Refining vulnerability assessment in catastrophe (CAT) models with distributional regression: Application to flood damage forecasting

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Abstract

In recent years, global insured losses from natural catastrophes have been increasingly driven by more frequent, localized, and medium-severity events. This trend is influenced by climate change and socioeconomic factors such as urbanization, posing significant challenges for at-risk individuals, insurers, and regulators. To estimate uncertain losses from perils like floods, insurers typically employ catastrophe (CAT) models that simulate physical hazards and assess the vulnerability of exposed assets.

However, conventional models often rely on univariate, deterministic mappings from physical parameters to damage estimates, with limited consideration of the underlying variability in vulnerability. To address this, our project proposes the use of distributional regression and deep learning alternatives to enhance traditional damage assessment techniques.

The proposed approach offers three key advantages. First, it enables flexible modeling of the full probability distribution of damage across different hazard intensities. Second, it retains the core structure of traditional models by forecasting damage based on physical hazard attributes, environmental conditions, and property characteristics. Third, it preserves information about aleatoric uncertainty, allowing for the extraction of various distributional functionals—such as quantiles or exceedance probabilities—tailored to different risk management objectives.

To demonstrate the application of the proposed method, we develop distributional models to assess the wide variability in flood damage using individual insurance data from the U.S. National Flood Insurance Program (NFIP). Our models allow flood parameters and building features to flexibly influence different aspects of damage distribution. Key model outputs are designed to be interpretable and comparable with existing empirical studies and actuarial CAT model frameworks. Our results highlight the promise of this approach as an alternative to conventional damage assessment methods under evolving climate risks.