NH41E-0449: Modeling Long-Term Household Flood Adaptation under Social Heterogeneity: A Coupled Agent-Based Modeling Framework

COMPLEX ADAPTIVE WATER SYSTEMS

Wenyu Chiou, Lehigh University, Bethlehem, PA, USA, wec324@lehigh.edu
Y. C. Ethan Yang, Lehigh University, Bethlehem, PA, USA, yey217@lehigh.edu
Tomohiro Tanaka, Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan, NM, tanaka.tomohiro.7c@kyoto-u.ac.jp
Sarawut Jamrussri, Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan, NM, jamrussri.sarawut.8z@kyoto-u.ac.jp
Shi Feng, Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan, NM, headwind0505@gmail.com

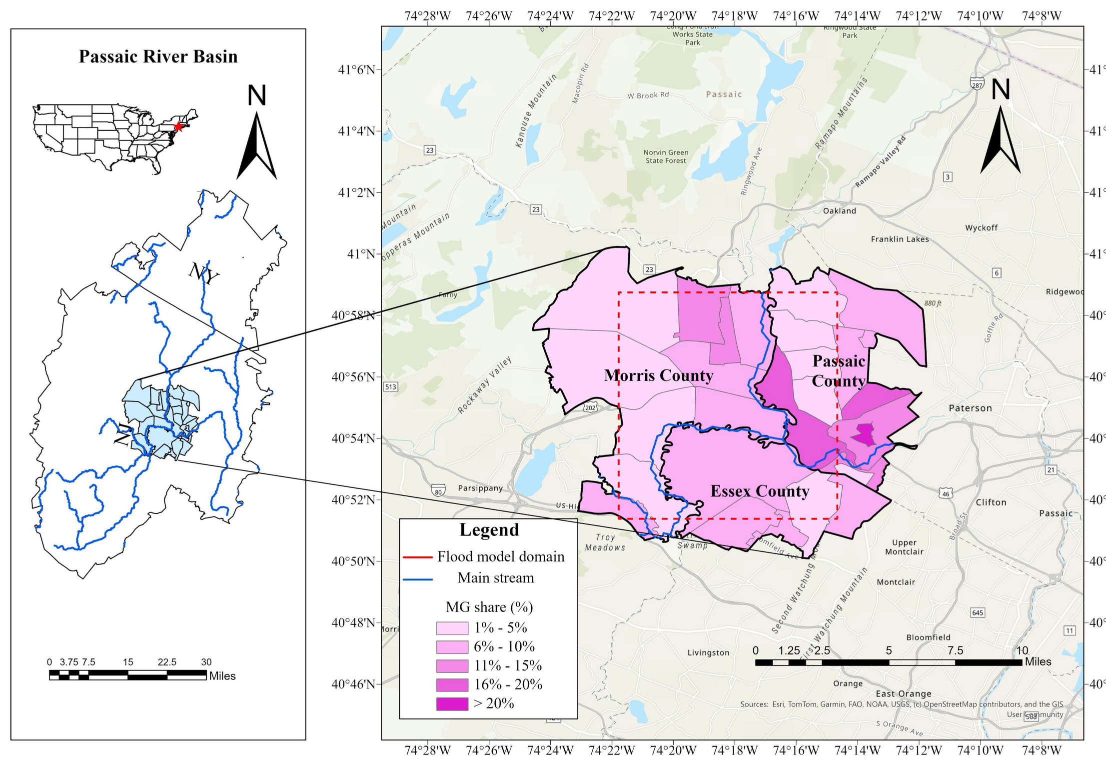
Lehigh University – Center for Catastrophe Modeling and Resilience

INTRODUCTION

- Flood adaptation varies across households with different social context.
- Homeowners and renters make different choices, and neighborhood social makeup strongly influences these decisions.
- Traditional models often assume uniform behavior, missing this complexity.
- **Our approach uses a coupled Agent-Based Model (ABM) to represent social diversity and household decision-making, and to explore long-term impacts on adaptation and financial outcomes.**

CASE STUDY AREA

Passaic River Basin

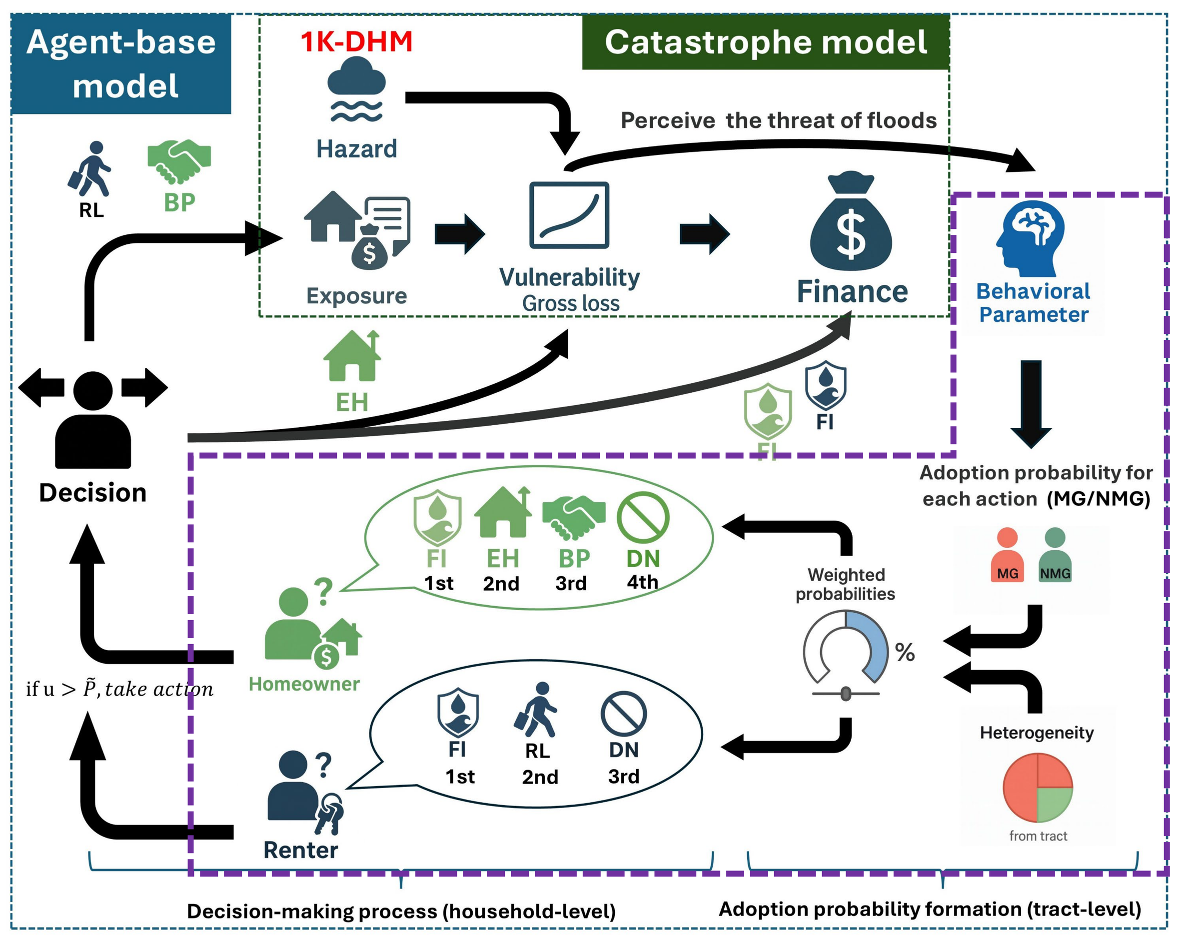


The **Passaic River Basin**, covering parts of New York and New Jersey, is highly flood-prone. Agents represent households (owners and renters) across census tracts in Essex, Morris, and Passaic Counties with varying shares of MG.

METHOD

Coupled ABM Framework

- Integrates a multilevel (tract & household) coupled ABM with exposure, hazard, vulnerability, and finance modules in the catastrophe model.
- The hazard component uses pre-run (2011–2023) grid-level peak flood depths from the *1K-DHM model*, a distributed hydrologic model based on kinematic wave theory.



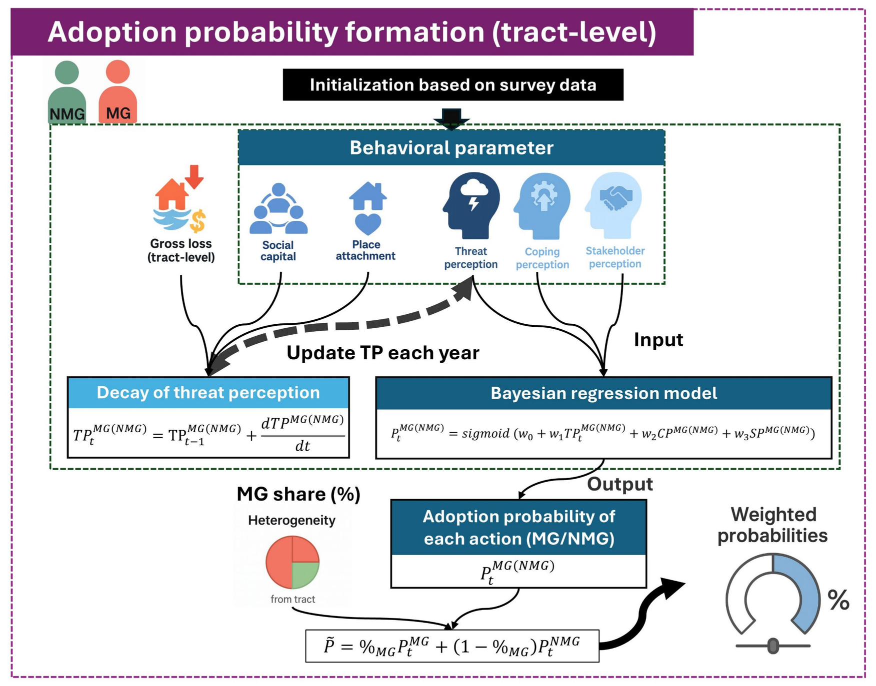
Note: The processes within the purple dashed box are discussed in the following section.

Decision-Making Process

- Each household takes one adaptation action per year following a fixed sequence.
- **Owners:** Flood Insurance (FI) → Elevation (EH) → Buyout (BP) → Do Nothing (DN)
- **Renters:** FI → Relocation (RL) → DN. (EH only once)
- A random seed $u \sim U(0,1)$; if $u > \tilde{P}$, the action is taken. Otherwise, the household proceeds to the next option, ending with DN if none are triggered. $\tilde{P}$ is the weighted adoption probability of each action.

Adoption Probability Dormation

- Tract-level social heterogeneity (MG/NMG share) informs the adoption probability of each adaptation action.
- Threat (TP), coping (CP), and stakeholder perceptions (SP) feed into a Bayesian regression model estimating MG/NMG action probabilities.
- The weighted probability ($\tilde{P}$) acts as the decision threshold for household actions.
- TP evolves with tract-level flood damage ratio (G_t/RCV_t) and decays by place attachment (PA) , social capital (SC) , and half-life function $\tau(t)$.



$$\frac{dTP_t^{MG(NMG)}}{dt} = \Delta(\psi(t)) \cdot \frac{G_t}{RCV_t} - \mu TP_t^{MG(NMG)}$$

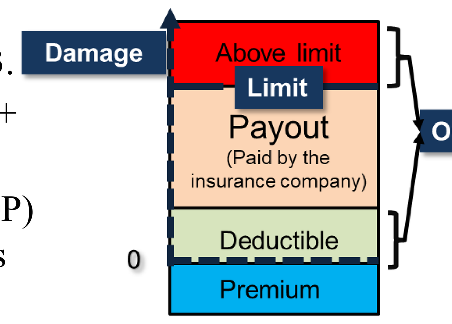
$$\Delta(\psi(t)) = \begin{cases} 1, & \frac{G_t}{RCV_t} > \theta \sim 0.5 \\ 0, & else \end{cases}, \mu = \frac{\ln(2) * (\alpha * (1 - PA^{MG(NMG)}) + \beta SC^{MG(NMG)})}{\tau(t)}$$

$$where\ \tau(t) = \tau_\infty - (\tau_\infty - \tau_0)e^{-kt}\ with\ \tau_\infty > \tau_0 > 0, k > 0$$

G_t: Total gross loss at tract t
RCV_t: Total replacement cost value at tract t
θ: Threshold of flood damage ratio
τ_∞: Asymptotic half–life
τ_0: Initial half–life
k: Saturation rate

Catastrophe Model

- **Exposure module**: defines replacement cost value (RCV) for homeowners (structure + contents), and for renters (contents only) at all tracts.
- **Hazard module**: provides tract-level peak flood depth from 2011 to 2023.
- **Vulnerability module**: estimates flood damage (homeowners: structure + contents; renters: contents only)
- **Finance module**: evaluates premium, payout (P), and out-of-pocket (OOP) based on coverage type (homeowners: structure + contents; renters (contents only).



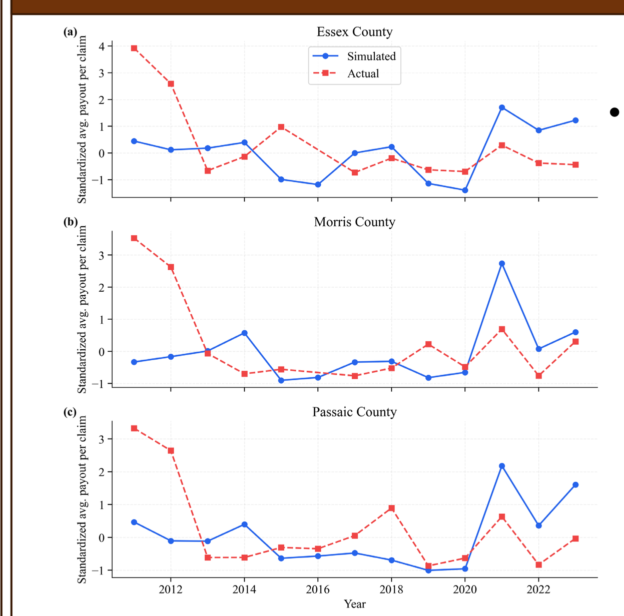
$$P = \max\{0, \min(G, L) - D\}$$

$$OOP = \begin{cases} G & if\ G \le D \\ D & if\ D < G \le L \\ D + G + L & if\ G > L \end{cases}$$

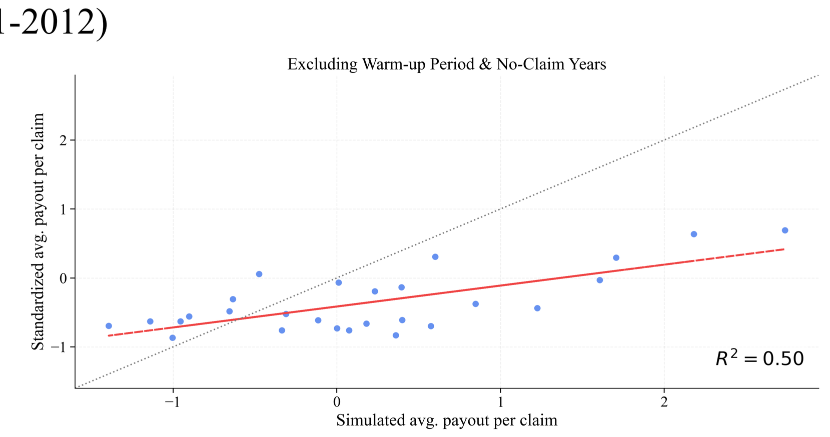
G: Household gross loss
L: Limit ($250K for structure coverage; $100K for contents coverage)

RESULT & DISCUSSION

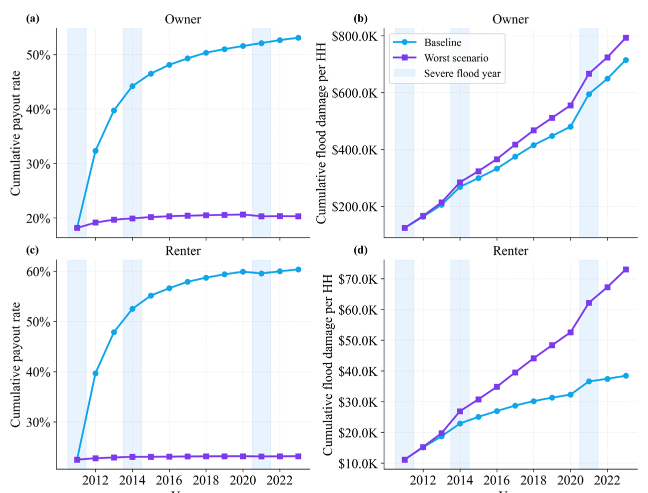
Model Diagnostics



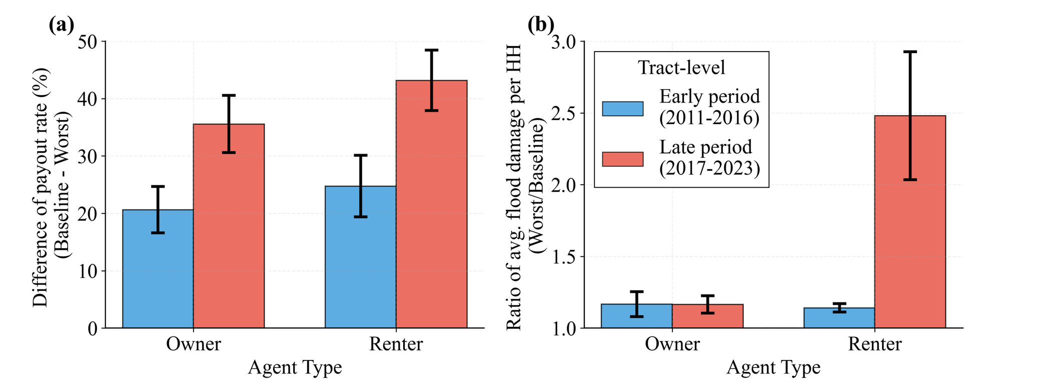
- To assess the model's stable performance, the goodness-of-fit analysis (R^2) was calculated after excluding the initial model's 'warm-up' years (2011-2012)



Asymmetric Impacts of Adaptation on Owners and Renters

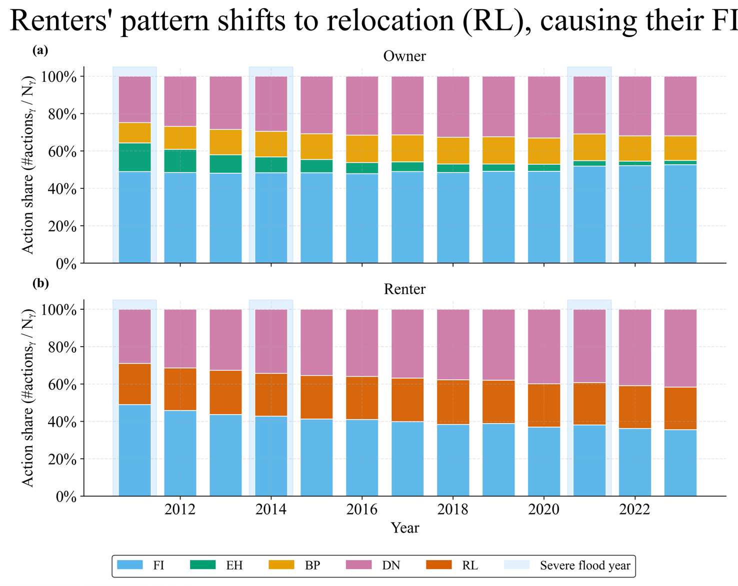


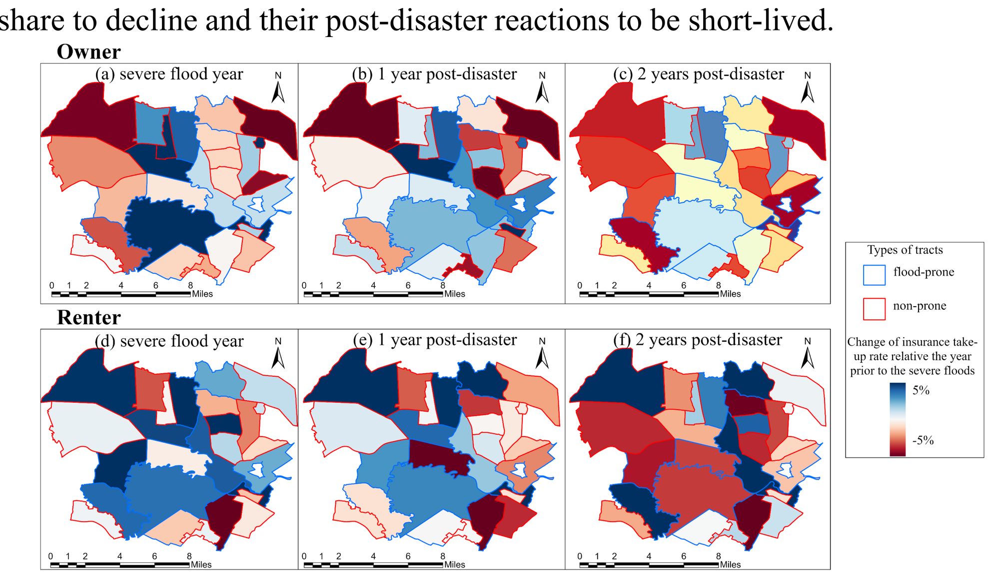
- Inaction's cost for renters escalates >2.5x in later periods.
- Adaptation yields 35% payout advantage for owners, and 43% for renters.



Divergent Behavioral Patterns of Homeowners and Renters

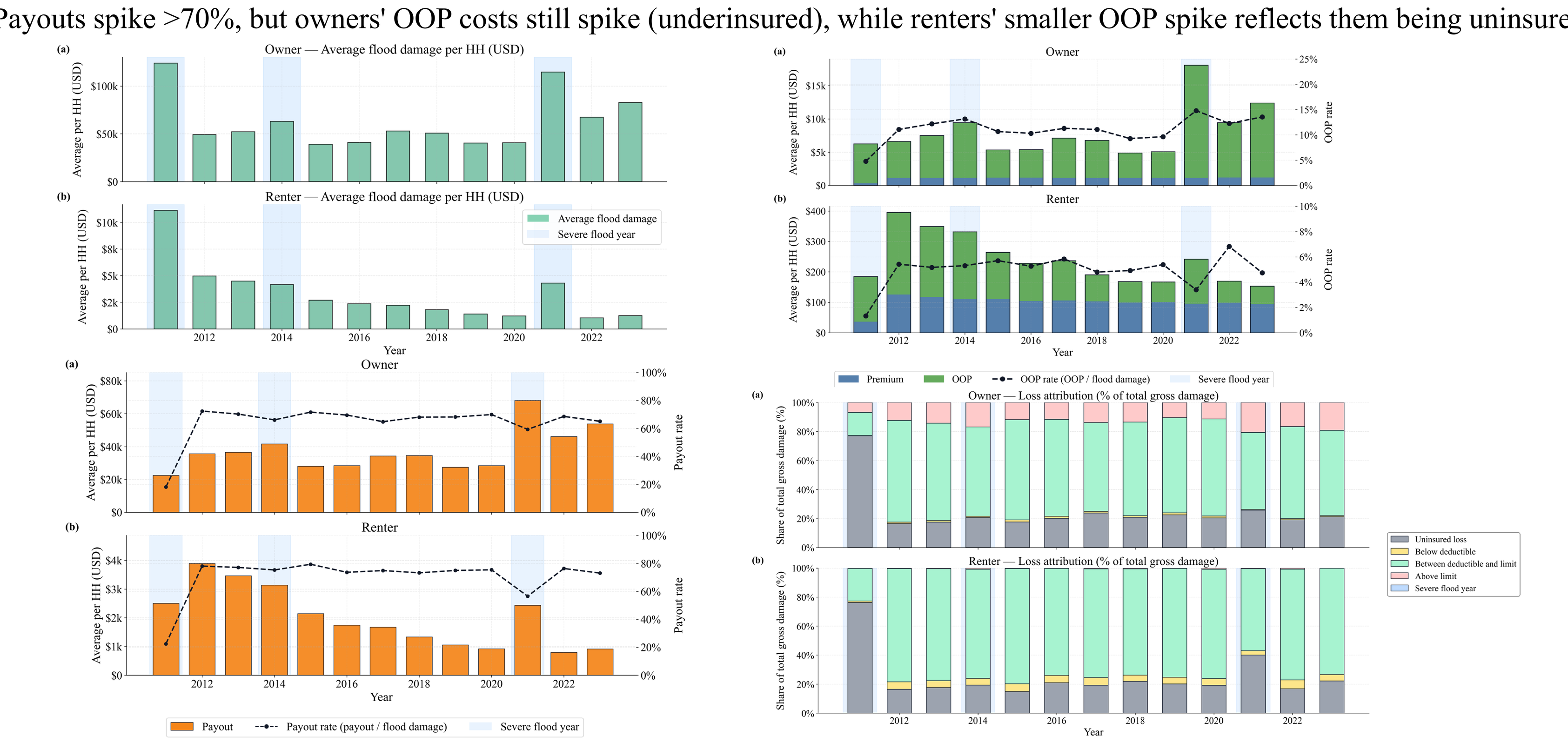
- Homeowners' adaptation pattern is stable, as the flat FI share is a statistical illusion masking offsetting spatial trends.
- Renters' pattern shifts to relocation (RL), causing their FI share to decline and their post-disaster reactions to be short-lived.





Flood Damage & Financial Outcomes

- Homeowners' damages remain high and spiky; renters' damages trend down, likely driven by RL.
- Payouts spike >70%, but owners' OOP costs still spike (underinsured), while renters' smaller OOP spike reflects them being uninsured.



CONCLUSION

- Adaptation benefits widen over time, and renters gain proportionally greater insurance advantages despite lower absolute losses.
- Homeowners appear stable overall, as FI flatness masks offsetting spatial trends, while renters relocate, driving FI decline and short-lived post-disaster reactions.
- Flood damage and financial outcomes diverge, with homeowners facing higher financial losses and OOP costs while renters gain greater insurance protection.

ACKNOWLEDGEMENTS

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