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# When Climate Risk Becomes Endogenous: Macro-Risk Feedback Loops in Insurance Pricing and Capital

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## INTRODUCTION

Climate change is often described as a series of isolated shocks—a flood here, a wildfire there, a storm that breaks one more record. But for insurers, the real challenge is not the individual event, it is the system of reactions that follows. These are not simple cause-and-effect relationships. They are macro-risk feedback loops—reinforcing cycles in which climate-driven losses interact with economic and financial conditions to amplify risk across multiple layers of the system. For example, a heavy loss pushes premiums up; higher premiums push people out of the market; uninsured losses weaken local economies; weaker economies reduce investment returns; lower investment income strains insurers' balance sheets; and round we go. By the time the next climate event arrives, the system is already on thinner ice.

Each cycle reinforces the next reshaping, the foundations of pricing, reserving, and capital modeling. Understanding these feedback loops is essential for insurers, regulators, and policymakers in order to prevent localized climate shocks from evolving into systemic financial stress. In this essay we explore how these loops form, examine their implications for pricing and capital, and explore an actuarial framework capable of assessing where we are in these self-reinforcing cycles.

The proposed approach extends existing climate stress testing by transforming climate risk from an exogenous shock into a dynamic, state-dependent process. The central argument of this essay is insurer responses—pricing, capital allocation, and coverage decisions—are endogenous drivers of climate vulnerability. This mechanism can be modeled through Climate Vulnerability Rating (CVR) migration and a Feedback Stress Index (FSI) that measures the strength of reinforcing risk dynamics over time.

While subject to data and calibration challenges, the framework offers insurers and regulators a structured way to identify emerging systemic stress, smooth procyclical responses, and align financial decision-making with long-term resilience. The framework is intended as a decision-support tool rather than a precise forecasting model.

## WHY THIS MATTERS?

Climate-risk analytics have made huge strides in the last decade, but the tools we use today still describe pieces of the problem rather than the systemic loop it creates. We treat climate change as a long-term headwind, not a short-term trigger of systemic feedback. The challenge with climate risk is not the absence of data, but the absence of structure. We have loss estimates, hazard projections, resilience indices, and stress tests, yet they remain loosely connected.

Useful but broad Indices exist—like the Climate Vulnerability Index (CVI), ND-GAIN, and municipal resilience scorings that measure infrastructure readiness, hazard exposure, and socio-economic resilience. Rating agencies increasingly acknowledge that climate risk may influence sovereign and municipal credit ratings. But climate-driven downgrades remain rare; the methodology is cautious and not designed for insurance decision-making. While informative, these methods are not actuarial tools built for pricing to decide how to load premiums or simulate balance-sheets.

The current insurance practices of risk management—ORSA, ALMs and capital adequacy regimes—look at a short term, typically single year, time horizon. Supervisors such as Australian Prudential Regulation Authority, the Bank of England, Monetary Authority of Singapore, and the European Central Bank have begun running climate vulnerability assessments. They stress-test insurers and banks under different hazards and map affordability, capital strain, and expected losses. These exercises capture exposure and sensitivity, but they are still snapshots—not continuous rating systems.

A climate event starts a loop by hitting multiple parts of the system simultaneously through interconnected stresses landing at once. Apart from the physical losses, it disrupts local economy, makes insurance and reinsurance costlier, and in the extreme case capacity disappears. This prices local communities out and gradually eats away resilience. What is missing is a framework that translates climate shocks into decision-relevant actuarial signals, while explicitly capturing how those signals **interact and reinforce one another over time**.

## CONSTRUCTING A CLIMATE-RISK FEEDBACK LOOP

Most currently available climate-risk tools are static by design looking at vulnerability and exposure at a point in time. Stress tests explore hypothetical futures while resilience indices rank preparedness. These approaches are valuable, but they do not answer a practical actuarial question, which is, how today's climate event changes tomorrow's pricing, capital needs, and risk profile, and how does that change feed back into future outcomes? One possible way to answer this is by borrowing selected elements from credit-risk methodologies—rating migration and state-dependent transitions—and from established catastrophe modeling practices such as earthquake zoning, to develop a framework that treats climate risk as observable, comparable, and dynamically evolving rather than a sequence of isolated events.

## CLIMATE VULNERABILITY RATINGS (CVR)

We first begin by constructing a Climate Vulnerability Rating (CVR), a state variable that evolves over time and that can be assigned to a defined geography or portfolio segment. The rating aggregates physical risk, economic resilience, and insurance-specific factors into a single measure that reflects not only hazard exposure, but also the system's ability to absorb and recover from shocks. Inputs may include hazard frequency and severity trends, current and projected exposure concentration, insurance penetration, protection gaps, mitigation investments, public-sector capacity, and historical claims volatility.

## RATING MIGRATION AS THE ENGINE OF THE FEEDBACK LOOP

CVRs are dynamic by design, changing to reflect changed local realities. They can be downgraded following severe events, deterioration in economic resilience, or high loss volatility. They can be upgraded when mitigation measures, infrastructure investment, or improved risk governance materially reduce vulnerability. They can provide a common language across pricing, underwriting, capital management, and reinsurance, much as credit ratings do across financial markets.

Once the CVR exists, the feedback loop is modeled by CVR migration over time according to transition probabilities calibrated from historical loss experience, scenario analysis, and stress testing. A severe flood may move a region from A to BBB; repeated events may push it further down the scale. Recovery is possible but not guaranteed.

Following each downgrade, we can anticipate higher technical premiums and capital charges, tighter underwriting limits/conditions, and reduced reinsurance availability. While these are rational responses for firms, the resulting economic strain feeds back into vulnerability, increasing the likelihood of further downgrades. The loop now appears embedded in the rating migration process itself.

## MEASURING THE LOOP: A FEEDBACK STRESS INDEX

It is not sufficient to determine just the rating factor for each location. Different regions may be susceptible to varying climatic phenomena. High frequency of events can mean shorter feedback loops, faster worsening of conditions and reduced available time for mitigation. Socio-economic factors can determine how fast and strong the feedback mechanism is. Well-to-do neighborhoods are usually better placed to absorb shocks and recover sooner from any kind of disaster. They are also not likely to lose out drastically on insurance coverage due to reducing affordability. In terms of the CVR, these are the locales that are likely to see smaller fluctuations, and possible upgrades.

To complement CVR, we therefore need a Feedback Stress Index (FSI), an indicator designed to measure how tightly the feedback loop is wound. This can be measured by studying over time premium elasticity, coverage attrition, claims ratio volatility, reinsurance capacity shifts, downgrade frequency, investment income reduction, and protection gap growth.

A rising FSI value signals that responses to climate risk are beginning to amplify rather than absorb shocks. For insurers, this provides early warning of emerging systemic stress. For regulators, it offers a macroprudential lens on climate-driven instability. This allows insurers to move beyond isolated stress tests for specific events towards multi-period simulations of feedback dynamics, determining how today's pricing and capital decisions influence tomorrow's vulnerability.

## PRACTICAL USE CASES OF A CLIMATE FEEDBACK FRAMEWORK

A framework that captures climate-driven feedback loops is valuable only if it improves insurance decision making. The CVR and FSI are not intended as abstract metrics, but as tools that can be deployed across the insurance value chain.

- Pricing—Insurers already reprice after climate events. The problem is not re-pricing itself, but how abruptly and locally it occurs. By anchoring pricing adjustments to CVR migration rather than single-event losses, insurers can distinguish between transient shocks in otherwise resilient regions, and structural deterioration in vulnerability. This allows for smoother premium paths, clearer communication with policyholders, and reduced volatility in affordability. In effect, CVR acts as a stabilizer, preventing pricing decisions from overreacting to noise while still responding to genuine risk signals.
- Capital Allocation and Solvency—CVRs provide a structured way to reflect climate risk in capital assessments by combining fat tails with gradual deterioration in infrastructure, affordability, and therefore resilience. Regions or portfolios with persistent downgrades attract higher capital buffers, not because of a single extreme loss, but because of elevated uncertainty and feedback risk. Conversely, improvements in resilience can justify capital relief over time. This creates

incentives that align financial strength with long-term risk reduction, rather than rewarding short-term premium growth in increasingly fragile markets.

- Portfolio Steering and Exposure Management—One of the least discussed climate risks is concentration risk disguised as diversification. Multiple regions may appear geographically distinct while sharing similar vulnerability dynamics. Using CVRs, insurers can manage exposure limits by rating bands, steer new business toward higher-resilience areas, and identify clusters of correlated downgrade risk.
- Reinsurance Strategy and Market Signaling—Reinsurance markets already act as an early-warning system for climate stress, but signals are often fragmented and reactive. CVRs could become a shared reference point and increase predictability at market level for cedants and reinsurers, reducing the risk of sudden capacity withdrawals driven by asymmetric information. With a clearer view of risk and accumulation, cedants and reinsurers can align expectations on adjustments to structures, attachment points, limits, and pricing systematically with vulnerability migration.
- Regulatory Oversight and Macroprudential Monitoring—From a regulatory perspective, the greatest risk is not insurer failure in isolation, but collective responses that amplify economic stress. This is especially true of climate-change-fueled weather phenomena that affect large areas and populations. The FSI provides a macroprudential view by highlighting when pricing capital tightening and coverage withdrawal begin reinforcing one another. Regulators can use this to target supervisory attention, calibrate countercyclical capital measures, or coordinate with public-sector risk mitigation efforts. In this sense, the framework helps connect micro-prudential solvency assessments and system-wide stability.
- Incentivizing Risk Reduction and Adaptation—Perhaps, the most important use case lies outside insurance balance sheets. Because CVRs are upgradeable, they create a measurable reward for investment in mitigation, infrastructure, and disaster management. Municipalities, developers, and policymakers can see how resilience investments translate into improved insurability and lower long-term costs. Unlike blunt restrictions or post-event subsidies, this mechanism rewards ex ante risk reduction—rewarding prevention rather than cure.
- Avoiding the "Uninsurability" Cliff—Left unmanaged, climate risk narratives tend toward a single endpoint: uninsurable regions. CVRs allow insurers and regulators to identify stress early and adjust gradually. The goal is not to deny coverage, but to prevent the system's response from becoming more damaging than the original event.

## LIMITATIONS AND IMPLEMENTATION CHALLENGES

While the proposed framework offers a structured way to model climate-driven feedback loops, it also introduces practical and conceptual challenges. Recognizing these limitations is essential, not as a weakness of the approach, but as a guide to responsible implementation and identifying future refinement opportunities.

- Data Gaps and Measurement Uncertainty—Climate risk data remains uneven in quality and granularity. Loss histories are short relative to climate time horizons, and resilience indicators are often qualitative or inconsistently reported. CVRs would need combining heterogeneous data sources into a single signal. This aggregation involves judgment, introduces model risk, and the potential for false precision.
- Calibration and Procyclicality Risk—A framework built around rating migration risks becoming procyclical if not designed carefully. Downgrades following major events may reinforce already tightening market conditions, accelerating coverage withdrawal, and affordability stress. To avoid this, calibration must distinguish between short-term volatility and structural vulnerability. Transition probabilities should incorporate recovery dynamics and mitigation effects, rather than

relying solely on loss experience. This is easier said than done—other than loss history, other inputs can be qualitative and hard to quantify.

- Model Complexity and Transparency—Capturing feedback loops necessarily increases model complexity. Linking climate scenarios, rating migration, pricing responses, and capital impacts introduces layers of interaction that can be difficult to capture, explain to boards, regulators, and stakeholders. If a framework becomes opaque, it risks losing trust—particularly in regulatory or public-facing contexts. Clear documentation, explainability, and governance are therefore as important as technical accuracy.
- Behavioral and Political Constraints—Insurance responses do not occur in a vacuum. Political pressure, regulatory intervention, and social expectations can delay or distort actuarial signals. Premium increases may be capped, withdrawals may be restricted, capital relief may be granted for policy reasons. These interventions can dampen or redirect feedback loops in ways that are difficult to model. While the framework can highlight emerging stress, it cannot fully predict how non-market forces will alter outcomes.
- Coordination Challenges Across Stakeholders—The effectiveness of CVRs increases with shared adoption. However, insurers, reinsurers, regulators, and public bodies operate under different incentives and time horizons. Without coordination, fragmented implementation may weaken signals or create inconsistent responses. A rating downgrade that influences pricing but not public investment, or vice versa, limits the framework's ability to break feedback loops.
- Ethical and Distributional Considerations—Assigning vulnerability ratings to regions raises ethical questions. Poorer areas may face downgrades driven by limited resources rather than poor risk management, potentially worsening inequality. Importantly, CVRs and FSIs should function as indicators, not forecasts. They are designed to inform decisions, and target mitigation and support, rather than replacing judgement and simply justifying exclusion. There is a risk that ratings become treated as definitive assessments of future insurability or lack thereof, rather than as signals of evolving vulnerability. Used carelessly, the framework could reinforce exactly the rigidity it seeks to avoid.

## CONCLUSION

Climate risk is often described as "nonlinear" and framed as a modeling problem rather than a modeling, governance, and coordination problem. Its nonlinearity does not come from the climate alone, but from the system's reaction to it. By borrowing the discipline of credit ratings and embedding it within actuarial modeling, this approach makes feedback loops visible, measurable, and importantly, manageable. It does not eliminate climate risk, but it allows insurers and policymakers to identify when rational responses begin to create collective instability. The value of this framework lies not in eliminating uncertainty, but in organizing it—making feedback loops visible before they become unavoidable. Its success depends as much on cautious interpretation and institutional discipline as on actuarial technique. In a climate-stressed world, the question is no longer whether losses will occur. It is whether actuarial frameworks can identify and moderate the feedback mechanisms that can prevent their own responses from becoming the next source of risk.

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