INSURANCE AND ACTUARIAL ENGINEERING

Prime Re Solutions

Tariffing a Nuclear Cover

ASTIN Colloquium, São Paulo 2025

Agenda

Swissnuclear Szenarien

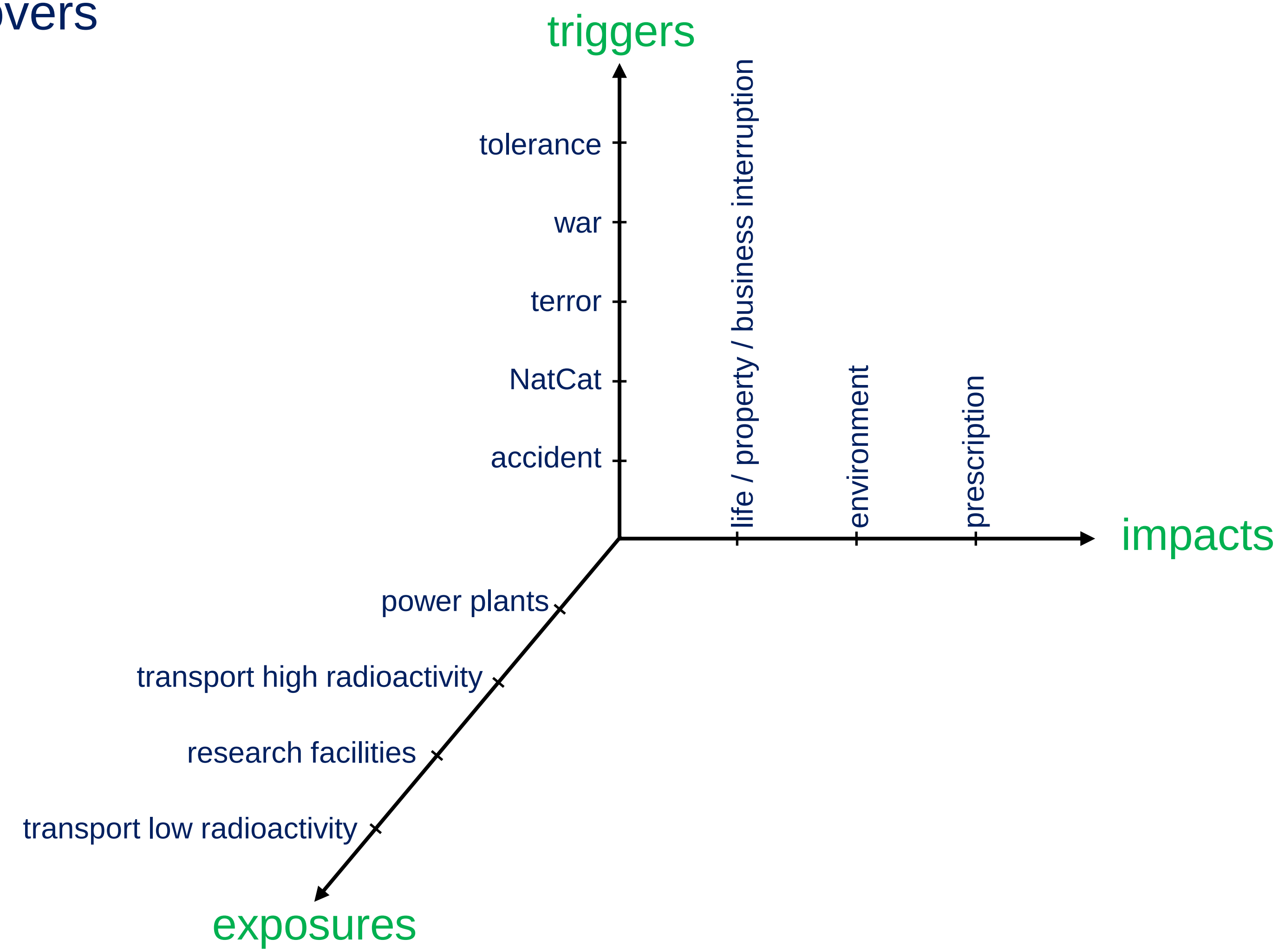
- Beschreibung des EVT-basierten Experten Models
- Unabhängige Validierung
- Zeitplan

The Swiss Nuclear Pool

- Legal foundations
  - Paris and Brussels Conventions on TPL in the field of nuclear energy
    - establish rules and compensation mechanisms in the event of nuclear accidents
    - ensure that affected parties can seek damages
- Signatories
  - all European countries with nuclear power plants
- Covers
  - 70 – 1’200 MEUR
  - Depend on intricate combinations of
    - 4 types of exposures
    - 5 triggers
    - 3 impacts

Exposures, triggers and impacts

- 3 x 4 x 5 = 60 covers



The Swiss Nuclear Pool

- Legal foundations
  - Paris and Brussels Conventions on TPL in the field of nuclear energy
    - establish rules and compensation mechanisms in the event of nuclear accidents
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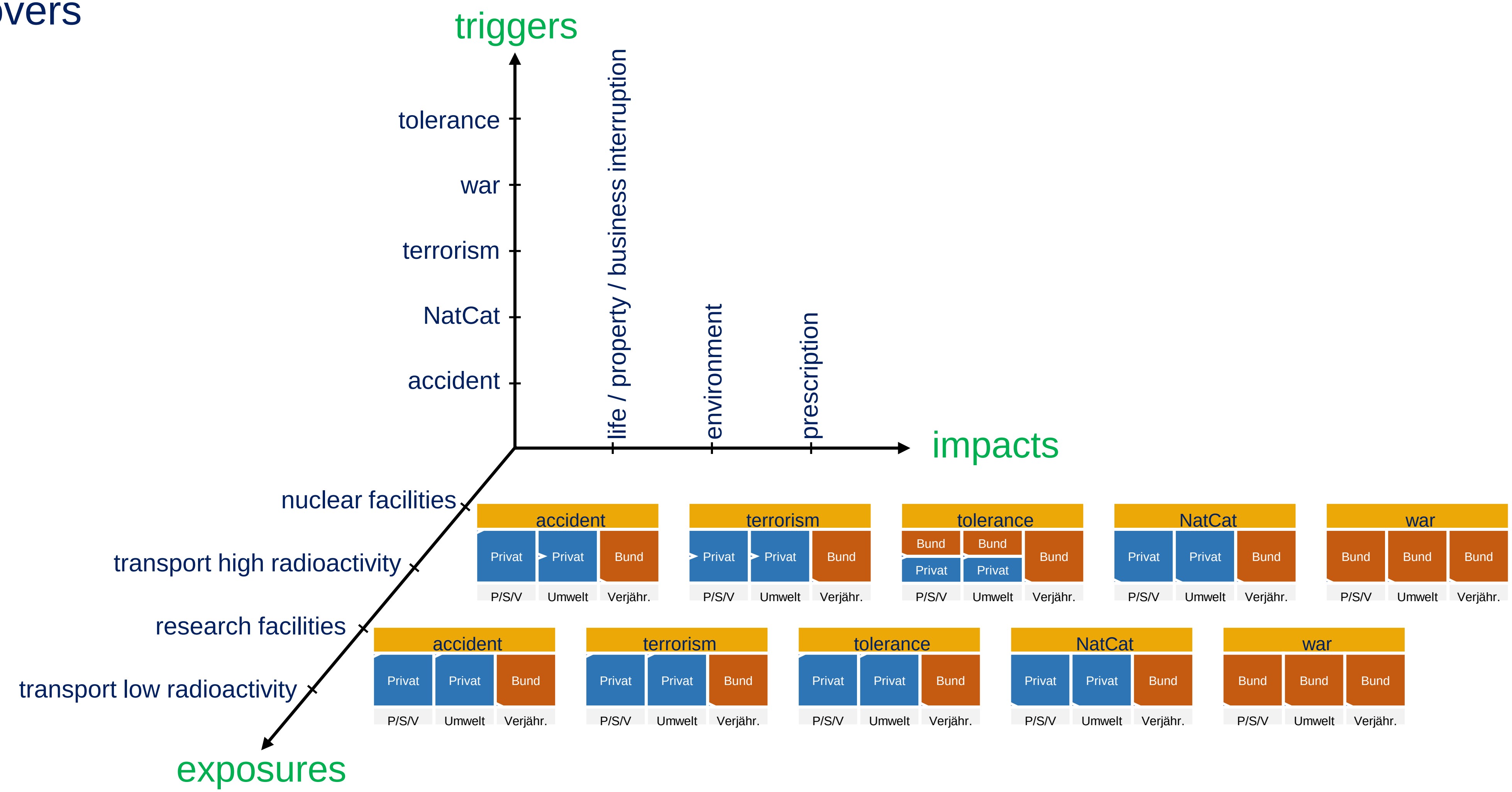
- Signatories
  - all European countries with nuclear power plants
- Covers
  - 70 – 1’200 MEUR
  - Depend on intricate combinations of
    - 4 types of exposures (where)
    - 5 triggers (how)
    - 3 impacts (what)
- Insurers of the Swiss nuclear exposures
  - Swiss Nuclear Pool – covers the basis (Zurich, Swiss Re, Helvetia, Allianz, SCOR, …)
  - Swiss Federation – covers what the Pool doesn’t

Exposures, triggers and impacts

- 3 x 4 x 5 = 60 covers



Exposures

- Nuclear facilities
  - Power plants
    - Beznau 1 (PWR)
    - Beznau 2 (PWR)
    - Gösgen (PWR)
    - Leibstadt (BWR)
  - 1 storage facility of burnt fuel rods
- Transport high radioactivity
  - Burnt fuel rods
- Research facilities
  - Paul Scherrer Institute
- Transport low radioactivity
  - Clothing, pipes, …

Tariffs

- Swiss Nuclear Pool
  - One premium per exposure
  - No details about allocation to triggers and impacts

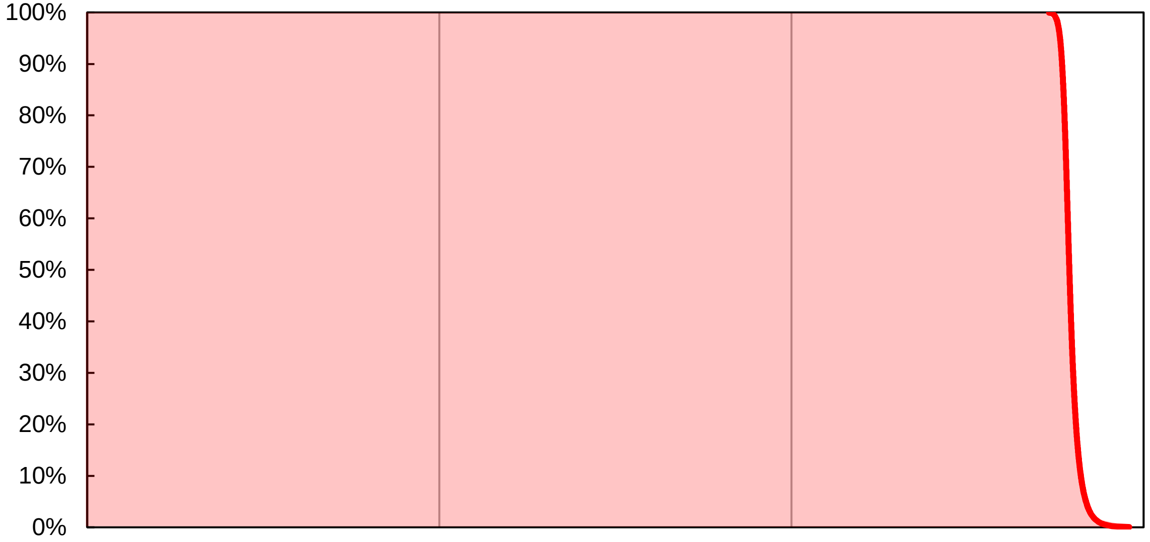
- Swiss Federation
  - Currently crude tariffs
    - Any loss = total loss

    $\Rightarrow$ frequency model
    - Calibration to implicit frequencies from Swiss Nuclear Pool premiums
  - Soon actuarial tariffs (facultative excess-of-loss reinsurance)
    - All losses pareto distributed

    $\Rightarrow$ EVT collective frequency-severity model
    - Calibration to scenarios provided by Swissnuclear

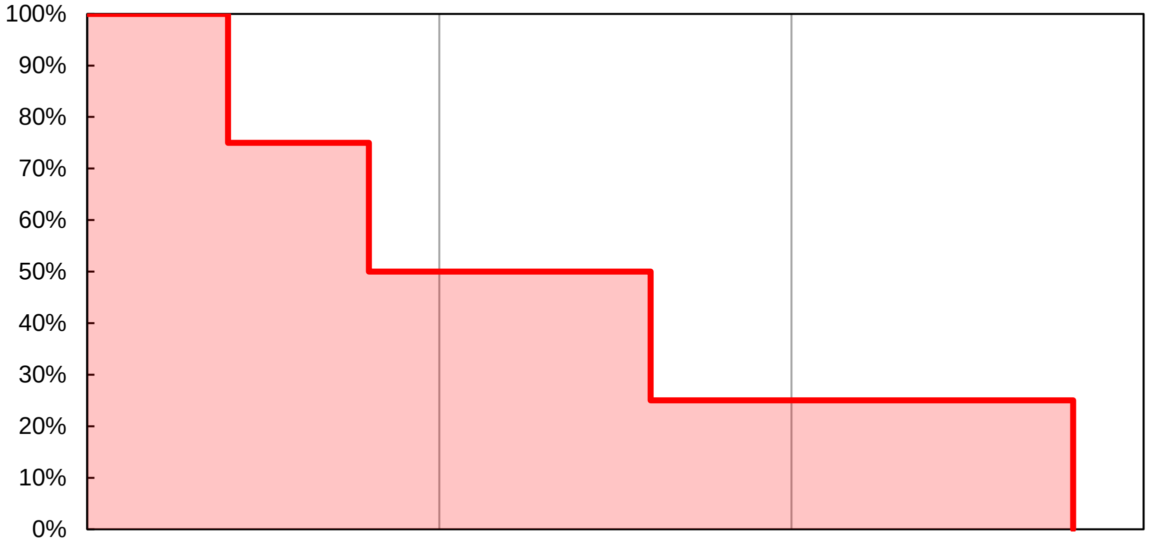
Severity model

- X = severity
  - Random variable
    - total loss distribution



Severity model

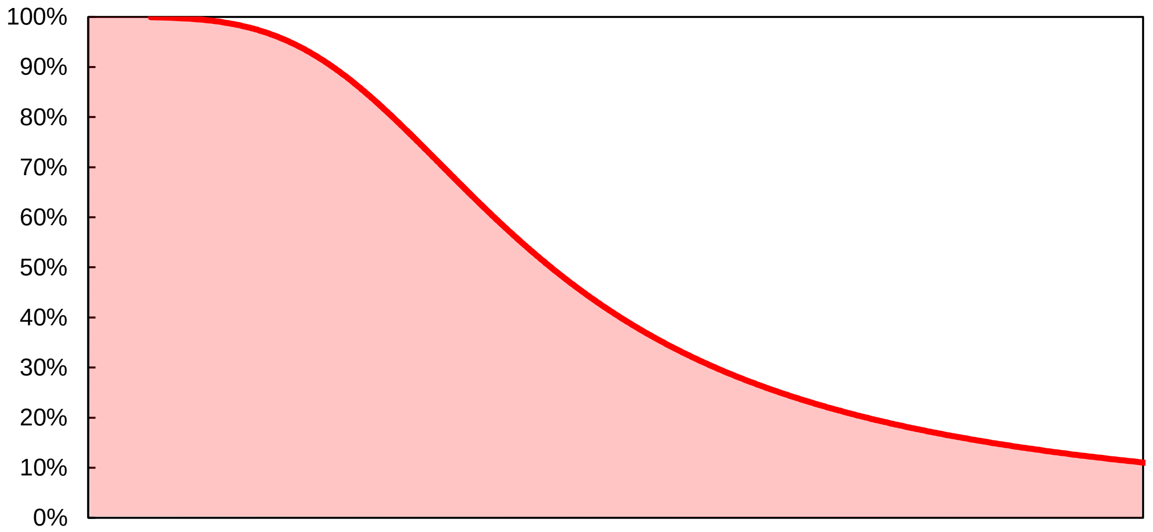
- X = severity
  - Random variable
    - ~~total loss distribution~~
    - Discrete distribution



Severity model

- X = severity
  - Random variable
    - ~~total loss distribution~~
    - ~~Discrete distribution~~
    - Pareto distribution

$$\mathbb{P}[X \le x] = 1 - \left(\frac{T}{T + x}\right)^{\alpha}$$



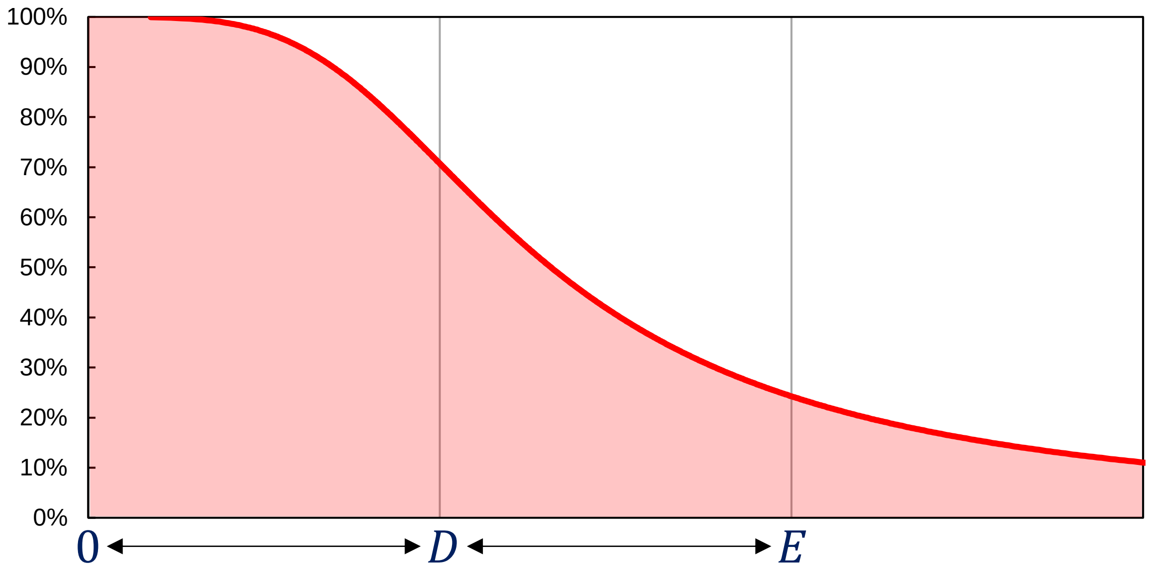
Insured loss

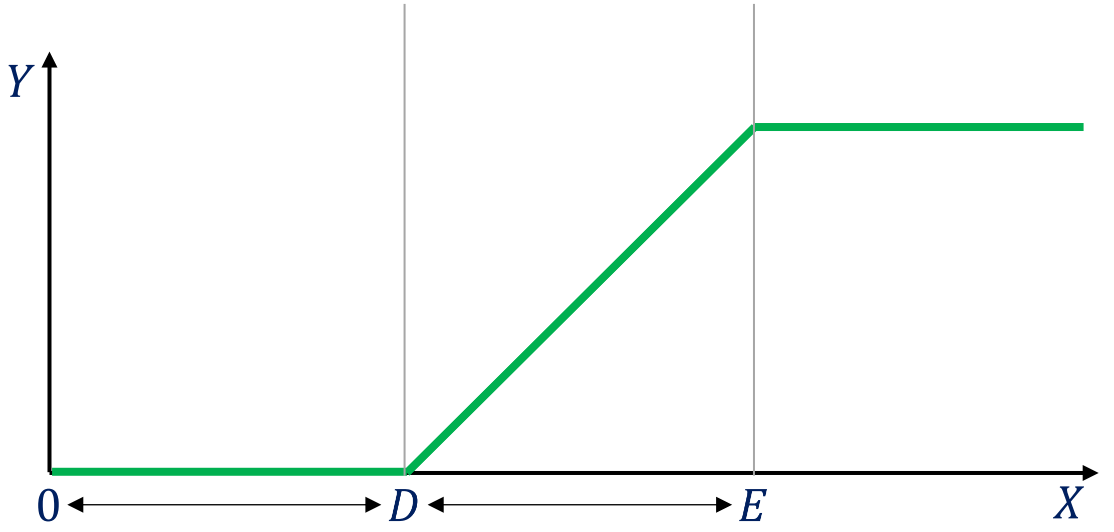
- X = severity
  - Random variable
    - ~~total loss distribution~~
    - ~~Discrete distribution~~
    - Pareto distribution

$$\mathbb{P}[X \leq x] = 1 - \left(\frac{T}{T+x}\right)^{\alpha}$$

- Y = insured loss with
  - Deductible D
  - Exhaustion E

$$Y = L_{D,E}(X) = \begin{cases} X \leq D: & 0 \\ D < X < E: & X - D \\ E \leq X: & E - D \end{cases}$$





Actuarial premium

- Aggregate annual insured loss

random variable

$$S = \sum_i^N Y = \sum_i^N L_{D,E}(X_i)$$

  - $X =$ severity — Pareto distributed: $\mathbb{P}[X \leq x] = 1 - \left(\frac{T}{T+x}\right)^\alpha$
  - $N =$ frequency — Poisson distributed: $\mathbb{P}[N = n] = \frac{\lambda^n e^{-\lambda}}{n!}$

- Premium $P =$ expected loss $+$ risk margin

$$= \mu[S] + \rho \cdot \sigma[S]$$

standard deviation

risk aversion $\sim$ 40%

average

Actuarial premium

- Aggregate annual insured loss

random variable

$$S = \sum_{i}^{N} Y = \sum_{i}^{N} L_{D,E}(X_i)$$

  - X = severity — Pareto distributed: $\mathbb{P}[X \leq x] = 1 - \left(\frac{T}{T+x}\right)^{\alpha}$
  - N = frequency — Poisson distributed: $\mathbb{P}[N = n] = \frac{\lambda^n e^{-\lambda}}{n!}$

- Premium P = expected loss + risk margin

$$= \mu[S] + \rho \cdot \sigma[S]$$

$$= \mu[N] \cdot \mu[Y] + \rho \cdot \sqrt{\mu[N] \cdot \mu[Y^2]}$$

analytic formula ☺

Actuarial premium

- $P = \lambda \cdot \frac{T^{\alpha}}{\alpha - 1} \cdot [(D+T)^{1-\alpha} - (E+T)^{1-\alpha}]$

$$+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^{\alpha}}{(\alpha-1)(\alpha-2)} \cdot [(D+T)^{2-\alpha} - (\alpha-1) \cdot (E+T)^{2-\alpha} + (\alpha-2) \cdot (D+T) \cdot (E+T)^{1-\alpha}]}$$

Actuarial premium

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$$+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^{\alpha}}{(\alpha-1)(\alpha-2)} \cdot [(D+T)^{2-\alpha} - (\alpha-1) \cdot (E+T)^{2-\alpha} + (\alpha-2) \cdot (D+T) \cdot (E+T)^{1-\alpha}]}$$

  - D = deductible
  - E = exhaustion

Actuarial premium

- $P = \lambda \cdot \frac{T^{\alpha}}{\alpha - 1} \cdot [(D+T)^{1-\alpha} - (E+T)^{1-\alpha}]$

$$+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^{\alpha}}{(\alpha-1)(\alpha-2)} \cdot [(D+T)^{2-\alpha} - (\alpha-1) \cdot (E+T)^{2-\alpha} + (\alpha-2) \cdot (D+T) \cdot (E+T)^{1-\alpha}]}$$

  - $D =$ deductible
  - $E =$ exhaustion
  - $\rho =$ risk aversion $\sim$ 40%

Actuarial premium

- $P = \lambda \cdot \frac{T^\alpha}{\alpha-1} \cdot [(D+T)^{1-\alpha} - (E+T)^{1-\alpha}]$

  $+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^\alpha}{(\alpha-1)(\alpha-2)} \cdot [(D+T)^{2-\alpha} - (\alpha-1) \cdot (E+T)^{2-\alpha} + (\alpha-2) \cdot (D+T) \cdot (E+T)^{1-\alpha}]}$

  - D = deductible
  - E = exhaustion
  - ρ = risk aversion ~ 40%
  - λ = Poisson intensity
    = probability of a claim

Actuarial premium

- $$P = \lambda \cdot \frac{T^{\alpha}}{\alpha-1} \cdot \left[(D+T)^{1-\alpha} - (E+T)^{1-\alpha}\right]$$
$$+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^{\alpha}}{(\alpha-1)(\alpha-2)} \cdot \left[(D+T)^{2-\alpha} - (\alpha-1) \cdot (E+T)^{2-\alpha} + (\alpha-2) \cdot (D+T) \cdot (E+T)^{1-\alpha}\right]}$$

  - D = deductible
  - E = exhaustion
  - ρ = risk aversion ~ 40%
  - λ = Poisson intensity
    = probability of a claim
  - T = Pareto shape
  - α = Pareto tail

Actuarial premium

- $P = \lambda \cdot \frac{T^{\alpha}}{\alpha-1} \cdot \left[(D+T)^{1-\alpha} - (E+T)^{1-\alpha}\right]$

  $+ \rho \cdot \sqrt{\lambda \cdot \frac{2T^{\alpha}}{(\alpha-1)(\alpha-2)} \cdot \left[(D+T)^{2-\alpha} - (\alpha-1)\cdot(E+T)^{2-\alpha} + (\alpha-2)\cdot(D+T)\cdot(E+T)^{1-\alpha}\right]}$

  - $D =$ deductible — depends on exposure, trigger and impact
  - $E =$ exhaustion — depends on exposure, trigger and impact
  - $\rho =$ risk aversion ~ 40% — reinsurance market standard?
  - $\lambda =$ Poisson intensity
    $=$ probability of a claim — must be calibrated to scenarios
  - $T =$ Pareto shape — must be calibrated to scenarios
  - $\alpha =$ Pareto tail — must be calibrated to scenarios

Swissnuclear scenarios

exposure	trigger	scenario description	frequency
nuclear facility	accident	*Transient, core damage, containment barrier intact*	2.0E-08
nuclear facility	accident	*Transient, core damage, containment damage*	3.0E-09
nuclear facility	accident	*Airplane crash, large aircraft, core damage, containment damage*	8.0E-08
nuclear facility	NatCat	*Strong earthquake with core damage, containment barrier intact*	6.0E-06
nuclear facility	NatCat	*Strong earthquake with core damage, containment damage*	1.0E-06
nuclear facility	NatCat	*Extreme winds and tornadoes, core damage, containment damage*	1.0E-08
nuclear facility	terrorism	*External attack, Design Base Threat (includes FLA)*	?
nuclear facility	war	*Kamikaze drone (Switchblade, Lanzet)*	?
…	…	…	…

Calibration of the distributions to the scenarios

- $N =$ frequency
  - Poisson distributed $\mathbb{P}[N = n] = \frac{\lambda^n e^{-\lambda}}{n!}$
  - Parameter λ calibrated with moments: $\lambda = \sum$ frequencies

Swissnuclear scenarios

				impact		
exposure	**trigger**	***scenario description***	**frequency**	**life/property/BI**	**environment**	**prescription**
nuclear facility	accident	*Transient, core damage, containment barrier intact*	2.0E-08	250’000’000	50’000’000	?
nuclear facility	accident	*Transient, core damage, containment damage*	3.0E-09	10’000’000’000	10’000’000’000	?
nuclear facility	accident	*Airplane crash, large aircraft, core damage, containment damage*	8.0E-08	10’000’000’000	10’000’000’000	?
nuclear facility	NatCat	*Strong earthquake with core damage, containment barrier intact*	6.0E-06	250’000’000	250’000’000	?
nuclear facility	NatCat	*Strong earthquake with core damage, containment damage*	1.0E-06	10’000’000’000	10’000’000’000	?
nuclear facility	NatCat	*Extreme winds and tornadoes, core damage, containment damage*	1.0E-08	10’000’000’000	250’000’000	?
nuclear facility	terrorism	*External attack, Design Base Threat (includes FLA)*	?	250’000’000	5’000’000	?
nuclear facility	war	*Kamikaze drone (Switchblade, Lanzet)*	?	50’000’000	5’000’000	?
…	…	…	…	…	…	…

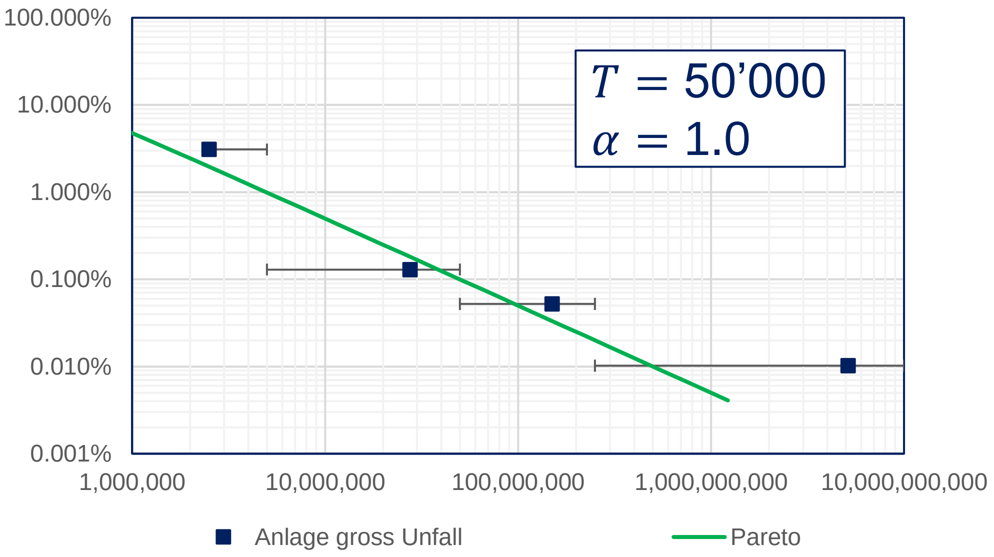
4 loss ranges:

S1 0 – 5’000’000
S2 5’000’000 – 50’000’000
S3 50’000’000 – 250’000’000
S4 250’000’000 – ∞

Calibration of the distributions to the scenarios

- N = frequency
  - Poisson distributed $\mathbb{P}[N = n] = \frac{\lambda^n e^{-\lambda}}{n!}$
  - Parameter λ calibrated with moments: $\lambda = \sum$ frequencies

- X = severity
  - Pareto distributed $\mathbb{P}[X \leq x] = 1 - \left(\frac{T}{T+x}\right)^{\alpha}$
  - Parameters T & α calibrated with a χ^2 fit to their best fits



Summary and outlook

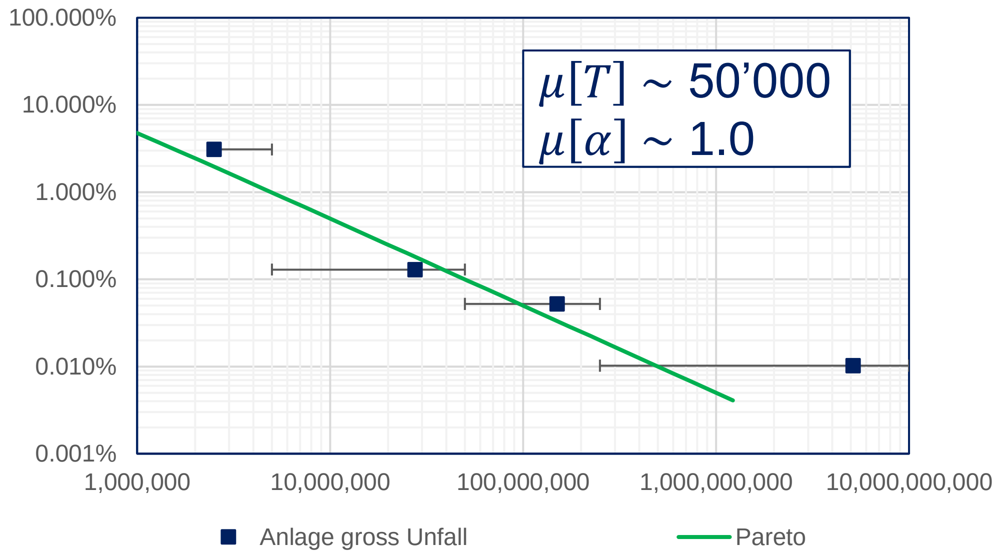
- The Swiss Federation insures the Swiss **nuclear industry** in excess of the Swiss Nuclear Pool’s covers
  - It used to price these covers with crude total loss tariffs
  - These eventually generated unplausible premiums
- The problem is similar to a **facultative excess-of-loss** reinsurance exercise and the Swiss Federation is now implementing an actuarial premium calculation
  - based on a **collective Poisson-Pareto** model
  - where the parameters are calibrated to **scenarios** provided by Swissnuclear
  - and the premium takes an **analytic form**
  - accounting for the **expected loss** and a **risk margin**

- The risk margin accounts here only for the **process risk**
- It would be interesting to also account for the contribution of the **parameter risk** to the risk margin!
  - See ASTIN Colloquium, Brussels 2024

Fuzzy calibration of the distributions to the scenarios

- N = frequency
  - Poisson distributed $\mathbb{P}[N = n] = \frac{\lambda^n e^{-\lambda}}{n!}$
  - Parameter λ calibrated with moments: $\lambda = \sum$ frequencies

- X = severity
  - Pareto distributed $\mathbb{P}[X \leq x] = 1 - \left(\frac{T}{T+x}\right)^{\alpha}$
  - Parameters T & α calibrated with a χ^2 fit
    ~~to their best fits~~
    to their best fit distributions
  - Sample these distributions numerically
    to obtain the fuzzy distribution of X
  - No longer analytic formula 😢



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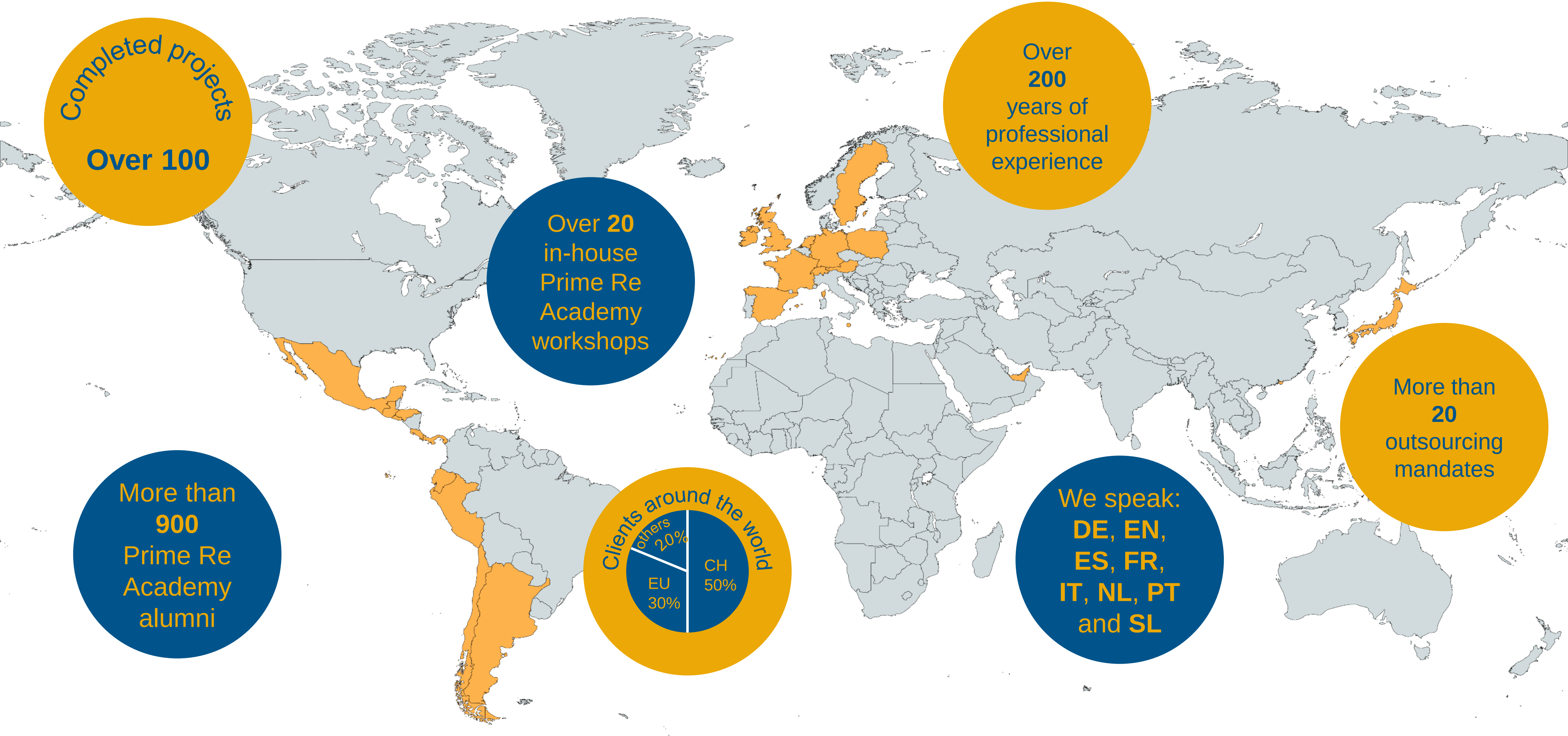
Track record & facts



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