The influence of climate change on insurance sustainability: Evidence from Spanish agricultural insurance

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Insurance
Data
Science

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Our research goals

1. Measure and quantify climate change in the Iberian Peninsula at different scales, countries, regions, and provinces.
   → **IACI** → **SACI** → **pSACI**.
2. Pick one line of business (**wine grapes**) and one risk (**hailstorm**).
3. Study the impact of climate change on crop insurance business sustainability.
   - Assess the impact of climate change on premiums → Using **SACI** and regressions models.
   - Assess the impact of climate change on the Solvency Capital Requirement (SCR)→ Using **SACI** and quantile regression models for **high quantiles** (e.g., 99th percentile)
   - Finally, Assess geographical heterogeneity of that impact → Using **pSACI** and mixed models (linear regression & quantile regression).

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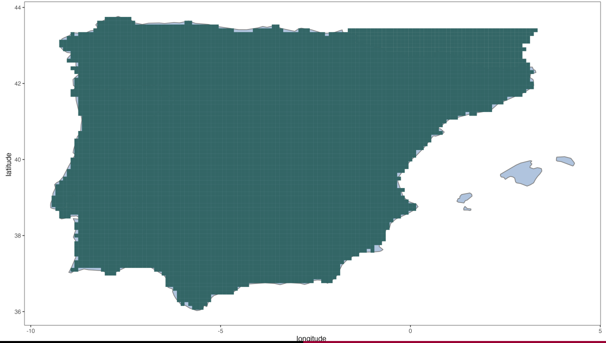
Climate Data Bases

The IACI building-blocks are 6,526 cells that approximate the Iberian Peninsula:

- Each cell is 0.1°x0.1° ($\approx 123.2Km^2$) from 36° to 47.7° lat.N., from -9.5° to 3.3° long. E.
- In each cell data from **ERA5-Land reanalysis**, and **Permanent Service for Mean Sea Level**(for sea levels) are downloaded to feed the formulae. **Monthly data.**
- These data are combined to calculate **mean values** over **time** and/or **space** and replaced in the index components.



Spanish Actuarial Climate Index (SACI)

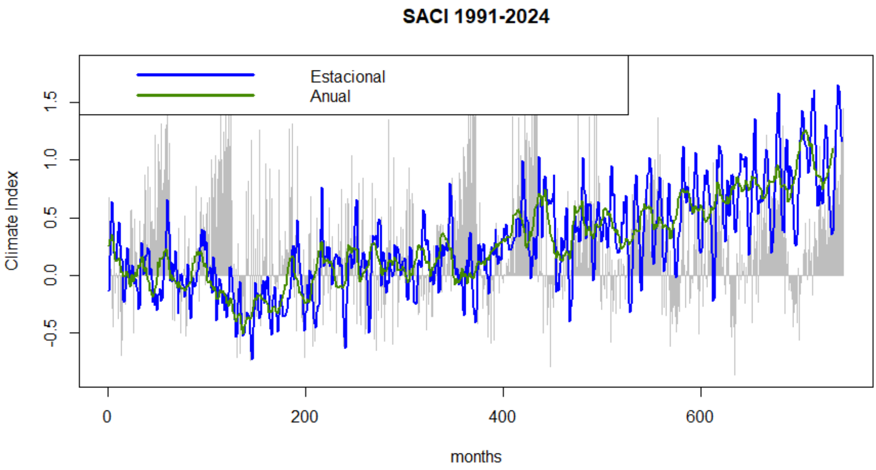
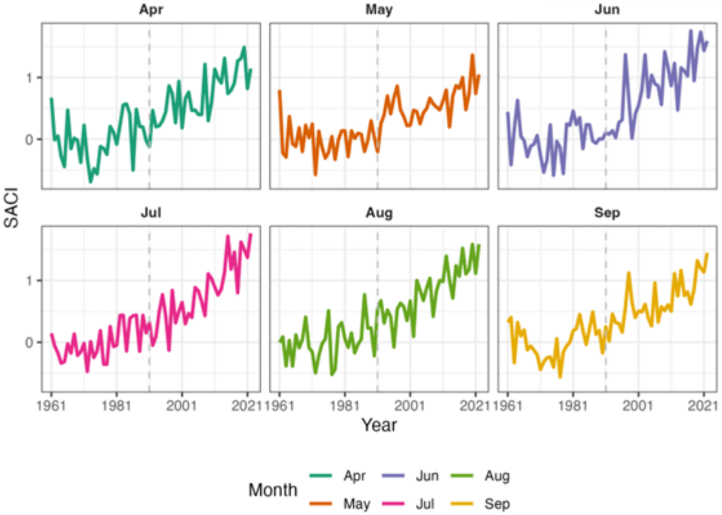


Figure: SACI from 1991 to 2022, 3 and 12 months moving averages

Evolution of SACI over Hailstorm Relevant Months (1961–2021)



Spanish Actuarial Climate Index (pSACI)

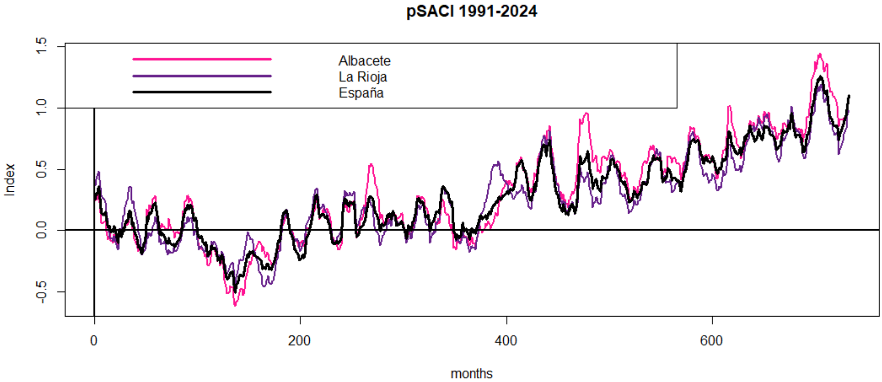


Figure: pSACI 1991-2022 for 2 provinces. 12-month moving average. Detail of spatial heterogeneity.

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Wine grapes hailstorm claims dataset

Supplied by Agroseguro[1]

- **Time Span:**
  - 1990–2022
- **Coverage:**
  - 49 provinces / 240 regions
  - 893,144 annual policies (avg)
- **Data Scale:**
  - 7,547,286 records
  - 692,733 claims

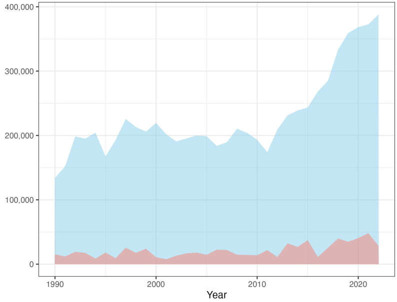
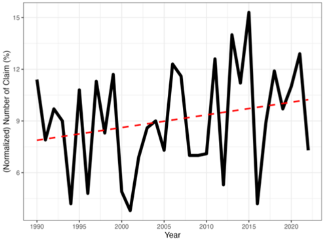


Figure: Yearly numbers of plots (blue) and claims (pink) over time.

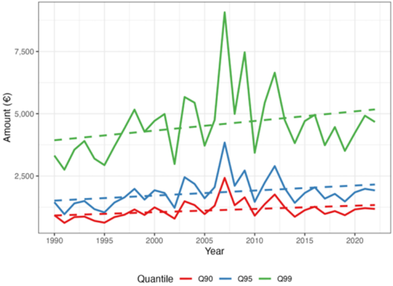
[1] *Agroseguro* is the Spanish coinsurance pool of agricultural insurance, consisting of 17 insurance companies.

Wine grapes hailstorm claims dataset

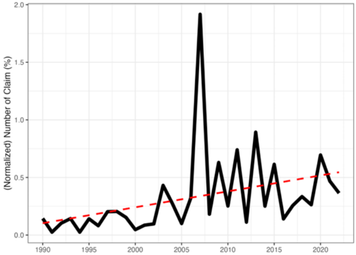
Normalized Number of claims **N**



Normalized loss quantiles **L**



Normalized loss costs=1 **LC1**



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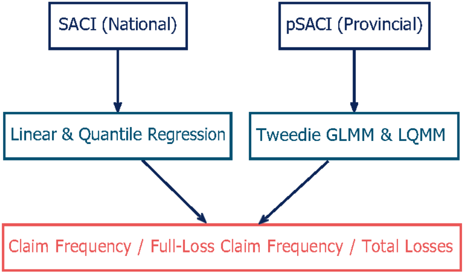
Climate Change Impact Analysis – Methodology



- We use SACI / pSACI / components as the independent variables.
- N, LC1, and L as the dependent variables

Explained Variables: Monthly Claim frequency and losses

Claim Frequency

- Normalized monthly number of claims, **N**

$$N = \frac{\text{Monthly claim count}}{\text{Annual plot count}}$$

- Normalized monthly number of full-loss claims (i.e. losses = insured capital), **LC1**

Loss Severity

- Homogenized monthly total loss, **L**

$$\text{Homogenized Monthly Loss}_{j,k} = \frac{\text{Monthly Loss}_{j,k}}{\text{Insurance Value Index}_k}$$

$$\text{Insurance Value Index}_k = \underbrace{\frac{\text{Insured Capital}_k}{\text{Insured Capital}_{1990}}}_{\text{Inflation adjustment}} \times \underbrace{\frac{\text{Yield}_{1990}}{\text{Yield}_k}}_{\text{Yield fluctuation}}$$

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Spanish-wise goals achievement (Losses)

Data

- Monthly SACI / It's components, 1990–2022
- National hailstorm insurance metrics: Claim Frequency (N), Full-Loss Frequency ($LC1$), **Monthly Losses (L)**

Models

- **Linear regression** — estimates mean effects

$$E(Y) = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n \qquad Y \in \{N, LC1, \log(L)\}$$

- **Quantile regression** (90th /95th / 99th) — captures tail behaviour

$$Q_\tau(Y|X) = X\beta_\tau,$$

- Remember:

$$Q_{\log(L)}(\tau|X = x) = \log\left(Q_L(\tau|X = x)\right), \qquad (1)$$

Economic Implications

Key finding. A 0.1-point increase in the Spanish Actuarial Climate Index (SACI) lifts

- the *expected* monthly hail-losses by $\approx 9\%$ ($\beta = 0.878,\ e^{0.1\beta} = 1.091$);
- the *99th-percentile* (VaR) losses by $\approx 6\%$ ($\hat{\beta}_{0.99} = 0.619,\ e^{0.1\hat{\beta}_{0.99}} = 1.064$).

Economic magnitude. Within the 2022 SACI range (1.05 in May–1.76 in July), these elasticities imply

$$\Delta E(L) \approx 0.22\text{–}0.30\,\text{M€}, \qquad \Delta\text{VaR}_{0.99} \approx 0.81\text{–}1.38\,\text{M€}.$$

Role of seasonality. Monthly dummies remain material. Moving from May to July increases losses by

$$\%\Delta L = \left(e^{\Delta\text{SACI}\cdot\beta+\Delta\text{Month}} - 1\right) \times 100\% \approx 37\%$$

highlighting that SACI and seasonal factors jointly drive hailstorm exposure.

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Province-wise goals achievement (Losses)

- **Regions Analyzed:**
  - La Rioja, Albacete, Ciudad Real, Cuenca, Toledo
- **Method:**
  - **Tweedie GLMM:** Captures mean effects under mixed distribution (zero-inflated + continuous)

$$Y_{ij} \sim \text{Tweedie}(\mu_{ij}, \phi, p)$$
$$\log \mu_{ij} = \beta_0 + u_j + (\beta_1 + v_j)\, \text{pSACI}_{ij}$$

  - **LQMM:** Assesses effects at high quantiles of total loss (e.g., 95th/99th)

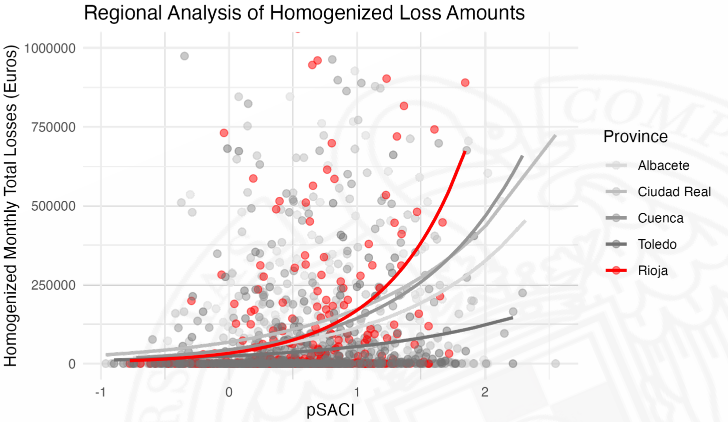
$$Q_\tau(\log L_{ij}) = \beta_0(\tau) + u_j(\tau) + [\beta_1(\tau) + v_j(\tau)]\, \text{pSACI}_{ij} \qquad \tau \in \{0.90, 0.95, 0.99\}$$

Province-Specific Random Effects and Adjusted Coefficients (Total Monthly Losses)

Province	Random Effects		Adjusted Coefficients	
	Intercept	pSACI	Intercept	pSACI
Albacete	0.0039	-0.0714	10.5897	1.0517
Ciudad Real	0.5448	-0.1968	11.1306	0.9263
Cuenca	0.1114	0.0553	10.6971	1.1784
Toledo	-0.4993	-0.3101	10.0865	0.8130
La Rioja	-0.1806	0.5122	10.4051	1.6353

Table: Selected provincial random effects and adjusted coefficients for homogenised total losses (L). Adjusted values incorporate $\beta_0 = 10.59$ and $\beta_1 = 1.12$.

Nonlinear Relationship: pSACI and Insurance Losses



pSACI Extremes and Expected Monthly Losses (2022)

Provincial extremes of pSACI and expected losses

Province	Max. pSACI		Min. pSACI	
	$pSACI$	Loss (€)	$pSACI$	Loss (€)
Albacete	2.02	332,759	–0.02	38,977
Ciudad Real	1.91	399,108	–0.17	58,555
Cuenca	2.25	623,250	–0.09	39,638
La Rioja	1.72	548,254	–0.15	25,971
Toledo	1.64	91,178	–0.23	19,888

- **Cuenca**: €0.04 M $\rightarrow$ €0.62 M (+15×) as pSACI jumps from –0.09 to 2.25.
- **La Rioja** also highly sensitive (€0.52 M swing).
- **Toledo** least sensitive; peak loss < €0.1 M.
- pSACI elasticity differs sharply across provinces ⇒ pricing and capital must be regional.

Province-Specific Random Effects and Adjusted Coefficients for 99th-Percentile Total Losses

Province	Random Effects		Adjusted Coefficients	
	Intercept	pSACI	Intercept	pSACI
Albacete	7.5901	0.6542	13.2018	1.7909
Ciudad Real	7.7040	0.6457	13.3157	1.7824
Cuenca	7.7122	0.7513	13.3238	1.8880
Toledo	6.8817	0.5018	12.4934	1.6386
La Rioja	7.3522	0.8503	12.9639	1.9870

Table: Random effects and adjusted provincial coefficients for the intercept and pSACI slope at the 99th percentile. Adjusted coefficients combine fixed and random components, highlighting geographical differences in climate sensitivity.

pSACI Extremes and 99th Quantile Losses (2022)

Provincial extremes of pSACI and 99th quantile monthly losses

Province	Max. pSACI			Min. pSACI		
	$pSACI$	$\log L$	$L_{0.99}$ (€)	$pSACI$	$\log L$	$L_{0.99}$ (€)
Albacete	2.02	16.82	2.02×10^7	–0.02	13.17	5.23×10^5
Ciudad Real	1.91	16.71	1.81×10^7	–0.17	13.02	4.51×10^5
Cuenca	2.25	17.56	4.23×10^7	–0.09	13.15	5.14×10^5
La Rioja	1.72	16.38	1.30×10^7	–0.15	12.67	3.18×10^5
Toledo	1.64	15.18	3.91×10^6	–0.23	12.11	3.18×10^5

- **Cuenca**: 99 %-VaR jumps from €0.5 M to €42 M—an 80-times increase.
- Albacete Ciudad Real exceed €18 M in high-pSACI months (35 $\times$ baseline).
- Extreme losses escalate far faster than means $\Rightarrow$ solvency capital and reinsurance layers must scale with provincial pSACI levels.

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Conclusions

1. IACI and its regional indices can effectively quantify climate change in the Iberian Peninsula, especially in Spain.
2. The incremental increases in the Spanish Actuarial Climate Index (SACI) are closely associated with both higher claim frequencies and more severe losses, especially in the tail of the loss distribution.
3. The spatial heterogeneity of climate change demonstrates the need for province-level monetization of the effects of climate change on insurance premiums and solvency capital requirements (SCR).

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