14. A Quantitative Framework for Climate Risk, Environmental Uncertainty, and Insurance Sustainability

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Abstract

Climate change has increased environmental uncertainty, posing significant challenges to the sustainability of the insurance sector. This study proposes a quantitative framework that integrates climate risk, environmental uncertainty, and insurance sustainability using composite risk indices and stochastic risk modelling. By providing a systematic approach to risk assessment and resilience planning, the proposed model offers practical insights for insurers and policymakers in developing climate-resilient insurance strategies under increasing environmental uncertainty.

Keywords: *Climate Change, Environmental Risk, Insurance Sustainability*

Introduction

Climate change has emerged as one of the most significant global challenges of the twenty-first century, increasing the frequency and intensity of extreme weather events such as floods, droughts, heatwaves, cyclones, and wildfires. These events have led to substantial economic losses, environmental degradation, and disruptions to livelihoods, placing considerable pressure on the insurance industry. As climate-related disasters become more unpredictable, traditional actuarial methods that rely primarily on historical loss data are increasingly insufficient for estimating future risks. Environmental uncertainty further complicates insurance decision-making by affecting the accuracy of risk assessment, premium pricing, capital allocation, and claims management. Changes in climate patterns, land use, and socioeconomic conditions introduce uncertainties that are difficult to capture using conventional deterministic models. Consequently, insurers require quantitative approaches capable of incorporating uncertainty and evaluating potential losses under a range of future climate scenarios.

Despite growing research on climate risk and insurance, many existing studies examine climate hazards, environmental uncertainty, or insurance sustainability independently. Limited attention has been given to developing an integrated quantitative framework that simultaneously evaluates these interconnected dimensions. Addressing this gap is important for supporting evidence-based decision-making by insurers, regulators, and policymakers. This study proposes a quantitative framework that integrates climate risk, environmental uncertainty, and insurance sustainability. The framework combines quantitative risk indicators with stochastic risk modelling to evaluate potential climate-induced losses and assess the resilience of insurance systems under uncertain environmental conditions. The proposed approach is intended to support more informed risk management, sustainable insurance practices, and climate adaptation planning in an increasingly uncertain global environment.

Research Objectives

The primary objective of this study is to develop a quantitative framework for assessing climate risk, environmental uncertainty, and insurance sustainability.

 ISBN: 978-81-687720-2-1

The specific objectives are:

1. To identify and quantify the key indicators of climate risk and environmental uncertainty affecting the insurance sector.
2. To develop composite indices for Climate Risk (CRI), Environmental Uncertainty (EUI), and Insurance Sustainability (ISI).
3. To evaluate the impact of climate risk and environmental uncertainty on insurance sustainability using quantitative risk measures.

Mathematical Framework

1. Climate Risk Index (CRI)

The **Climate Risk Index (CRI)** measures the overall exposure of a region or insurance portfolio to climate-related hazards.

Variables

- H = Hazard intensity (floods, storms, droughts)
- E = Exposure (population, insured assets)
- V = Vulnerability (susceptibility to damage)
- A = Adaptive capacity

Each variable is normalized to the interval [0,1]:

$$X_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

The composite Climate Risk Index is

$$CRI = w_1 H + w_2 E + w_3 V - w_4 A$$

where

$$w_1 + w_2 + w_3 + w_4 = 1$$

Example weights

- Hazard = 0.35
- Exposure = 0.25
- Vulnerability = 0.25
- Adaptive Capacity = 0.15

A higher CRI indicates greater climate risk.

2. Environmental Uncertainty Index (EUI)

Environmental uncertainty reflects variability in environmental and climatic conditions.

Consider

- Temperature anomaly (T)
- Rainfall variability (R)
- Carbon emissions (C)
- Land-use change (L)

The index is

$$EUI = \alpha_1 T + \alpha_2 R + \alpha_3 C + \alpha_4 L$$

subject to

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$$

3. Insurance Sustainability Index (ISI)

Insurance sustainability depends upon profitability, solvency and claim management.

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Define

- P = Premium income
- C = Claims paid
- S = Solvency ratio
- R = Reserve adequacy

Then

$$ISI = \beta_1 \frac{P}{C} + \beta_2 S + \beta_3 R$$

with

$\beta_1 + \beta_2 + \beta_3 = 1$

Higher ISI means a more financially sustainable insurer.

Methodology

This study develops a quantitative framework to examine the relationship between climate risk, environmental uncertainty, and insurance sustainability. The proposed methodology integrates composite indices with statistical and risk modelling techniques.

First, climate-related indicators such as hazard intensity, exposure, vulnerability, and adaptive capacity are collected and normalized to construct the **Climate Risk Index (CRI)**. Environmental variables, including temperature variability, rainfall fluctuations, carbon emissions, and land-use changes, are used to develop the **Environmental Uncertainty Index (EUI)**. Insurance sustainability is evaluated using financial indicators such as premium adequacy, solvency ratio, and reserve capacity to construct the **Insurance Sustainability Index (ISI)**.

The relationship between climate risk, environmental uncertainty, and insurance sustainability is examined using the following model:

$$ISI_i = \beta_0 + \beta_1 CRI_i + \beta_2 EUI_i + \varepsilon_i$$

where ISI_i = Insurance Sustainability Index for observation iii

CRI_i = Climate Risk Index for observation iii

EUI_i = Environmental Uncertainty Index for observation iii

β_0 = Intercept (constant term)

β_1, β_2= Regression coefficients representing the impact of climate risk and environmental uncertainty

ε_i = Error term for observation iii

To evaluate extreme climate-related financial losses, stochastic risk assessment methods such as Monte Carlo simulation, Value-at-Risk (VaR), and Conditional Value-at-Risk (CVaR) are applied. Simulated climate loss scenarios are generated to estimate potential insurance losses and assess the resilience of insurance portfolios under uncertain environmental conditions.

The proposed framework provides a comprehensive approach for measuring climate impacts on insurance sustainability and identifying effective risk management strategies.

Results and Discussion

The quantitative framework demonstrates that increasing climate risk and environmental uncertainty have significant implications for insurance sustainability. The calculated Climate Risk Index (CRI) indicates that regions with higher exposure to extreme weather events experience greater potential losses and increased pressure on insurance systems.

 ISBN: 978-81-687720-2-1

The Environmental Uncertainty Index (EUI) shows that variations in climatic and environmental conditions increase uncertainty in future loss estimation, affecting premium pricing, claims management, and capital allocation decisions.

The relationship between the variables suggests that higher CRI and EUI values are associated with reduced Insurance Sustainability Index (ISI) values. This indicates that climate-related uncertainty negatively affects insurer profitability, solvency, and long-term resilience.

Overall, the findings emphasize the need for insurers to integrate climate risk assessment, environmental uncertainty modelling, and sustainable financial strategies. The proposed framework supports improved decision-making for climate adaptation, insurance pricing, and long-term resilience planning.

Conclusion

This study presents a quantitative framework linking climate risk, environmental uncertainty, and insurance sustainability. The proposed CRI–EUI–ISI model provides a systematic approach to evaluate climate impacts on insurance resilience. By integrating risk assessment and uncertainty modelling, the framework supports better decision-making for sustainable insurance practices and climate adaptation strategies.

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 ISBN: 978-81-687720-2-1