Temperature as a Premium Factor: Insurance Incorporating Climate Change. A Comparative Case Study Between Europe and North America.

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Motivation: Climate Risk Transfer Mechanism

Insurance as a tool for managing risks associated with climate change

Pooling risks
(policyholders and insurers, geographically)

Premium structure:

***premium* = *EL(X)*+Λ**
(Expected Loss + Load factor)

Adaptation of traditional insurance mechanisms to address challenges posed by rising global temperatures

EL(T) and Λ(T)

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EL(T) and Λ(T)

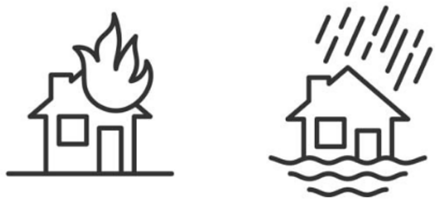
Understanding how climate change impacts natural disasters is crucial for effective risk management

- Increased frequency and intensity of extreme weather events (e.g., floods, droughts, wildfires)
- Differentiation between internal climate forces and external factors (e.g., natural climate cycles, solar radiation)
- Human activity's impact on climate systems
- Use of **statistical tools** to assess climate-related risks
- Rising temperatures linked to heightened catastrophe probabilities

Climate Change Challenges for the Insurance Industry

- Climate change alters traditional risk assessment and management practices in insurance
- Increased frequency and severity of catastrophic natural events leads to excessive financial impacts/losses

Climate-related insurance risk types



Physical linked to extreme weather events (e.g., floods, droughts)
Transition related to moving towards a low-carbon economy
Liability tied to environmental damage claims
Market arising from climate impact fluctuations
Reputational from inadequate climate responses
Operational related to supply chain disruptions
Regulatory due to changing laws on climate actions

$$premium(X) = EL(X) + \Lambda(X) = PFL(X) \cdot CEL(X) + \Lambda(X)$$

Probability of First Loss (PFL), Conditional Expected Loss (CEL)

RESEARCH QUESTIONS

- How accounting for temperature affects the expected loss estimation of climate-related damages in the insurance industry?
- What is the geographical translation of the varying temperature trends in the charged climate-related premium?
- How are the climate-related insurance premiums are differentiated under the various socio-economic path scenarios until 2030?

Insurance Premium Modeling

- **Total Expected Layer Loss (TEL):**

  $$TEL(X) = EAL(X) + EER(X)$$

  Expected Absolute Loss (EAL):

  $$EAL(X) = \int_a^{a+h} S_X(x)\,dx$$

  Expected Excess Return (EER):

  $$EER(X) = \gamma \cdot (PFL)^\alpha \cdot (CEL)^\beta$$

  Probability of First Loss (PFL):

  $$PFL = S_X(a) = P(X > a)$$

  Conditional Expected Loss (CEL):

  $$CEL = \frac{EL(X(a,a+h] | X>a)}{h}$$

- **Premium Calculation:**

  $$premium(X) = \rho \cdot TEL(X)$$

(Galeotti et al., 2013)

Temperature-Dependent Model:

- General Model:

  $$premium(X \mid T) = \rho \cdot TEL(X \mid T)$$

- Resulting Relationships:

  $PFL(X \mid T_1) > PFL(X \mid T_2)$, $T_1>T_2$

  $CEL(X \mid T_1) > CEL(X \mid T_2)$, $T_1>T_2$

  - Implies:

    $premium(X \mid T_1) > premium(X \mid T_2)$

Data Sources and Methodology

Temperature Data:

- Source: World Bank
- Temperature anomalies calculated as deviations from the 1950-1980 average for Europe and North America.

Natural Disaster Data:

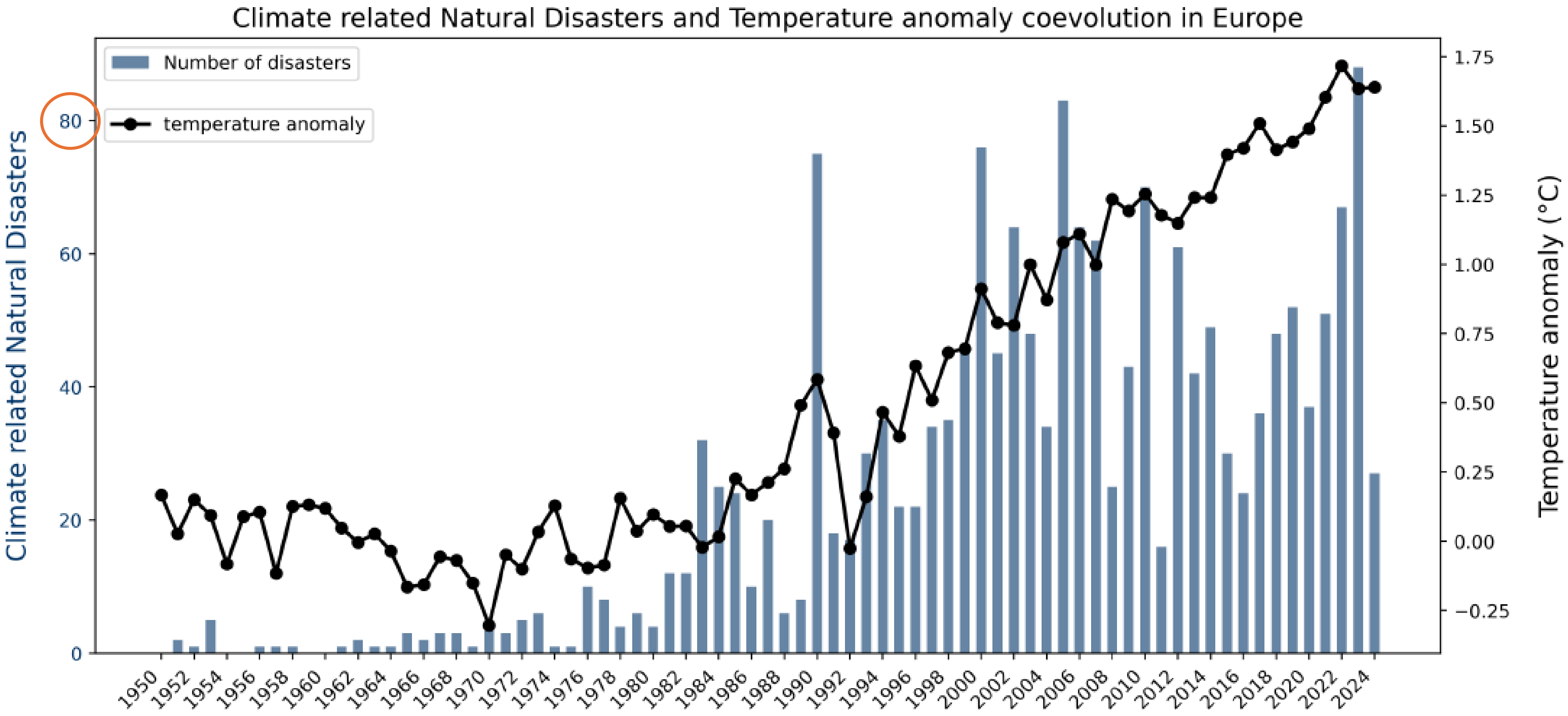
- Source: EM-DAT database
- Includes climate-related disasters: droughts, wildfires, floods, extreme temperatures, storms.
- Metrics: Number of disasters per year and economic damages (total and insured).

Methodological Framework:

- Historical period for model building: 1950-2014.
- Validation period: 2015-2024.
- Projection period under SSP scenarios: 2025-2030.
- Regression analysis to assess the relationship between temperature anomalies and disaster frequency.

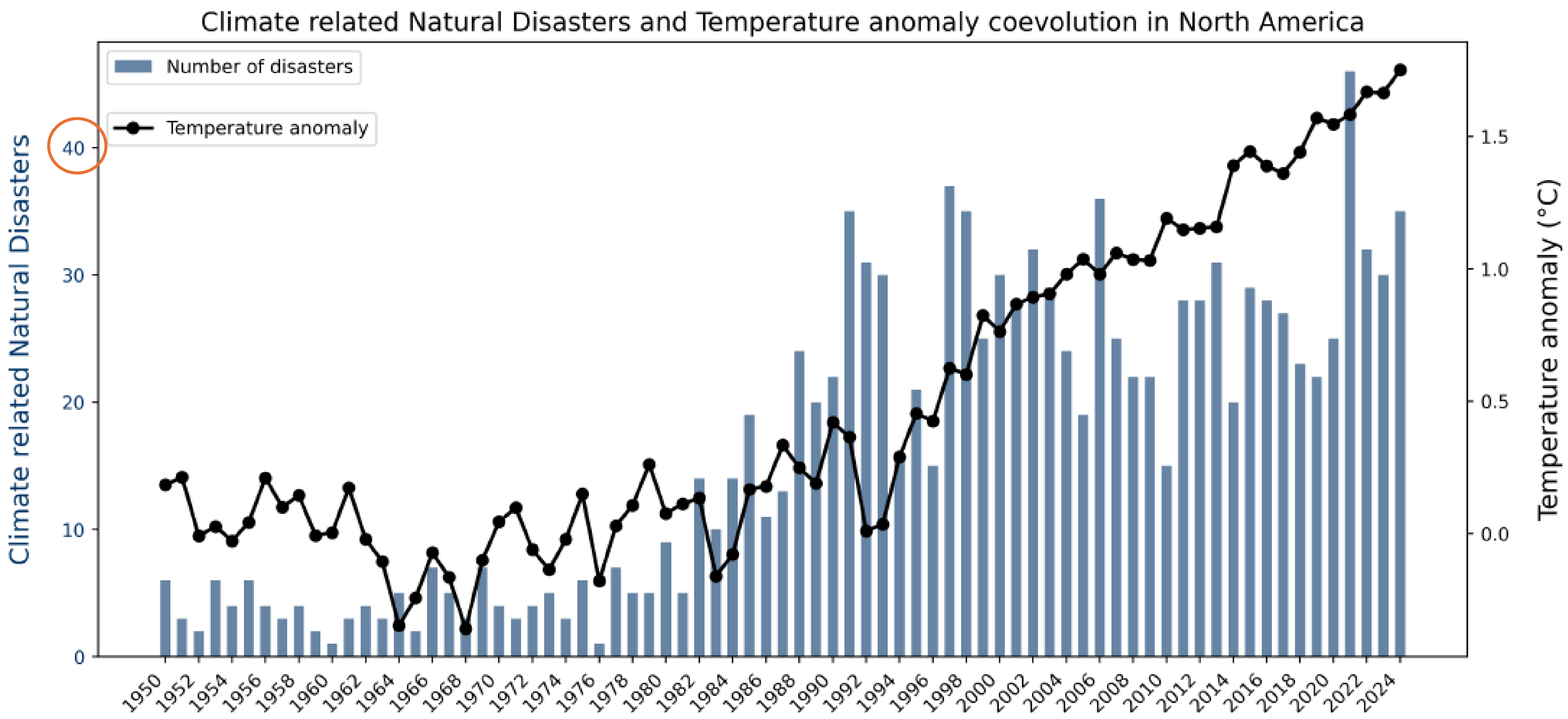
Image source: NOAA

Europe: Temperature Anomalies & Natural Disasters



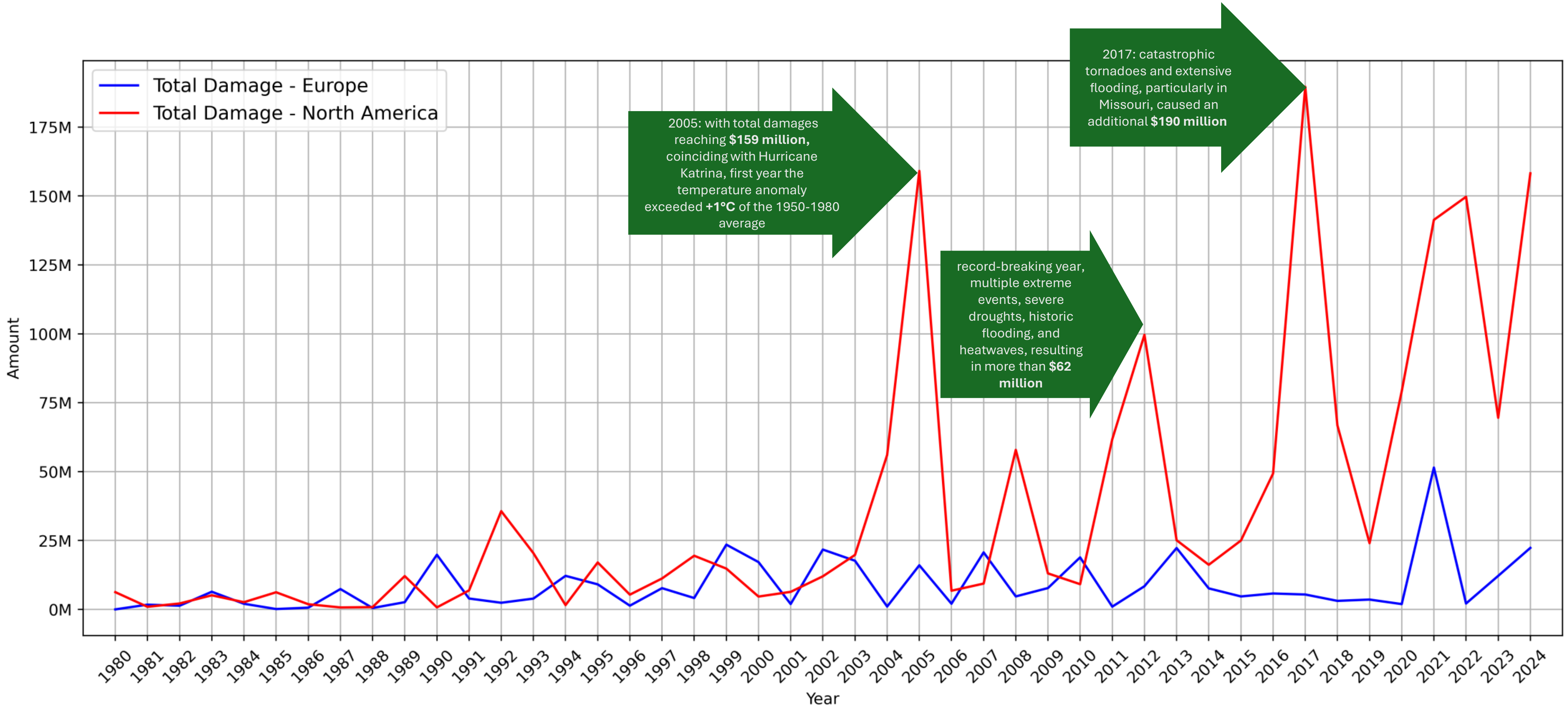
Data source: Temperature data from World Bank and Natural Disasters from EM-DAT.

North America: Temperature Anomalies & Natural Disasters



Data source: Temperature data from World Bank and Natural Disasters from EM-DAT.

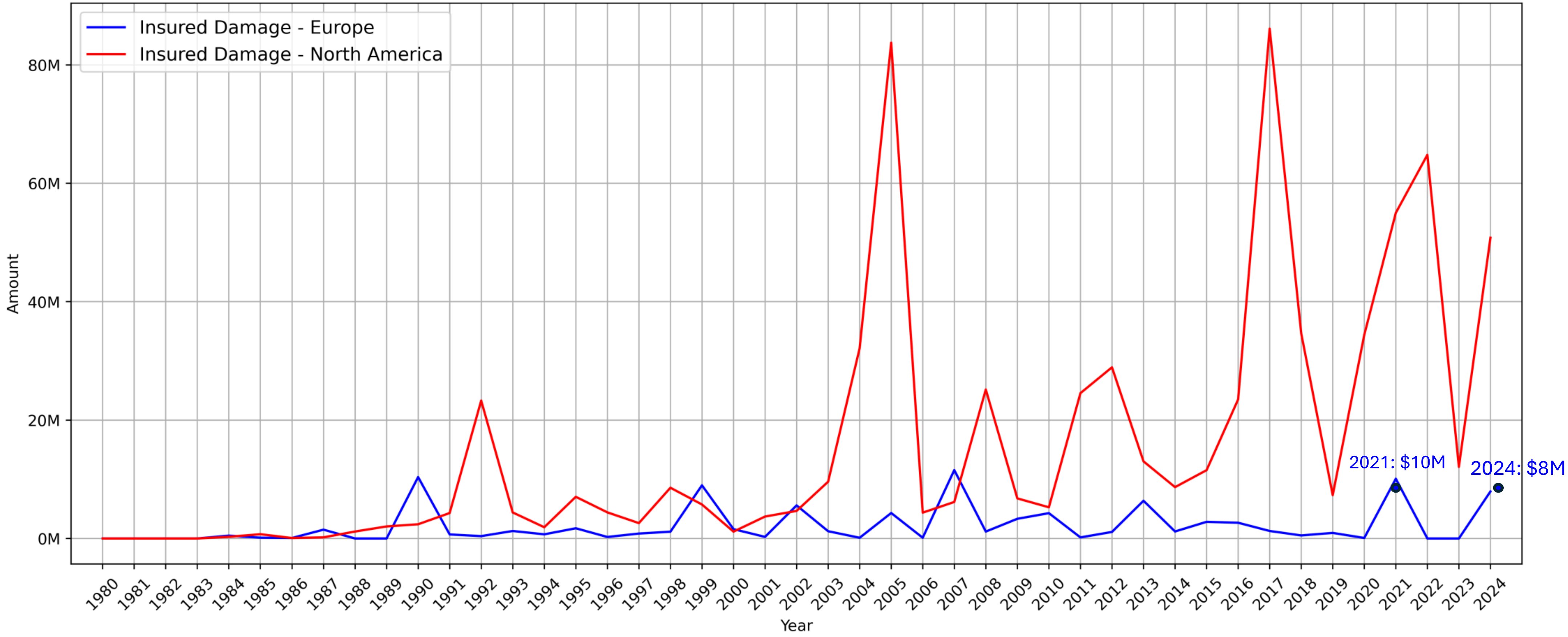
North America's Growing Vulnerability to Climate Disasters



$ 0.37M 50s – $119M early 20s , North America vulnerability factors: geography, urbanization, infrastructure level

Data source: EM-DAT.

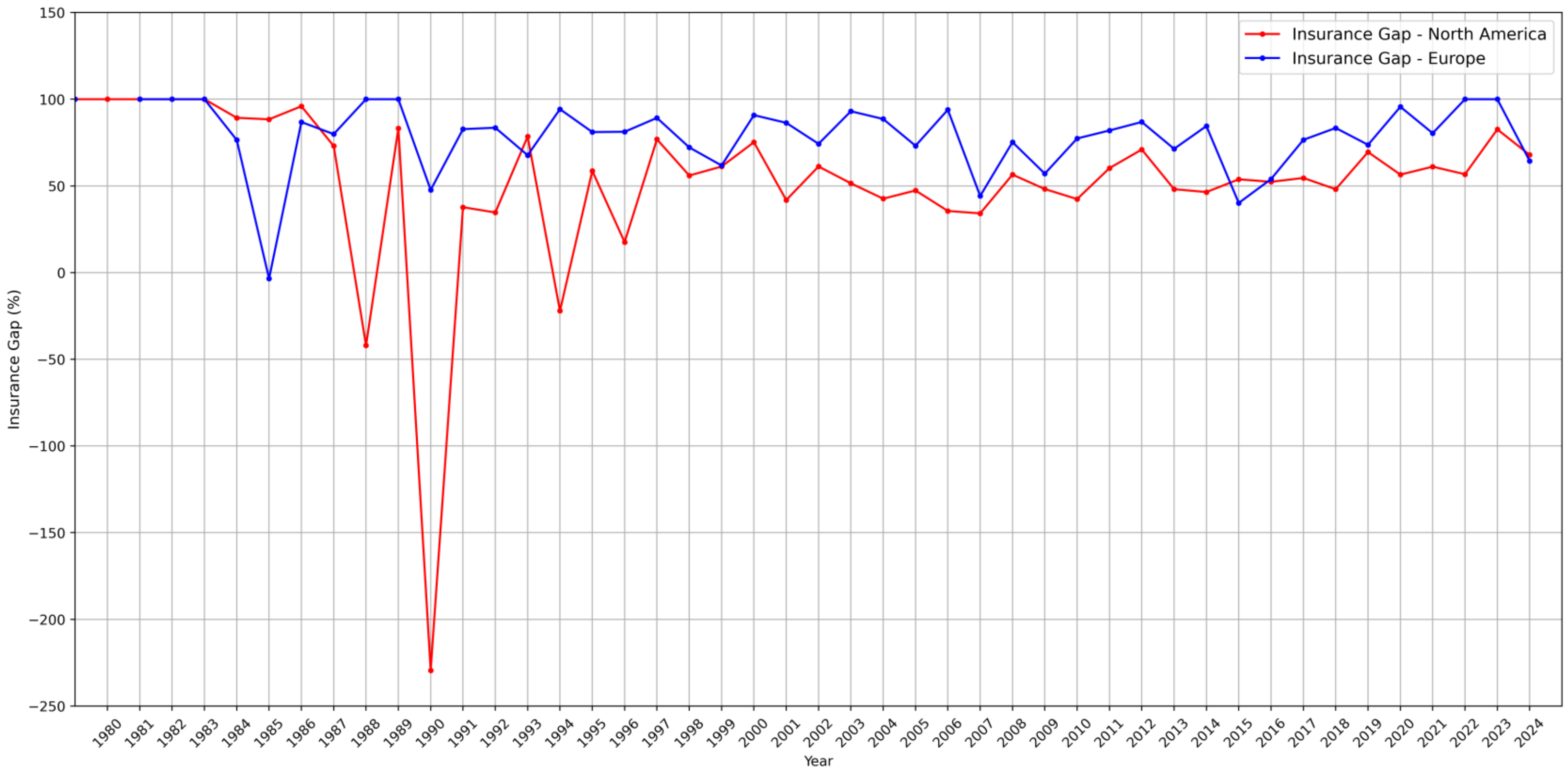
Insurance Penetration Differences: Shaping North America's Rising Claims Compared to Europe



Europe: consistently less insurance claims in response to its climate-related disasters,
Different geographic exposure, regional preparedness and response strategies, different levels of insurance penetration in the two markets

Data source: EM-DAT.

Europe exhibits a pattern of higher climate-related insurance Gap compared to North America



* Climate-related insurance gap is calculated as 100 minus the percentage covered and it represents the proportion of total damages that remains uninsured. The percentage covered is the insured damage divided by total damage, multiplied by 100, and indicates the proportion of damages that is covered by insurance.

Volatile insurance gap in N. America

The cyclical nature of extreme weather events, economic fluctuations, and varying insurance policies (more susceptible to these external shocks compared to Europe)

Higher Insurance Gap in Europe

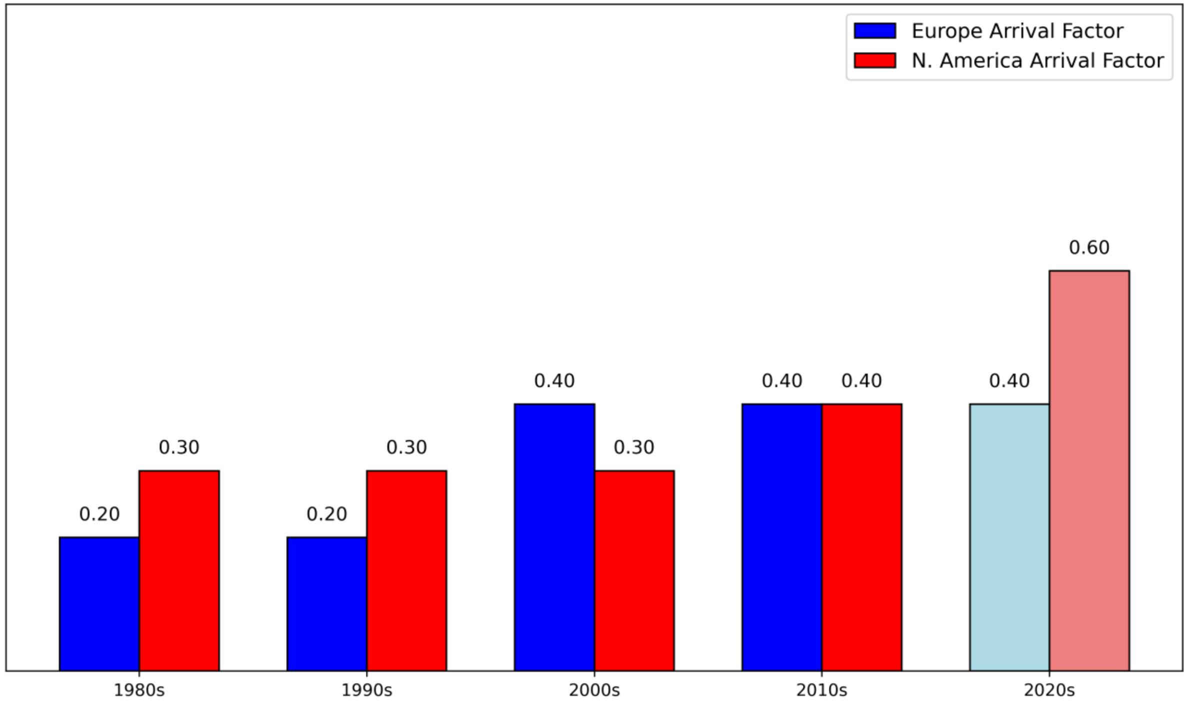
Differences in regulatory environments, varying levels of public welfare support, and lower penetration of insurance products in certain segments, cultural attitudes toward risk etc. (high moral hazard)

- ECB (2023) “European Climate Insurance Gap” :1/4 of the climate disasters are insured – Greece <5%

Data source: EM-DAT.

Increasing trend in extreme climate-related insured damages in both regions

Arrival factor of extreme climate-related insured damages



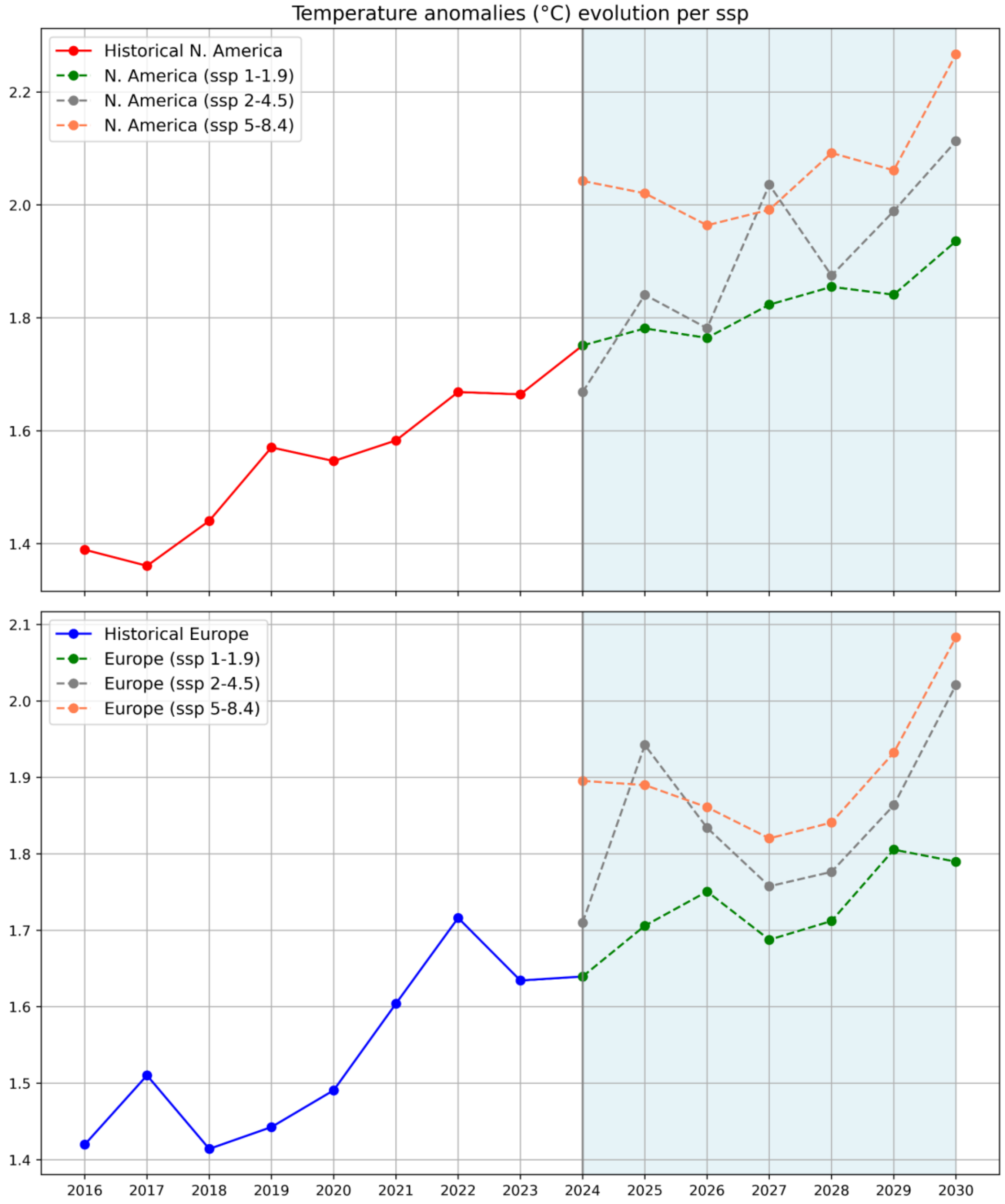
*The arrival factor is calculated per decade by calculating how many registered insured damages are greater than the average insured damages for each decade and divided by the count of above-average instances by 10.
** The arrival factors for the 2020s refers to the years 2020-2024.

- Insured damages in both regions exceed the average every two to three decades
- Reconsider, coverage limits and natural catastrophe premiums
- Various traditional risk pricing models are extended to account for climate
- Introduction of temperature anomaly, projections until 2030
- Temperature anomaly evolution until 2030

Data source: EM-DAT.

Europe Anticipates Higher Temperature Shifts than North America by 2030, Even in Mid-Scenario

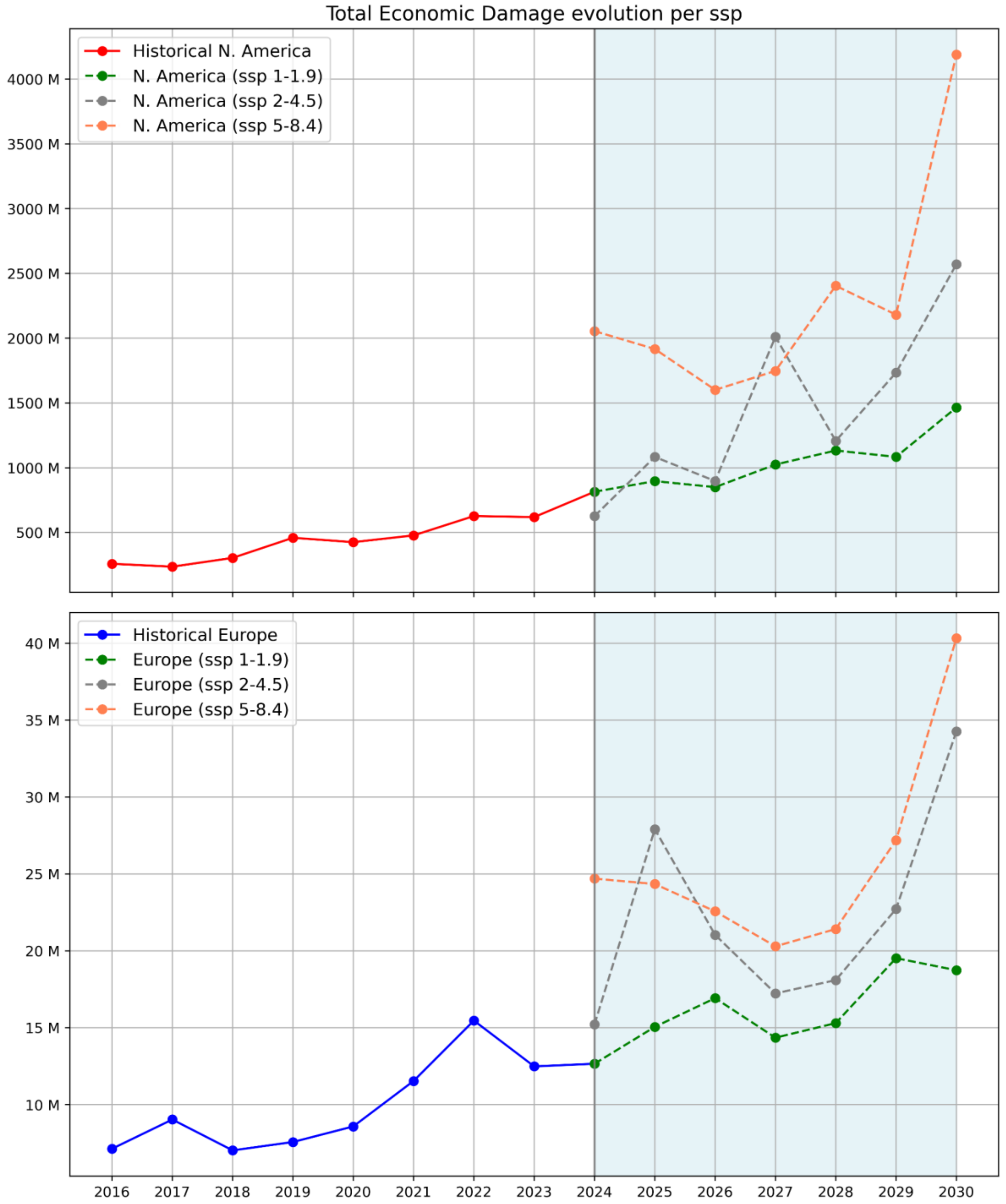
- SSP 1-1.9 (production model and legislation)/5-8.4 scenarios projected increase in both regions
- Signals potential significant climatic shifts – exacerbate weather-related challenges
- SSP 2-4.5 most probable, higher variability, complex
- N. America higher baseline temperature anomalies
- Europe's higher sensitivity to climate-related events (floods, wildfires, extreme temperatures)
- Require more rapid interventions than N. America
- Temperature increase, and physical damages don't translate always in the same pattern of economic losses in the insurance industry
- Feed projections to total damages model



Data source: Temperature historical and projection data from World Bank.

Total Economic Damages Expected to Rise Sharply in North America Compared to Europe by 2030

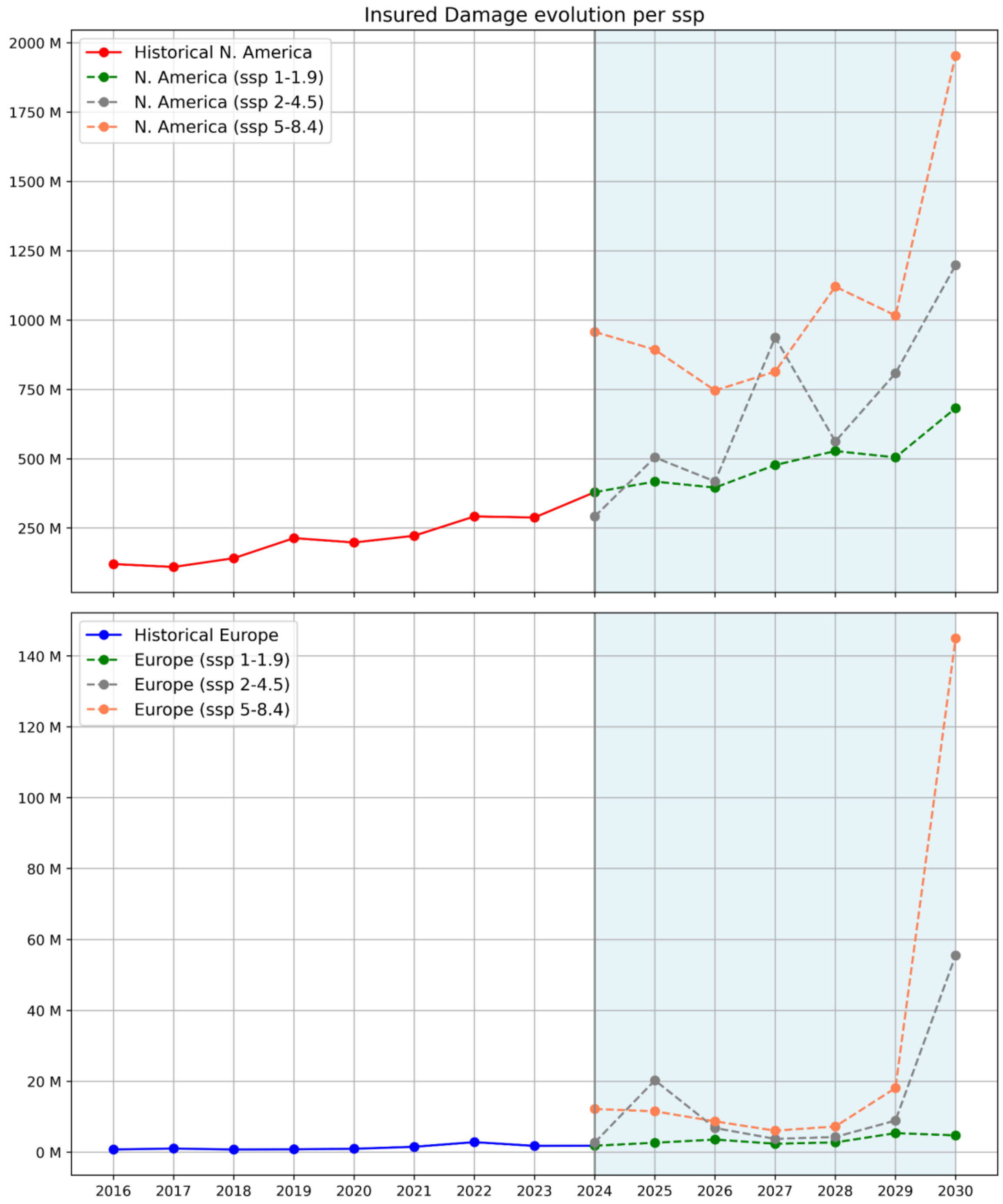
- Under the most optimistic scenario, N. America continues to present orders of magnitude greater total damages
- SSP 5-8.4 high increase in damages, troubling correlation between increased GHG emissions and economic consequences
- Europe, lower baseline, under SSP 2-4.5, notable variability in total losses
- Even moderate emission pathways could trigger unexpected economic repercussions by the end of 2025, even earlier than N. America
- Insured damages - financial burden of climate-related events in both regions



Data source: Historical total economic damage data from EM-DAT.
The projections after 2024 are derived from developed log-linear regression model.

Projected deepening of the European climate-related insurance gap until 2030

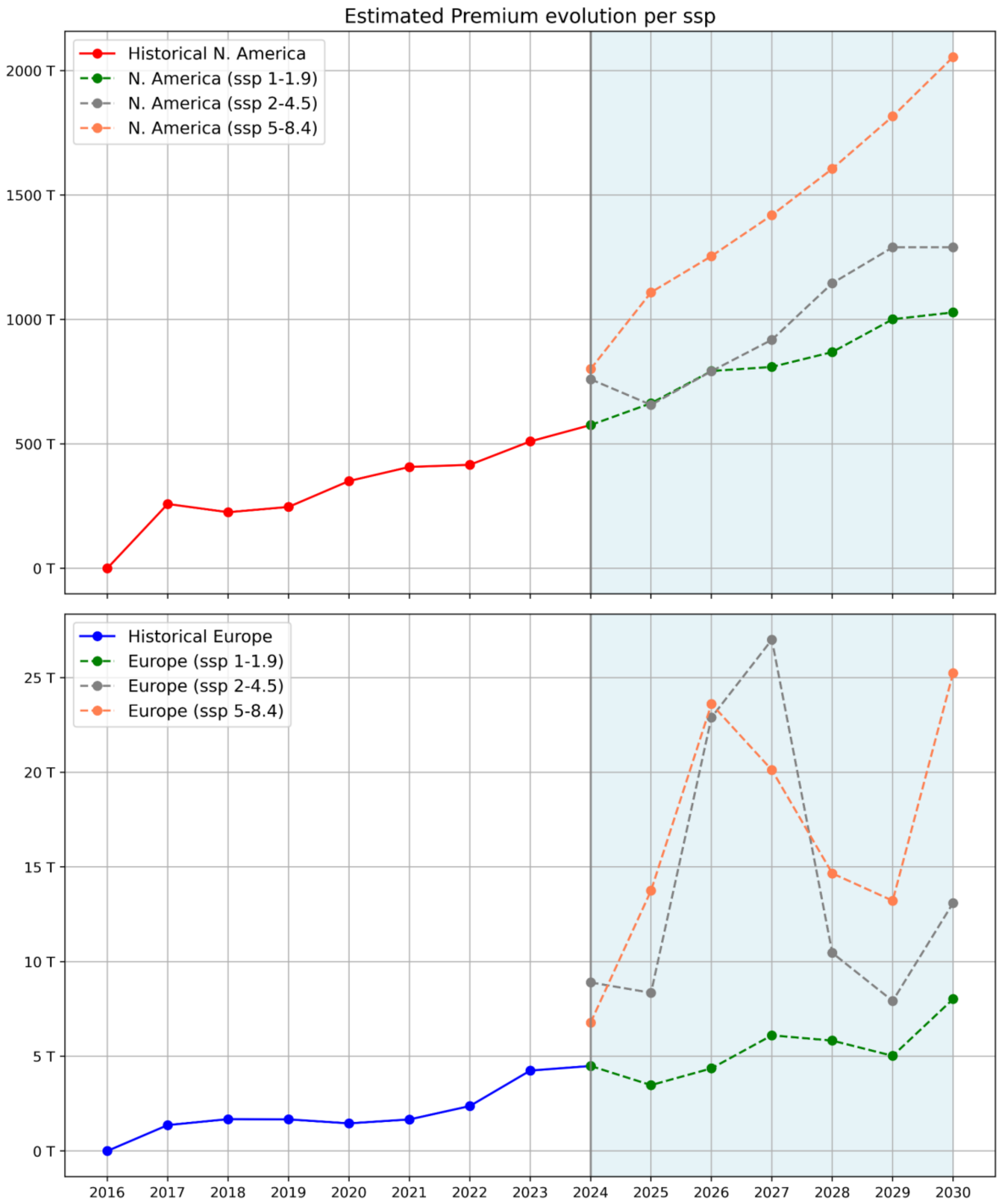
- N. America higher insurance damages under all SSP's
- Europe, low insurance damages, estimation of extended insurance gap until 2030
- Variability of insured damages under SSP's – benefits of climate mitigation strategies, insurance sector
- Highlight need for insurers to adapt their pricing models
- Dual Challenge: prioritize risk reduction (damages), ensure adequate coverage
- Natural disasters, more frequent, relationship between total and insured damages, more complex, influence insurance pricing



Data source: Historical insured economic damage data from EM-DAT. The projections after 2024 are derived from developed log-linear regression model for Europe and developed linear model for North America.

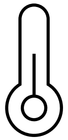
Europe's Urgent Need for Insurance Industry Transformation Due to Rising Premiums

- Projected evolution of climate-related premiums until 2030 (droughts, wildfires, floods, extreme temperatures, storms)
- N. America – higher premiums than Europe in all SSP's (reflects greater exposure to climate-related risk, better integration of climate factors to EL(X))
- Regional disparity calls insurers to adopt differentiated pricing strategies - account for unique climate threats
- Insurers – pool in Europe and N. America to differentiate more their pricing approaches
- SSP 5-8.4 - N. America dramatic increase
- Europe – early hikes 2025-2026 (4 times more than 2024, great challenge – individuals seeking coverage)
- Threat, financial stability of the European insurance market
- Europe reliance on public resources - last resort coverage - another layer of complexity, as risk management transcends the private sector, collaboration between insurers and policymakers



Data source: Results of model estimation.

RESEARCH QUESTION



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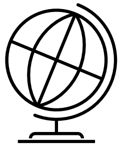

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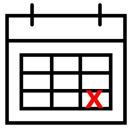

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Conclusion

- **Insurance** plays a pivotal role in mitigating potential losses due to climate change, using various mechanisms
- **Re-evaluation of what enters** Expected Loss (EL) and Expected Excess Return (EER) is critical for accurately **assessing risk** and determining insurance premiums (e.g., climate indicators – temperature anomaly)
- **Historical trends** indicate an alarming increase in climate-related disasters translated in total and insured economic dagames, prompting the need for **climate-informed risk assessment models** to address evolving climate-related challenges
- **Differences in regulatory frameworks** between regions in North America and Europe significantly influence insurance practices and strategies for managing climate-related risks

Future work

- **Increase resolution**: Case Study - California and Greece, focusing on the impact of wildfires on local insurance schemes in collaboration with the National Center for Disaster Preparedness (NCDP), Columbia Climate School, funded by the Fulbright research program

Thank you

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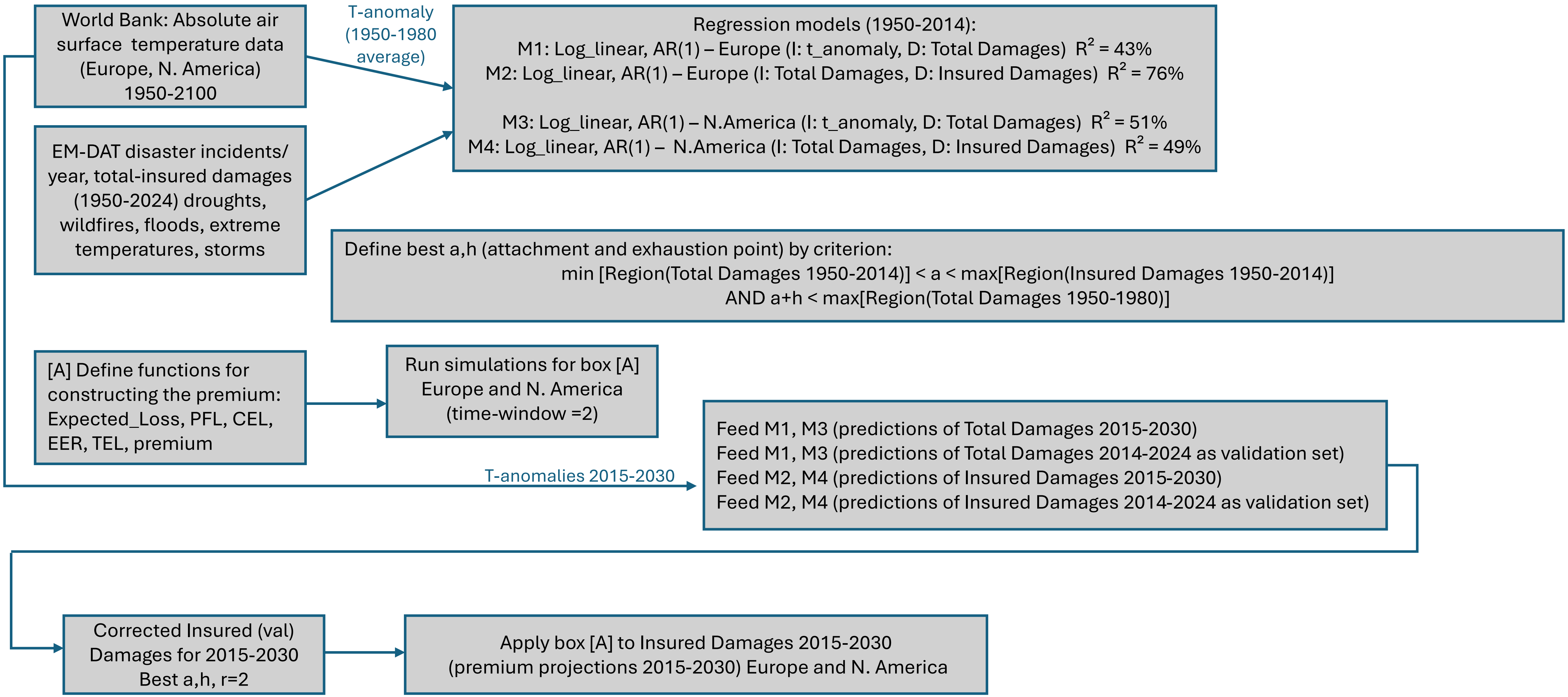
Code flow chart



Appendix – Theoretical Framework (not accounting for temperature)

(1) $$X(\alpha, \alpha+h] = \begin{cases} 0, X \leq \alpha & \text{, no loss in the layer } (\alpha, \alpha + h] \text{ for the insurer, any occurring loss is covered by the policyholder} \\ X - \alpha, \alpha < X \leq \alpha + h & \text{, the loss is covered by the contract} \\ h, X > \alpha + h & \text{, the loss charged to the layer } (\alpha, \alpha + h] \text{ is the exhaustion point } -\alpha, (\alpha + h) - \alpha = h \text{, after that point again the loss coverage is on the policyholder.} \end{cases}$$

- Non-negative random loss variable $X \in [0,\infty)$
- Insurance coverage concerns only the $X \in (0,X]$, with X the grater loss covered according to the contract
- The range $X \in (0,X]$ is characterized by the two layers, each layer refers to a different insurance product, with $X \in (0,X] = (\alpha_i, \alpha_i + h_i]$, and $i = 1, \ldots, n$ with each i representing one layer of insured risk
- Catastrophe insurance applies to the last layer $(\alpha_n, \alpha_n + h_i]$ only, with α the attachment point and α + h the exhaustion point

(2) $$EL(X) = E[x] = \int_0^\infty (1 - F_X(y))dy$$

- The expected loss (EL) corresponding to a risk level X.
- $F_X(x)$ the cumulative distribution function (CDF) and gives the probability $P(X \leq x)$.
- $1 - F_X(y) = P(X > y) = S_X(y)$, is the survival function of the probability function.
- Define two risk levels X1 and X2 such as X1 > X2, X1 represents higher risk level
- Satisfy the non-decreasing property of the CDF is satisfied, meaning $F_{X1}(x) < F_{X2}(x)$ for every x. The probability of losses that exceed x for X1 is greater than for x2, $P(X1 \leq x) \leq P(X2 \leq x)$

Appendix – Theoretical Framework (not accounting for temperature)

The survival function Sx(y) = P(X1 > y) = 1−Fx(y) for X1,X2 is:

(3) $S_{X1}(y) = 1 - P(X1 \leq x)$

(4) $S_{X2}(y) = 1 - P(X2 \leq x)$

(5) $S_{X1}(y) \geq S_{X2}(y)\ \textit{for every risk level}\ y.$

(6) $EL(X1) = \int_0^\infty S_{X1}(y)dy$

(7) $EL(X2) = \int_0^\infty S_{X2}(y)dy$

From (2) integrating the survival functions to derive the expected loss

(8) $\int_0^\infty S_{X1}(y)dy \geq \int_0^\infty S_{X2}(y)dy = EL(X1) \geq EL(X2)$

* For strict inequality, between the two expected losses we could claim that if X1 results in a higher risk of economic losses than *X*2 it implies there are scenarios or insurance claims that losses are much larger in magnitude or frequency for the higher risk compared to the lower risk level. Thus, there will be certain regions where (5) holds with strict equality when integrating for the whole range, and, by extension, (8) also holds with strict equality. In those certain regions, the specific risk ranges contribute more significantly to the overall area under the integral, the expected loss.

Appendix – Theoretical Framework (accounting for temperature)

Extension: expected economic loss **while in a hotter world** by defining EL of a risk level X (a specific insurance contract) as a function of temperature T.

(9) $$EL(X) = \int_0^{\infty} y \cdot S_X(y|T)dy$$

- Conditional probability within the survival function represents the probability that economic losses exceed a certain threshold y under temperature T
- All potential loss amounts y (weights the loss amount in each case) multiplied by the probability that the loss does exceeds each amount and summed over the range of possible losses
- **Assumption:** Following the empirical evidence, the environmental temperature influences the catastrophic risk. As temperature increases, there is greater volatility and severity in weather patterns. Increased probability of extreme events such as floods, storms, wildfires etc. affects the expected economic losses covered by the insurance product X. For T1>T2,

(11) $$EL(X|T1) = \int_0^{\infty} y \cdot S_X(y|T1)dy > \int_0^{\infty} y \cdot S_X(y|T2)dy = EL(X|T2)$$

(12) $$EL(X|T1) > EL(X|T2)$$

(12) Captures the evidence that as temperature rises, the integral associated with the expected loss at scenario T1 includes the higher probabilities of losses exceeding the threshold y, resulting in an overall higher expected economic loss. (monotonic relation: increases in temperature leading to extreme weather and more frequent and more severe natural catastrophes, can directly influence economic damages for insurance companies by raising their expected losses)

Appendix – Theoretical Framework (Insurance premium modeling)

By specializing the risk (the range that the insurer has agreed to cover according to the contract, α < X ≤ α + h and (1), (6), (7):

(13) $$EL(X(a,a+h]) = \int_0^\infty S_{X_{(a,a+h]}}(y)dy$$

- **Expected loss** occurring within this interval, higher than the attachment point but less or equal to the exhaustion point. Survival function for this loss layer

(14) $$EL(X(a,a+h]) = \int_a^{a+h} S_X(x)dx \equiv EAL(X)$$

- **Expected Absolute Loss** (quantification of the financial impact of potential losses for the insurer, which is directly derived from the loss distribution) – **Systemic part of the anticipated loss**

(15) $$EER(X) = \gamma \cdot (PFL)^{a} \cdot (CEL)^{\beta}$$

- Accounts **for potential excess returns** for the insurer to accept this risk, that is or else the load factor (Λ). An additional return the insurer could demand to take on losses associated with high-risk events highlighted by EAL – **Unsystematic part of the anticipated loss**
- γ, α and β are scaling parameters, represent the insurer's risk preferences or market characteristics.

Appendix – Theoretical Framework (Insurance premium modeling)

(16) $PFL = S_X(a) = P(x > a)$

- **Probability of the First Loss:** the probability that a loss exceeds a certain threshold α. Expresses the chance of exceeding a particular loss, a crucial information for the insurer for setting aside capital and establish informed premiums.

(17) $CEL = \dfrac{EL(X(a, a+h]|x > a)}{h}$

- **Conditional Expected Loss:** the expected loss given that a loss has occurred and is greater than α, indicating the monetary severity of the anticipated loss for the insurer, the average loss that is expected in a particular loss layer (from α to α + h). Dividing by h, the upper limit of the economic loss the insurer has agreed to cover normalizes the conditional expected layer loss across the interval, providing a per unit expected loss.

(18) $TEL(X) = EAL(X) + EER(X)$

- **Total Expected Loss**: the average loss expected over a certain period or given certain conditions and it includes all potential losses along with those losses that may not be significant enough to warrant separate management techniques from the insurance company.

Appendix – Theoretical Framework (Insurance premium modeling)

(19) $$premium(X) = \rho \cdot TEL(X)$$

- We **define a linear representation of a premium model** charged by the insurer. X represents the insurance contract declaring the loss layer the insurer agrees to cover, and ρ a factor that adjusts the premium reflecting the insurers mark up on the expected losses or a government upper limit to impose for a more accessible insurance price to the public (set ρ=2, traditional insurance rule, discussion for optimal ρ)

(20) $$premium(X|T) = \rho \cdot TEL(X|T)$$

(21) $$PFL(X|T1) > PFL(X|T2), \;\; for\; T1 > T2$$

(22) $$CEL(X|T1) > CEL(X|T2), \;\; for\; T1 > T2$$

$$premium(X|T1) > premium(X|T2)$$ (23)