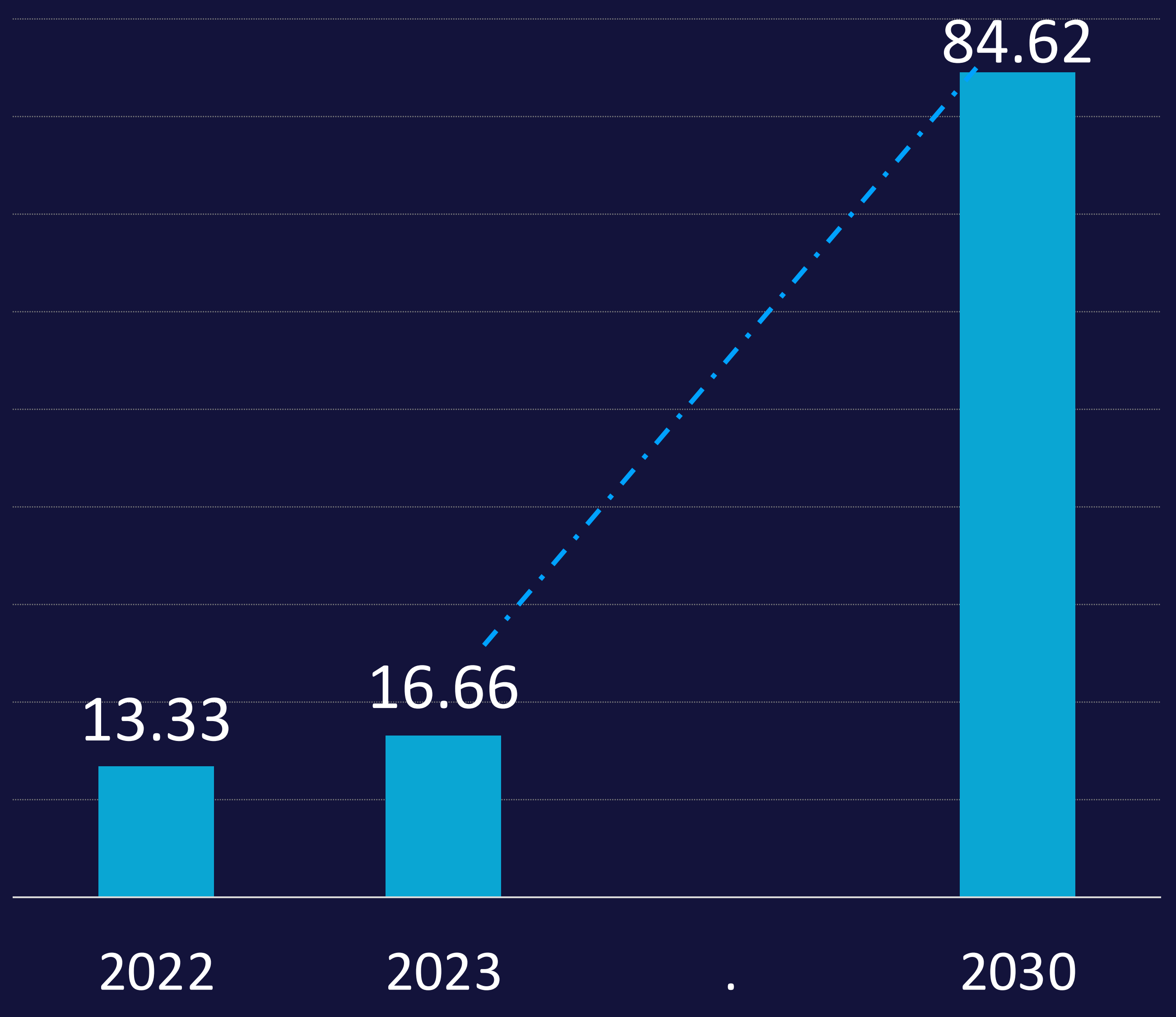
Global Demand

$84B

in 2030

25% per annum projected compound annual growth rate through 2028

Global Cyber Insurance Market Size
Billions USD



Cyber Damages

3 trillion a decade ago
$6 trillion in 2021

$10.5T

by 2025

Rate Changes & Capacity Crunch

2014 – 2023

Driven by ransomware, deteriorating loss ratios, uncertainty about risk exposure, uncertainty about the quality of underlying risk

DeRISK: Combine data and modelling solutions to enable risk transfer

For a
SINGLE
facility

2nd Generation Cyber Risk Quantification & Management SaaS Platform

The only **evidence-based data** and self-adaptive cyber risk quantification model for **industrial** environments

Probabilistic modelling of how a cyber-attack can spread and impact an organization, using a realistic representation of its OT network, along with real time inside-out and outside-in data

Single Facility Cyber Risk

Inside/Out data contextualized with underlying industrial process
Cyber Inside: Valuable insights, but also highly confidential. Valuable to attackers too!
Symmetry of knowledge: the same data and the same model across the risk transfer chain!

More than just a model

PORTFOLIO ACCUMULATION Modelling System (PAMS)

Exposure & Co-exposure - EXP -

What causes accumulation of losses?

Powered by OUTSIDE-IN & INSIDE-OUT Data

UNIT RISK Modeling System (URMS)

Number of Attempts - NoA -

How many attacks in a year?

Powered by OUTSIDE-IN Data

Attack Path Simulator - APA -

How can an incident propagate and cause a loss event?

Powered by OUTSIDE-IN & INSIDE-OUT Data

Loss Event Impact - LEI -

What is the financial impact ($)?

Powered by BUSINESS-RISK-LOSS Data

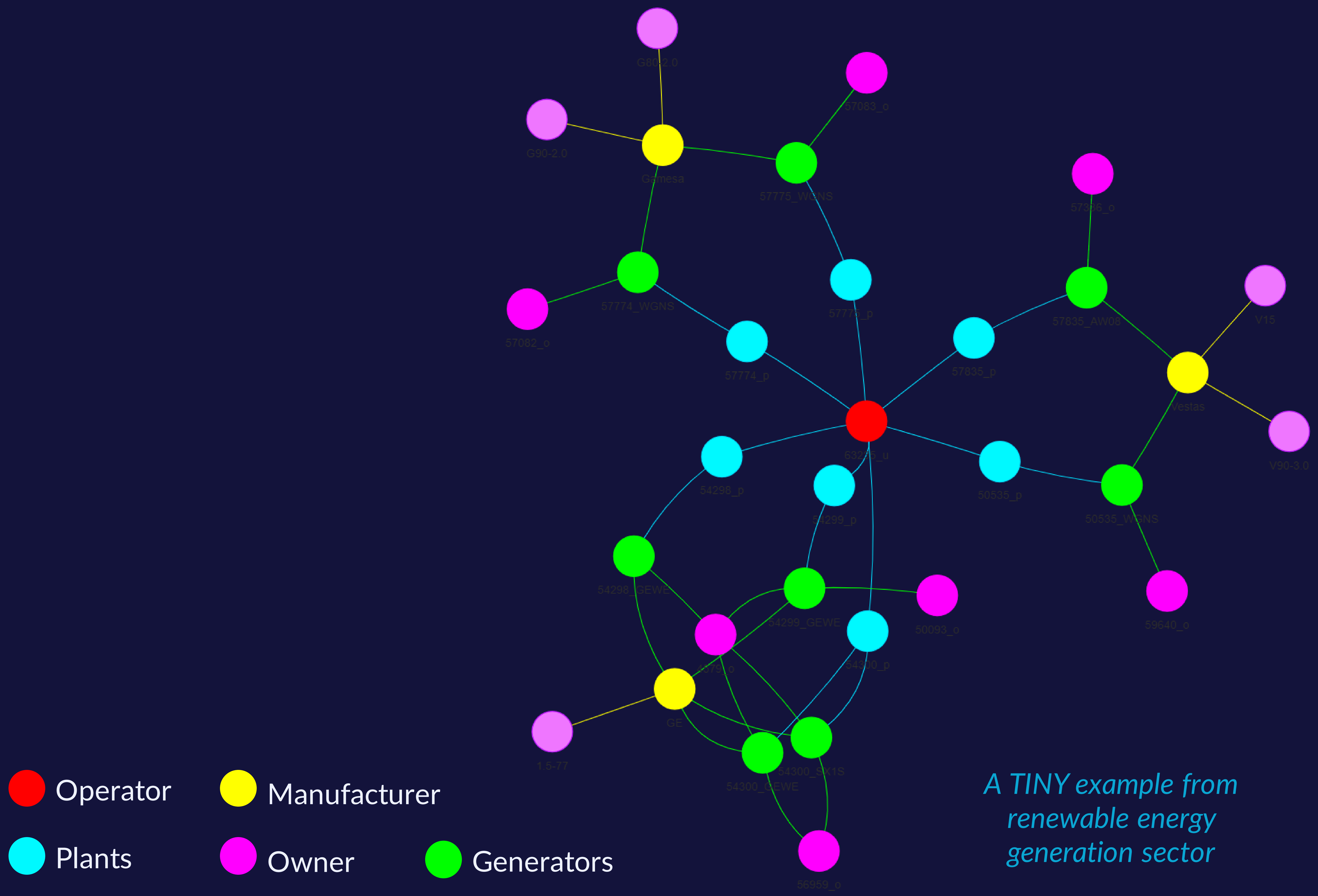
Risk Mitigation - MRS -

How to Mitigate?

Powered by BUSINESS-RISK-LOSS Data

Cyber Risk Accumulation

Reality is always more complicated

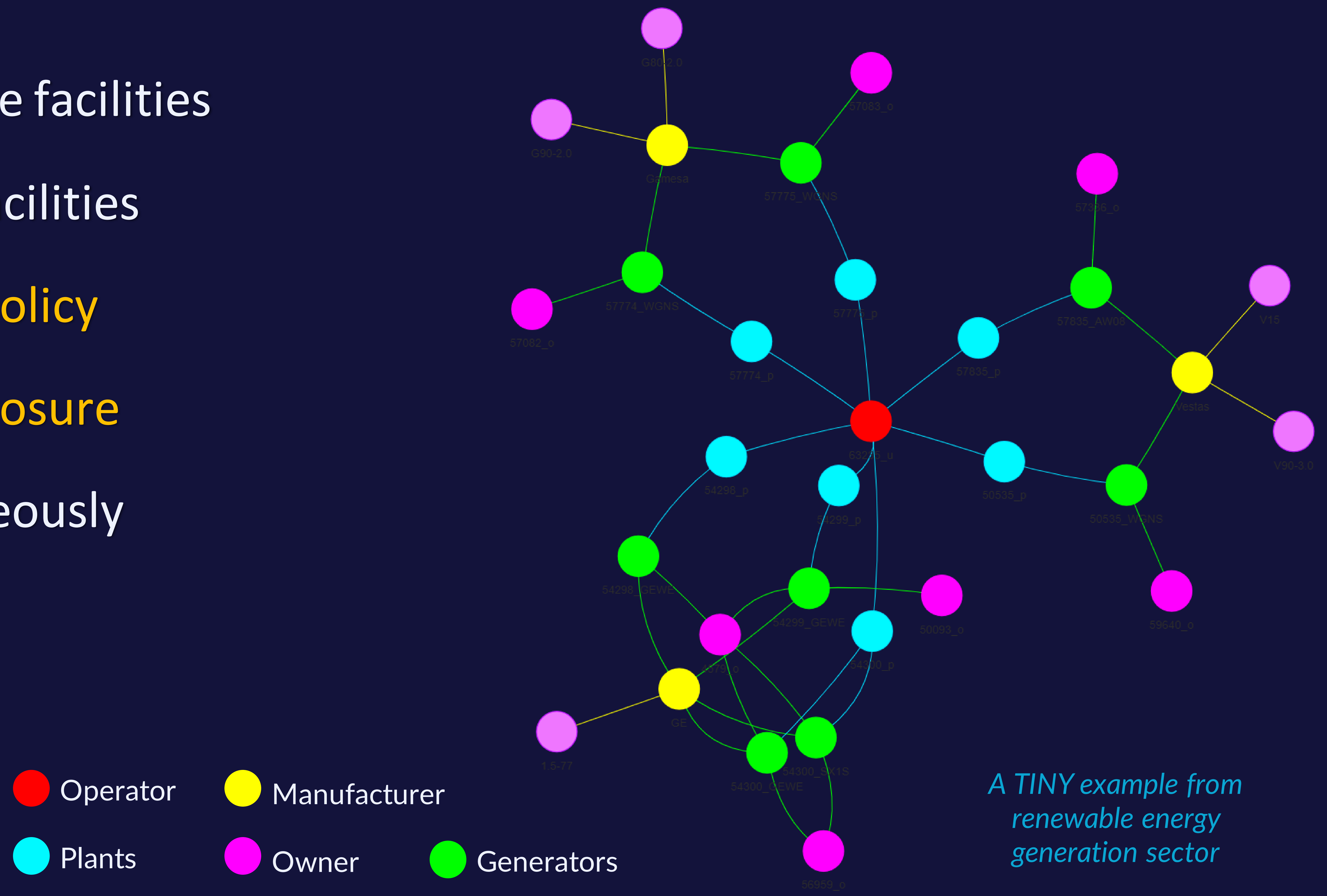


A TINY example from renewable energy generation sector

Cyber Risk Accumulation

Reality is always more complicated

- Risk owners operate across multiple facilities
- Insurance policies cover multiple facilities
- Accumulations start with a single policy
- The challenge is to describe co-exposure
- Solving large loss and cat simultaneously



A TINY example from renewable energy generation sector

Systemic Cyber Risk: More Challenging

SYSTEMIC RISK

A single event
triggering widespread failures
across multiple organizations or sectors

Path of hurricane Andrew, Aug 1992, colours represent wind speeds

What is the cyber equivalent of nat-cat modelling approaches?

Systemic Cyber Risk: More Challenging

SYSTEMIC RISK

A single event
triggering widespread failures
across multiple organizations or sectors

How do these events affect **confidence** in risk modelling?

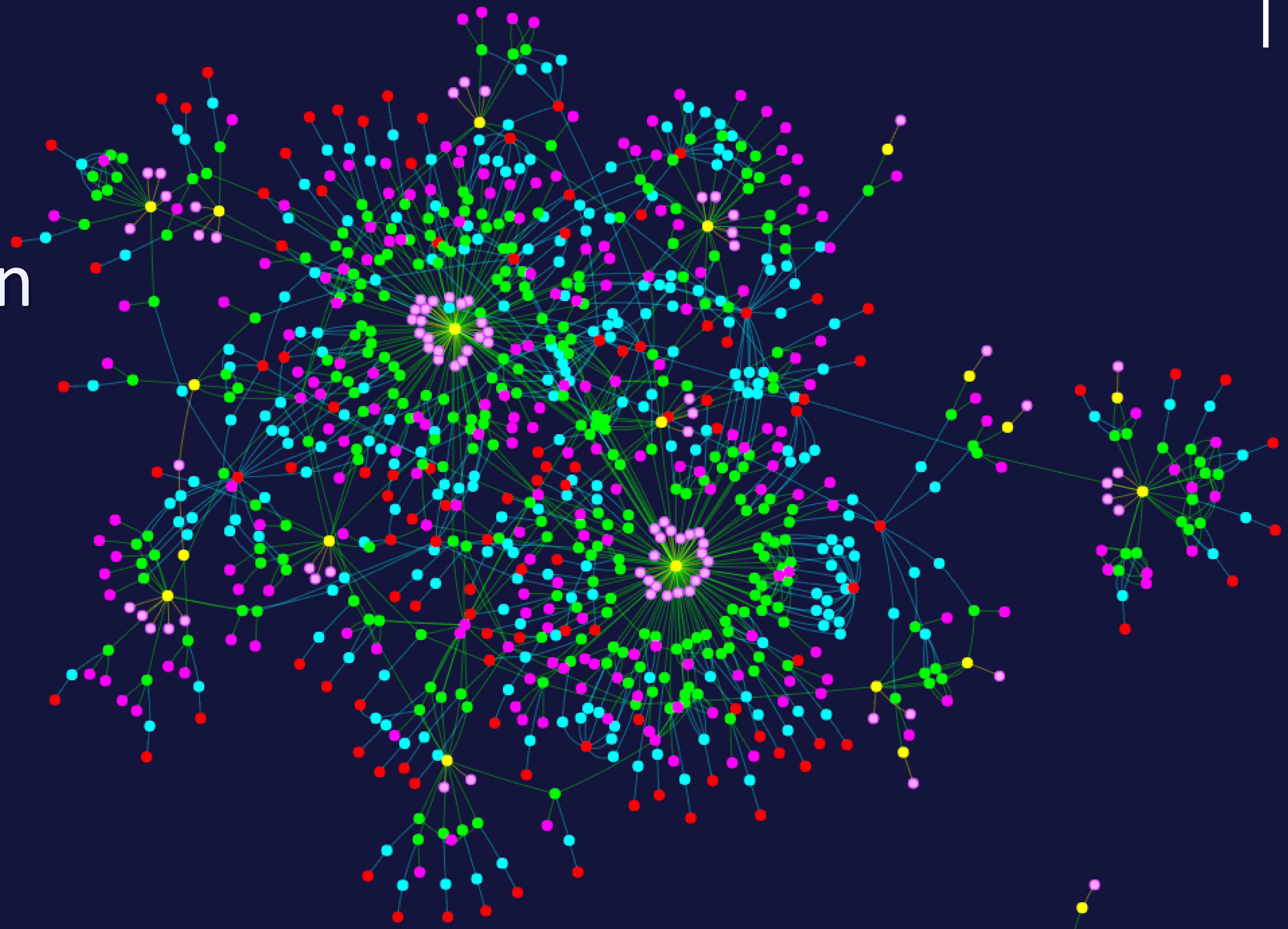
What are the **consequences** for rates, available insurance capacity & coverage?

More than a model: **dependencies**, dynamics, threat actors, threat landscape, scarcity of data

Systemic Cyber Risk: Complex Dependencies

Joint exposure dependency in high dimensions

Heterogeneous dynamic data, outside-in and inside-out



Exposure to …

The dynamic nature of cyber

Threat Landscape

- Vulnerabilities disclosure
- Actors' capabilities
- Geopolitical motivations
- Exploits in the wild

Technology Landscape

- IT/OT convergence
- Connectivity
- Increased automation
- Digitization and dependency

Different sources of dynamism have different effects
Both factors change the dynamics of events
Impact on losses needs to be evaluated
Forecasting the loss (not the event)
Event (Cyber Incident) based modelling

Systemic Cyber Risk Modelling

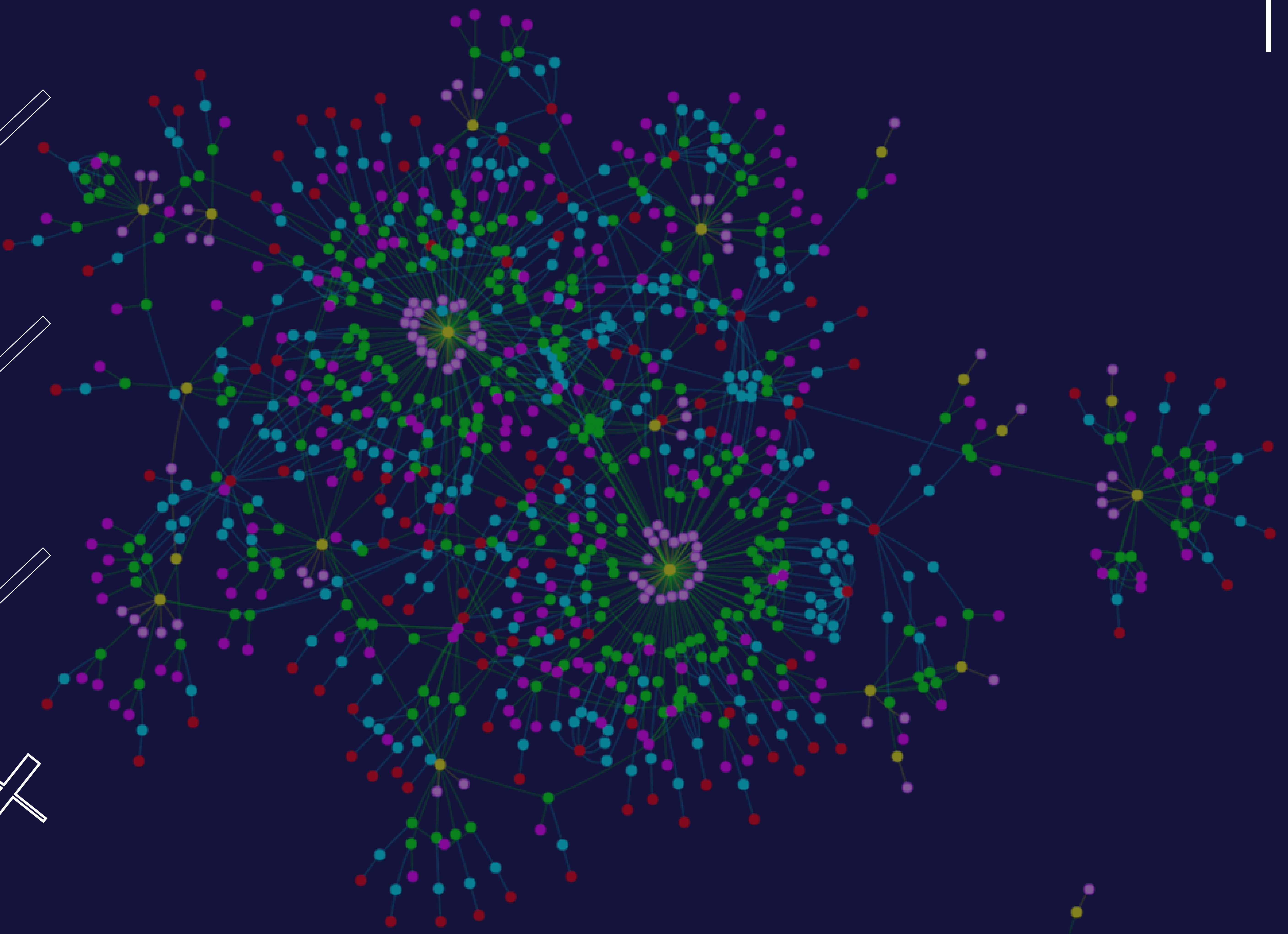
What kind of models are needed?

Asymmetric dependency and tail risk ✓

Capacity to incorporate specific knowledge about the portfolio cyber risk structure ✓

Capacity to handle high-dimensional joint distributions for large portfolio modelling ✓

Limitations of 'propagation simulation' models ✗



Definition: Bivariate Copula

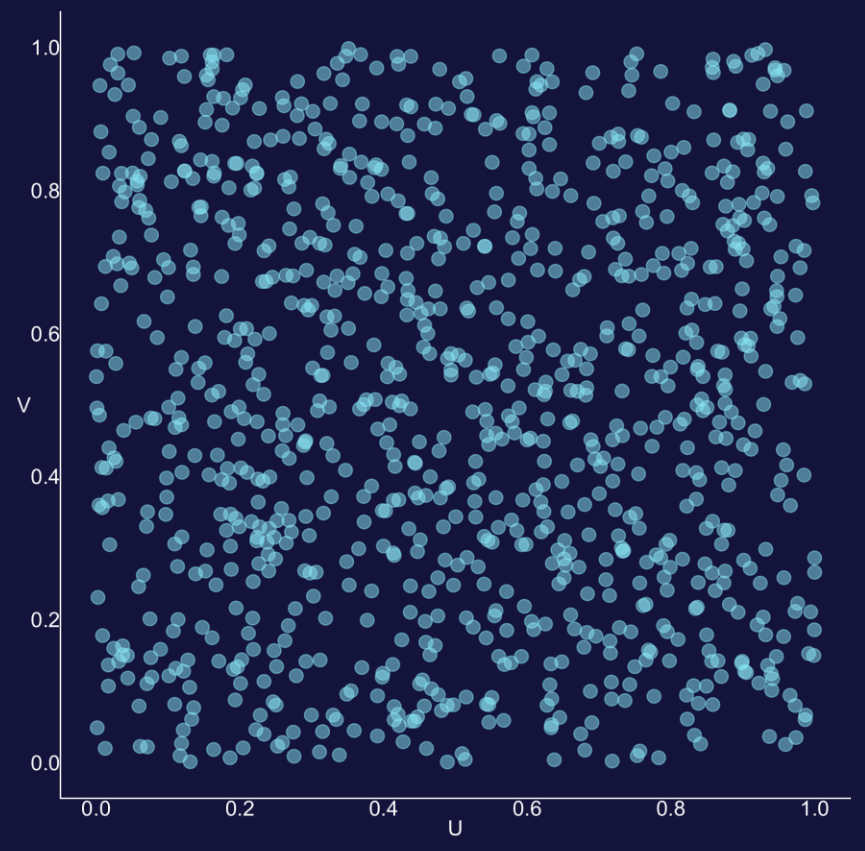
n-variate copula:

$$
\begin{aligned}
C : [0,1]^n &\longrightarrow [0,1] \\
C(u_1, \ldots, u_n) &= P(U_1 \leq u_1, \ldots, U_n \leq u_n)
\end{aligned}
$$

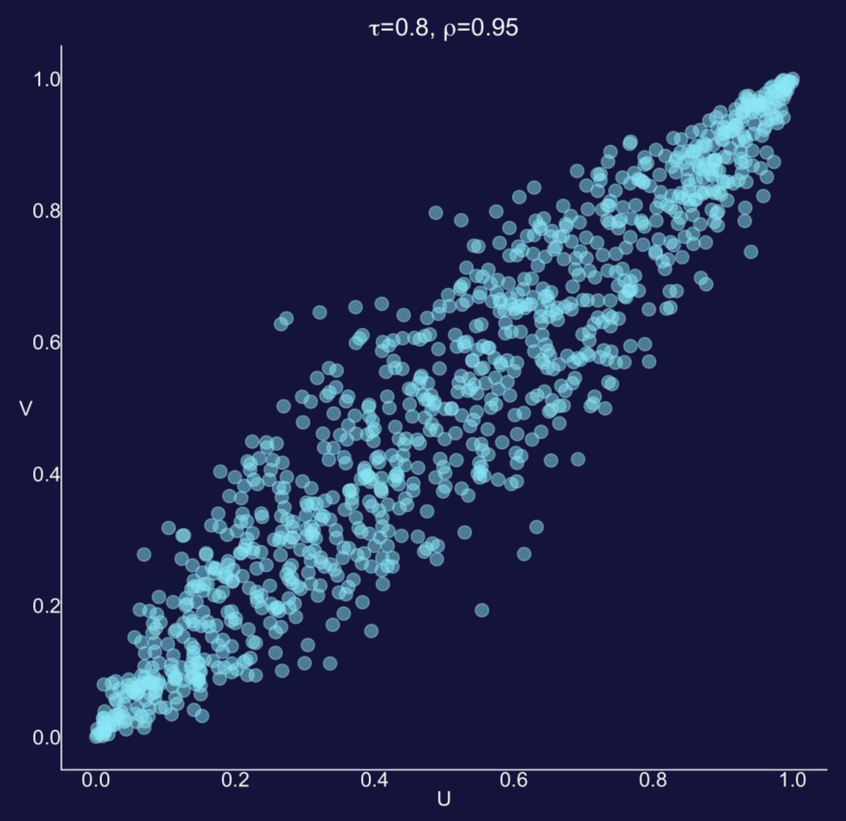
Sklar's Theorem:

$$
f(x_1, \ldots, x_n) = \underbrace{c\left(F_1(x_1), \ldots, F_n(x_n)\right)}_{\text{Copula}} \cdot \underbrace{\prod_{i=1}^{n} f(X_i)}_{\text{Margins}}
$$

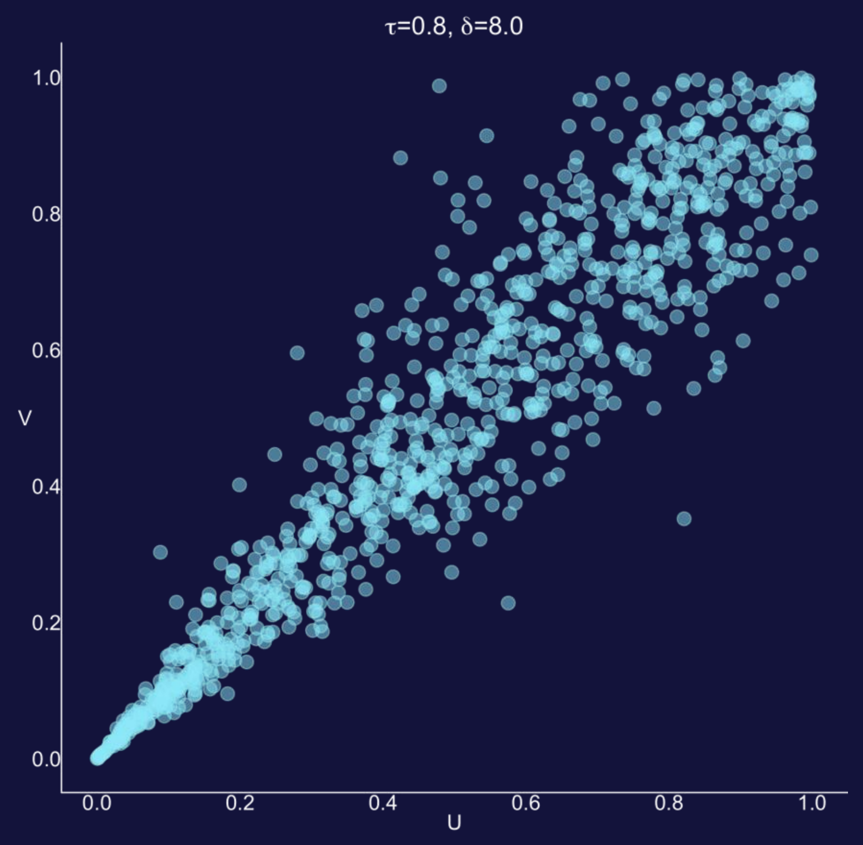
c is unique for continuous F_i.



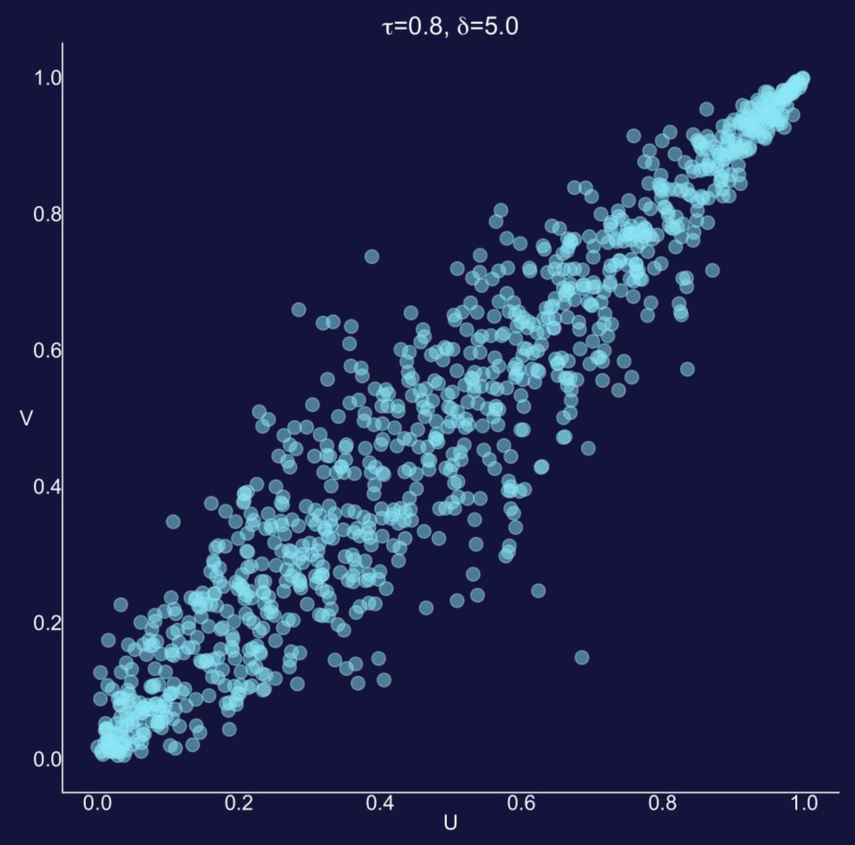
Product



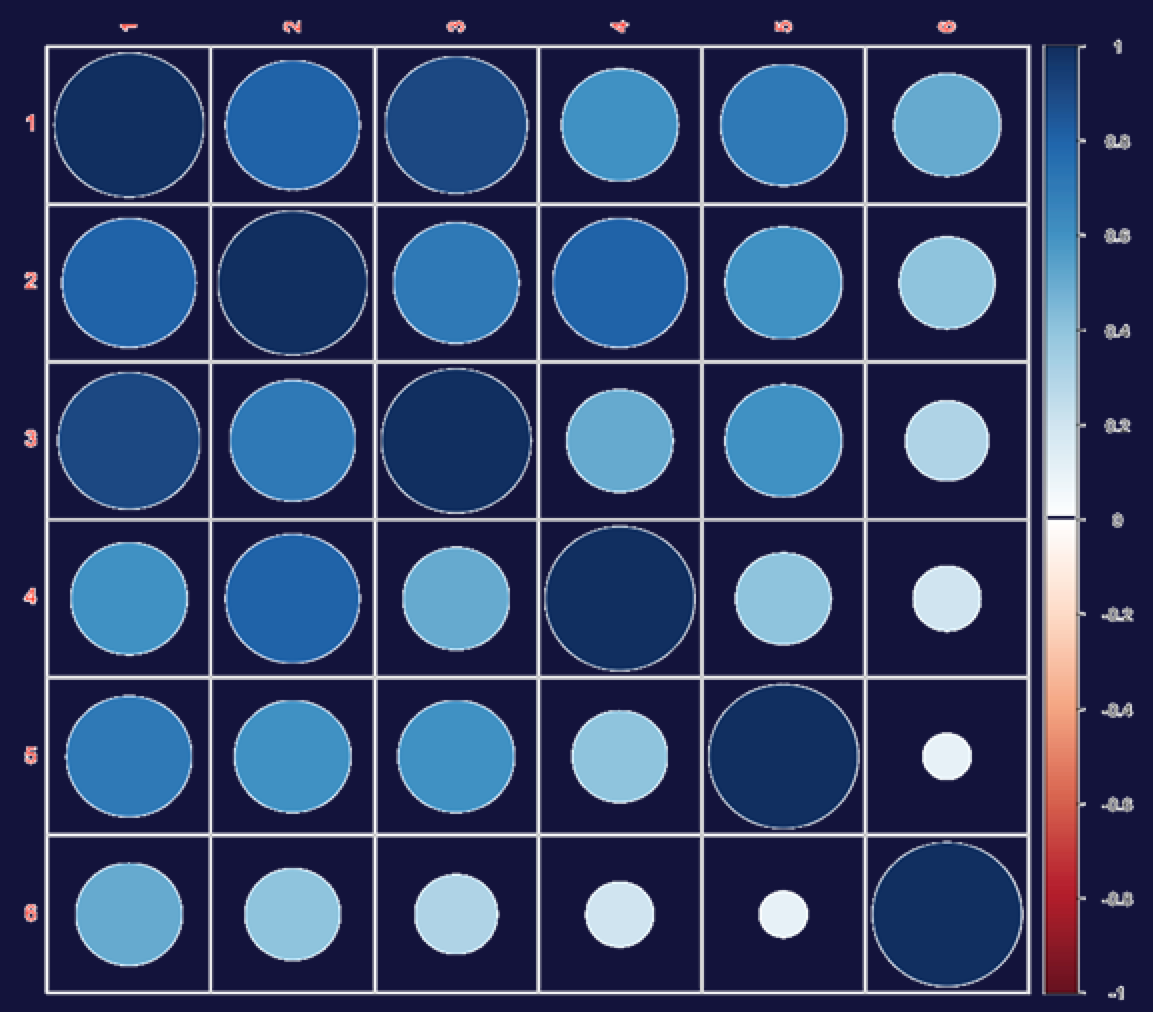
Gaussian



Clayton



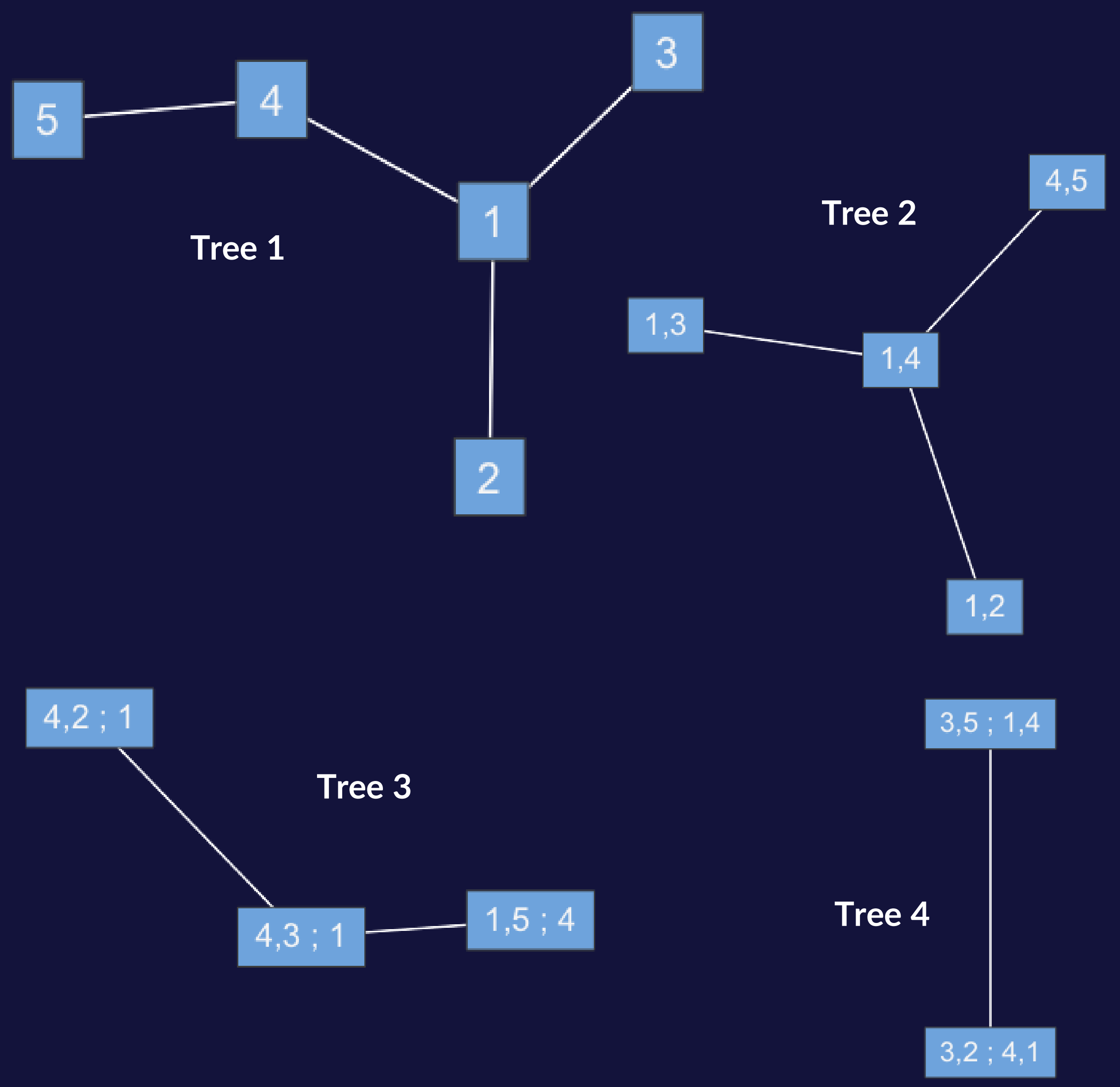
Gumbel



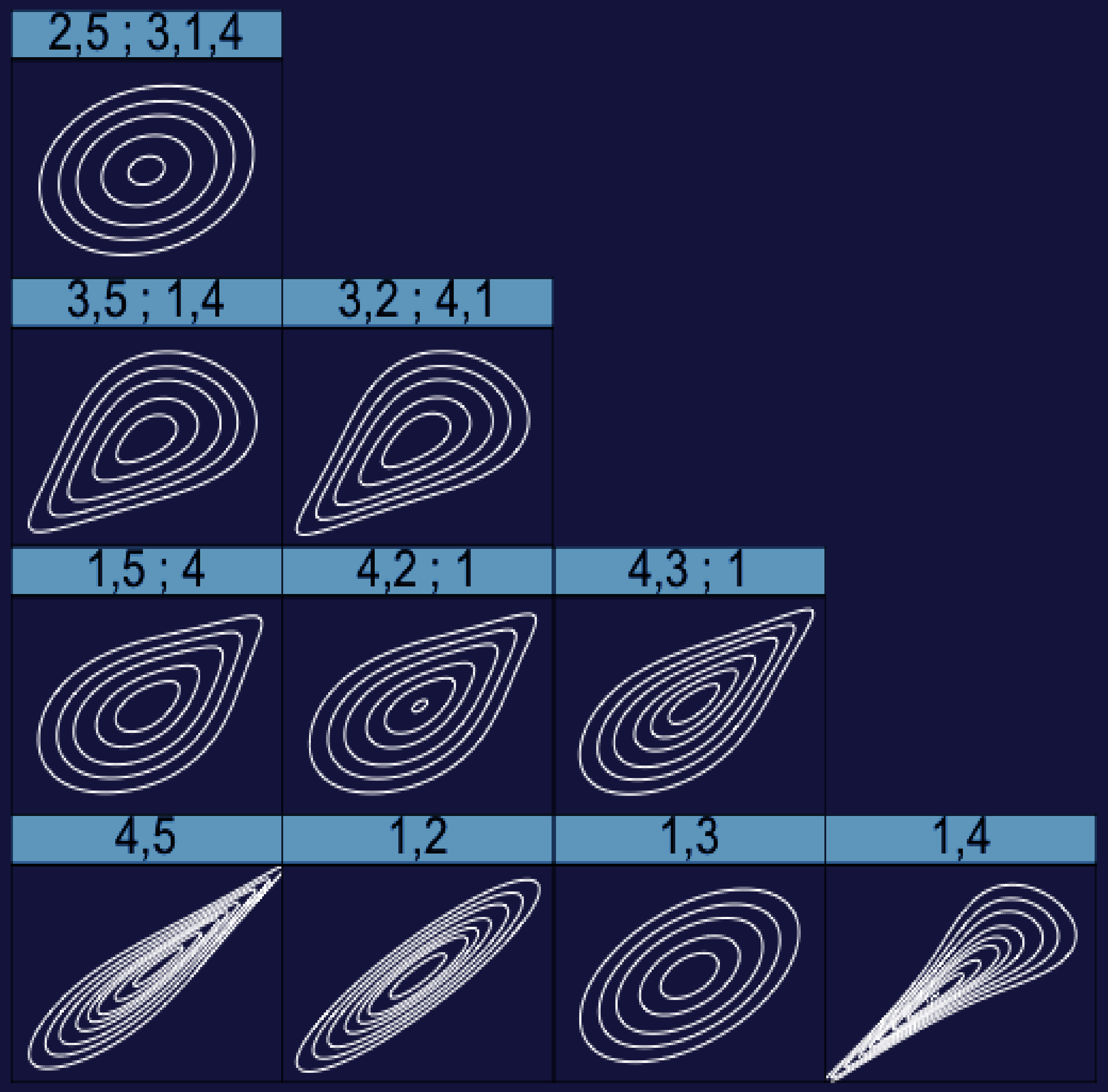
R-Vine Copulas: Factoring the joint distribution

R-vine Density: Product of (Conditional) Bivariate Copulas and Univariate Margins

$$f_{1,\dots,n}\left(x_1,\dots,x_n\right) = \underbrace{\prod_{T_j\in G}\prod_{e\in E^j} \underbrace{c_{i,k|\boldsymbol{S}}\left(F\left(x_i\left|\boldsymbol{x_S}\right.\right),F\left(x_k\left|\boldsymbol{x_S}\right.\right)\left|\boldsymbol{x_S}\right.\right)}_{\text{Pair-copula}}}_{\text{R-vine copula}} \cdot \underbrace{\prod_{i=1}^{n} f_i\left(X_i\right)}_{\text{Margins}}$$



Example of R-vine with 5 variables



Copulas associated with each edge of the left R-vine

Example of R-vine with 4 variables

$$C_{1,2}\ .\text{x}\ C_{2,3}\ \text{x}\ C_{2,4}$$

$$\text{x}\ C_{1,3|2}\ \text{x}\ .C_{1,4|2}$$

$$\text{x}\ C_{1,4|2,3}$$

R-vine copula

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Modelling Co-exposure: Large and Complex Portfolios

Simulating the vine & Risk Accumulation

Define the portfolio & build the dataset for facilities characteristics

Identify relationships between facilities

Simulate the R-vine and compute the joint distribution

Obtain NoA (Arrival) Univariate Distributions

Build the R-vine model

UNIT RISK Modeling System (URMS)

Number of Attempts - NoA -

How many attacks?

Powered by OUTSIDE-IN Data

Attack Path Simulator - APA -

How can an incident propagate and cause a loss event?

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Loss Event Impact - LEI -

What is the financial impact ($)?

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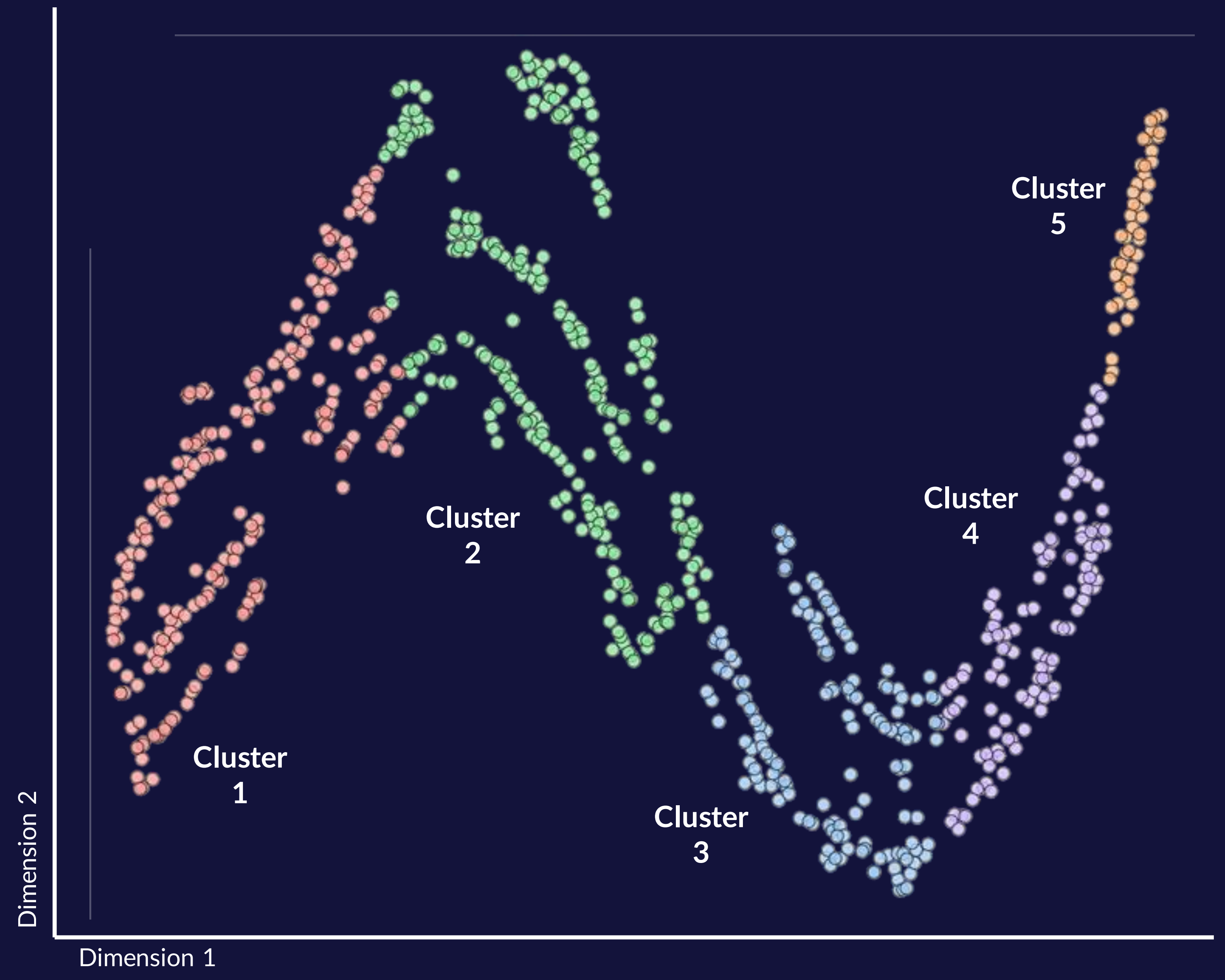
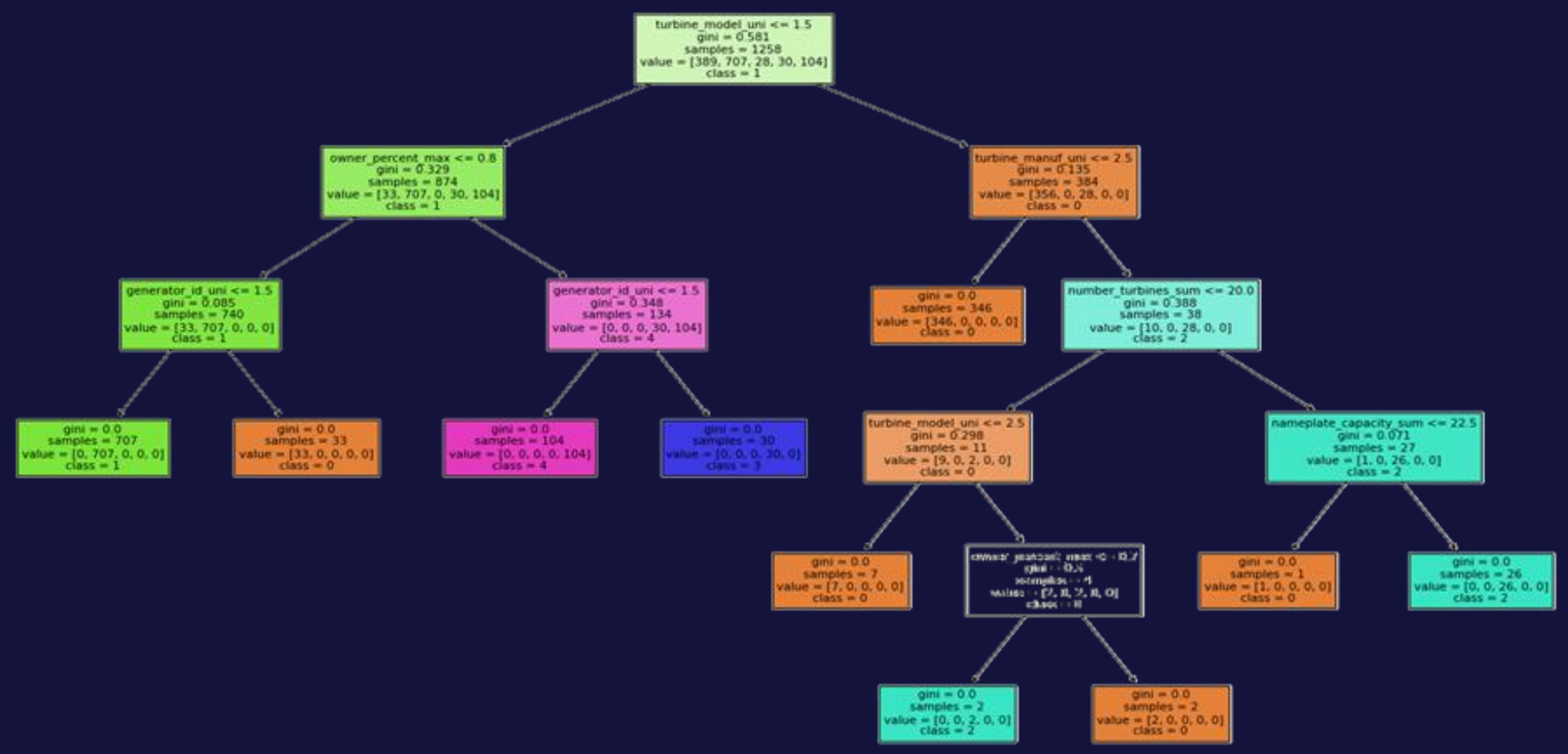
Risk Accumulation for 680 Facilities

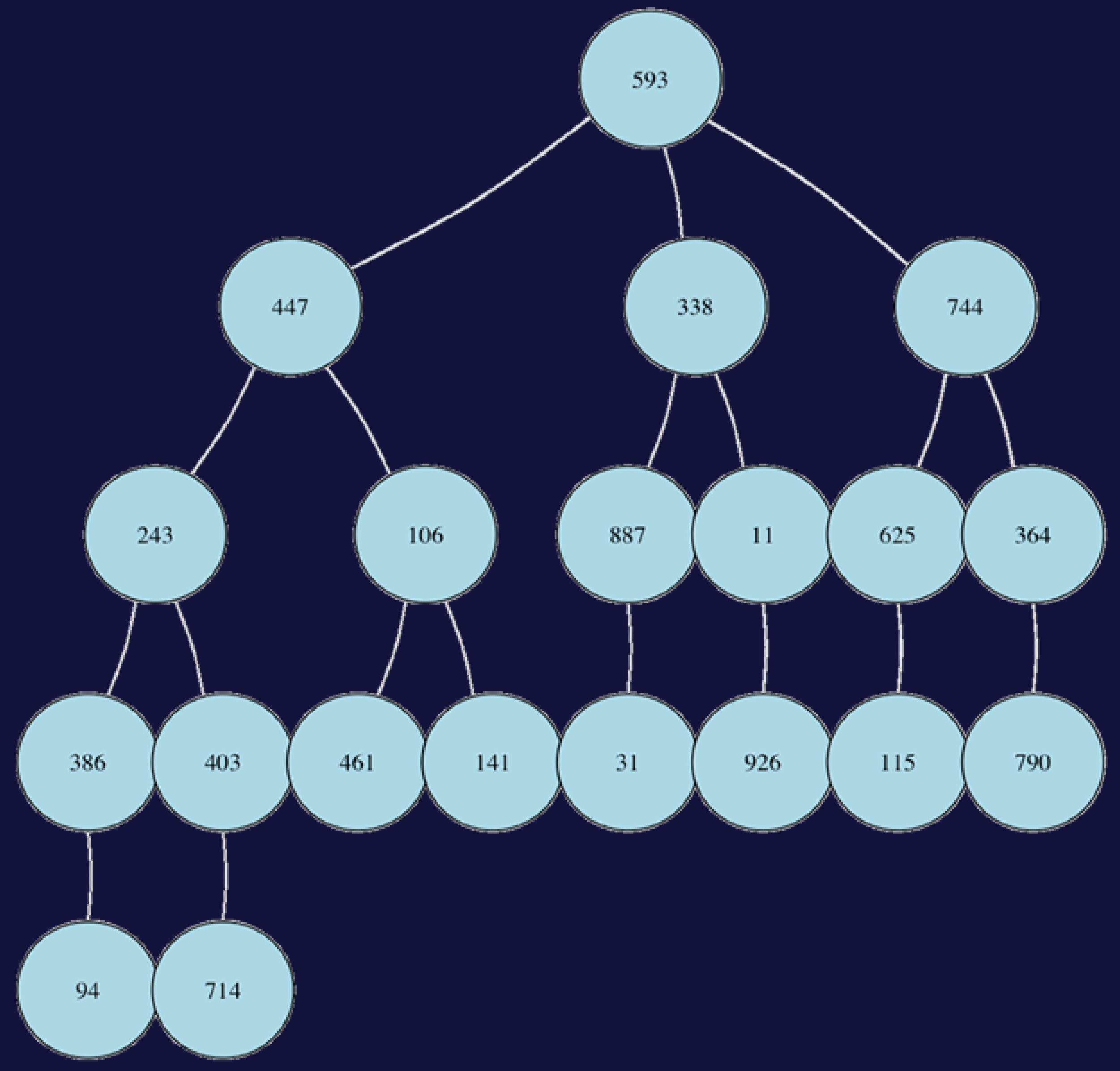
An illustrative example



Clustering strategy



Decision tree generated from the clustering strategy



Sub-tree of the first tree of the R-vine

If one facility experiences an attack attempt, it is more likely that this attempt will happen at facilities that are similar to it, compared to facilities bearing fewer similarities.

From facility relationships, build the first tree of the R-vine, where nodes represent each facility's NoA

- Prioritize edges of related facilities in tree construction
- Assign copulas and parameters to these edges
- For unrelated facilities, assign Product copulas

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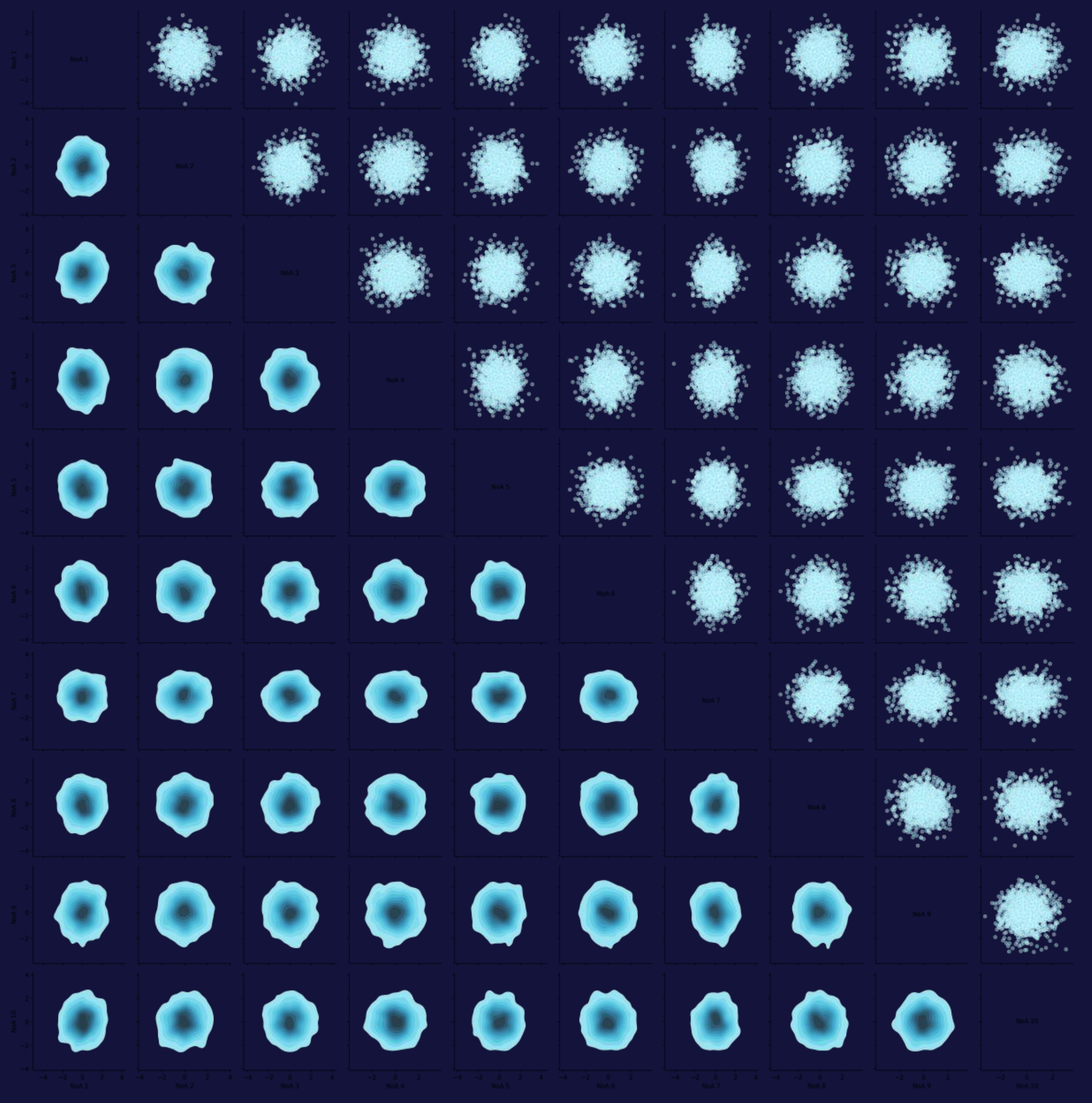
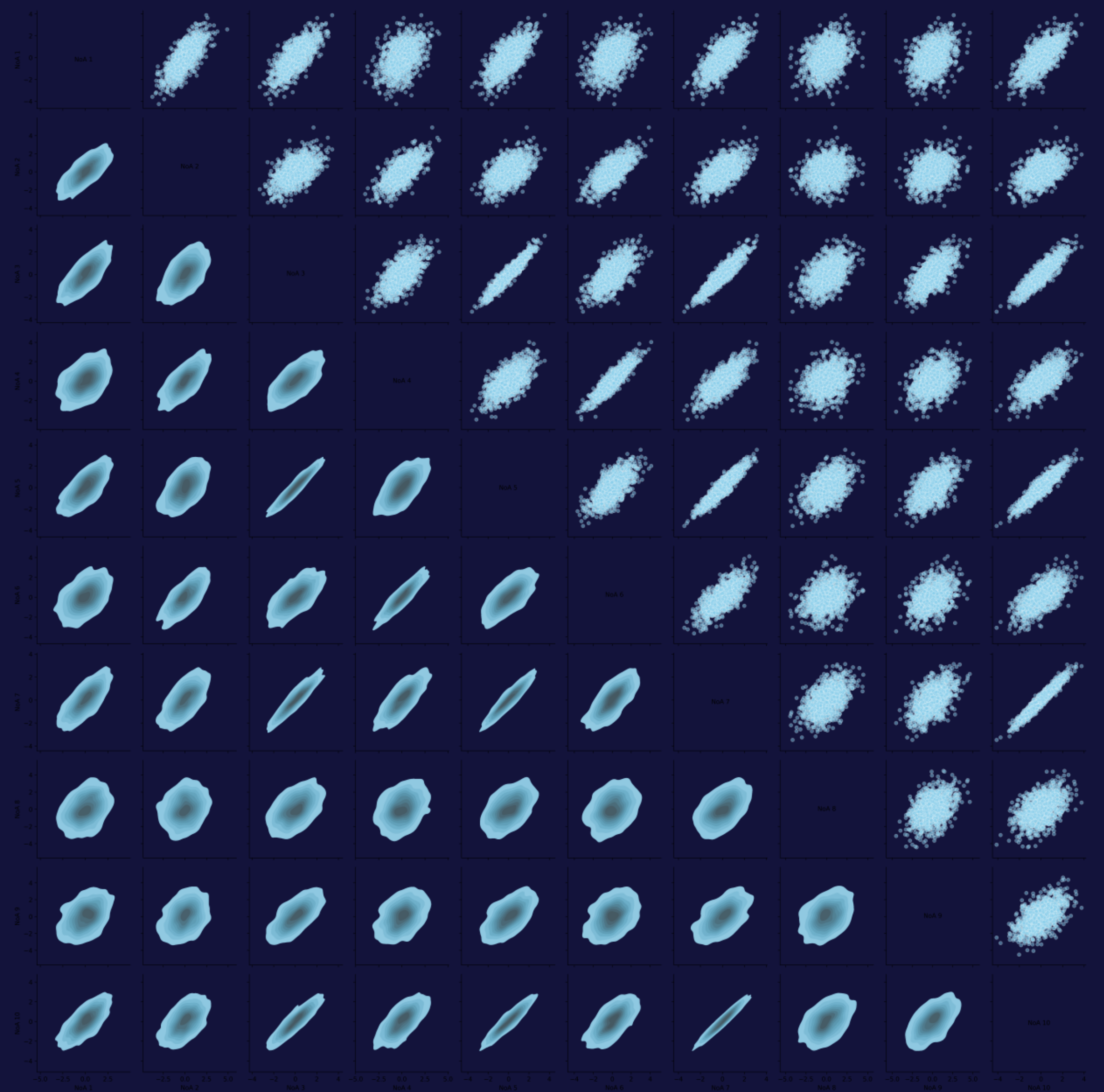
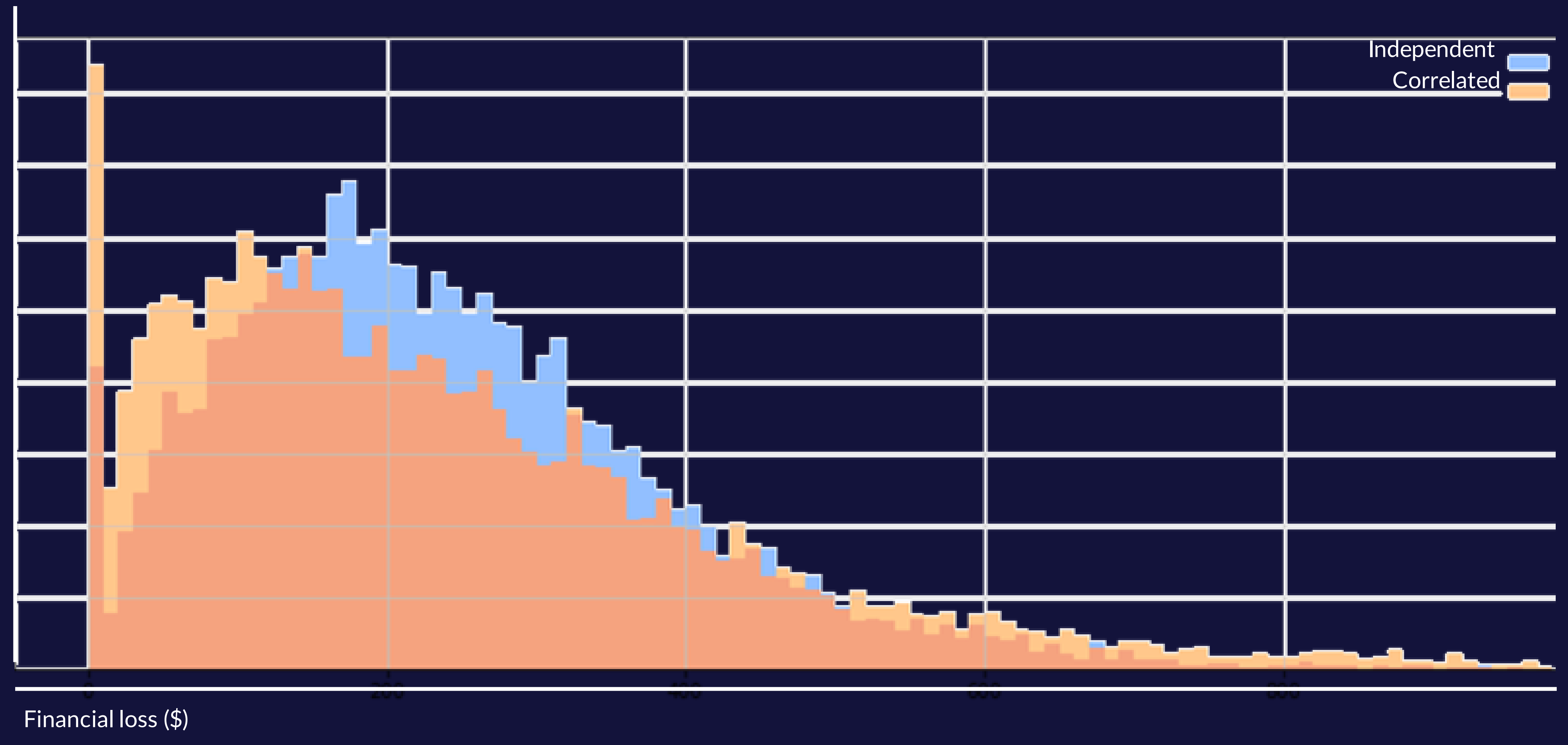
Correlated Exposure and Loss



Independent NoA sample



R-vine NoA sample



Loss distribution in both scenarios

- This model, informed by both facility attributes and their correlations, enables more robust risk assessments, aiding informed decision-making in risk management.

Takeaways and Upcoming Milestones

The Challenge

- Dynamic threat landscape
- Complex dependencies
- Scarcity of data
- Reliable models
- 1st generation failed

The Answer

- Filling the gap in systemic risk modelling

  Systemic arrival events are captured by distributions which high extreme tail dependence in arrival probability – if it hits one entity, it will 'almost certainly' hit many

- A novelty application of vine-copulas

  Cyber risk accumulation in large and complex portfolios

- R-Vine Copula: a promising approach for systemic cyber risk

  Best use of available data

  Less sensitivity to lack of data

  Suitable for leveraging domain knowledge

Thank You!

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Insurance Data Science Conference

Insurance
Data
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Bayes Business School,
City, University of London

15th-16th June



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