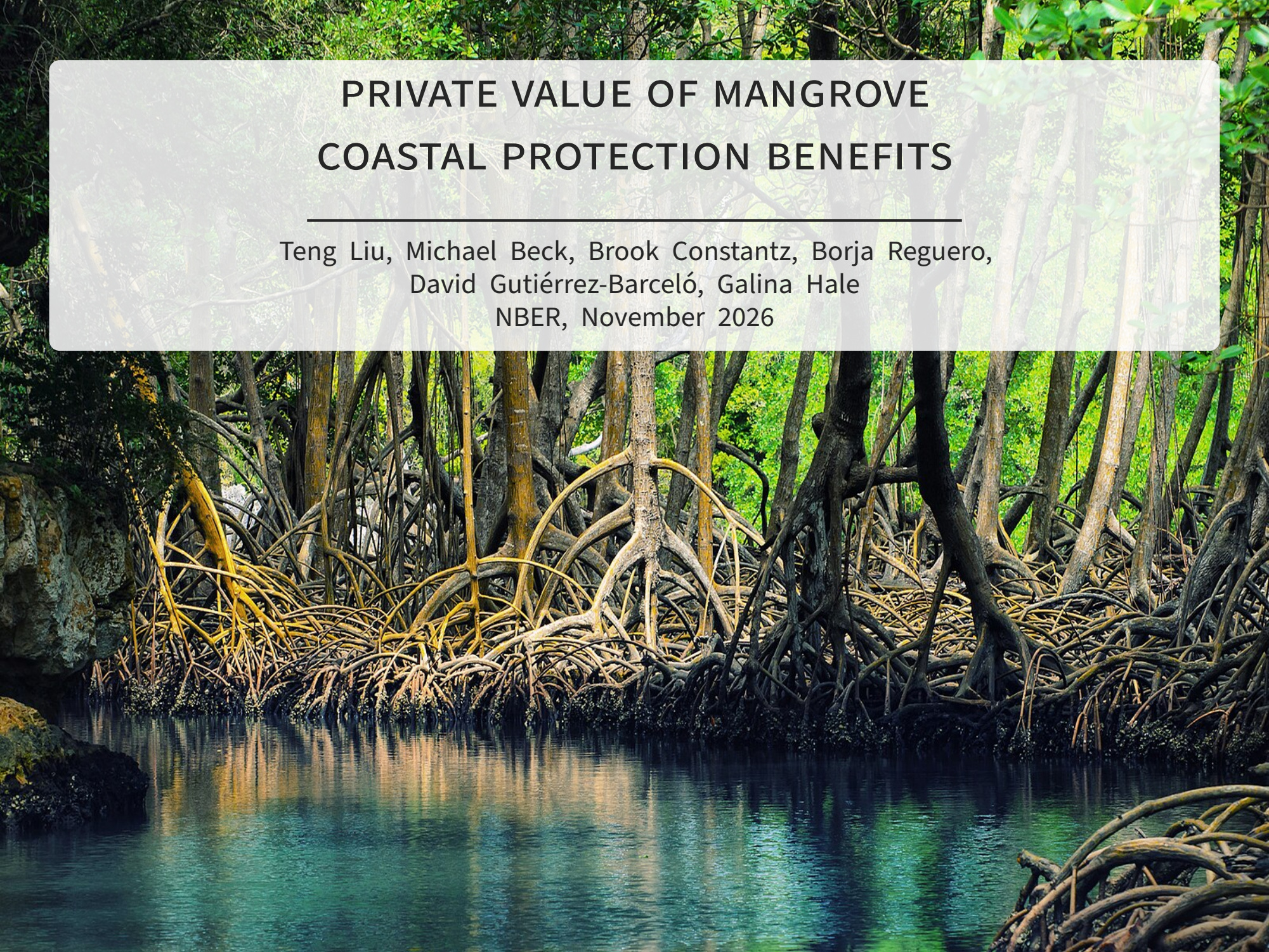


PRIVATE VALUE OF MANGROVE COASTAL PROTECTION BENEFITS

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NATURE IS TREATED AS A PUBLIC GOOD — AND UNDERFUNDED

- Ecosystems provide
  climate adaptation, flood protection, biodiversity, carbon storage
- These services are rarely valued quantitatively at the granular level
- They are treated as public goods and public and philanthropic funding falls far short of need (Flammer et al., 2025)
- Private finance for nature requires quantifiable private benefits:
  who gains, by how much, and how should that be priced?

MANGROVES IN FLORIDA: HIGH VALUE, HIGH EXPOSURE

- Mangroves reduce waves, storm surge, and shoreline erosion

  (Maza et al., 2019; Montgomery et al., 2019)

- Florida holds >90% of US mangroves
  and >1/3 of all National Flood Insurance Program policies

- Mangroves averted ~$725M in damages in Hurricane Irma and ~$4.1B in Hurricane Ian

  Catastrophe models: (Narayan et al., 2025)

- Global mangroves declined ~4% (1996–2010);
  development is the main threat in populated areas

- Flood protection is crucial for Florida's property-insurance crisis

WHAT THIS PAPER DOES

Question: what is the private value of mangrove flood protection, capitalized in residential property values?

1. Build a consumption-based asset-pricing model of house prices with storm disasters
2. Feed it two *different loss inputs*, each with and without mangroves:
   - RAP — risk-based asset pricing: modeled flood damages from hydrodynamic + catastrophe models (*ex ante*)
   - MAP — market-based asset pricing: post-hurricane price responses estimated in Liu et al. (2026) (*ex post*)
3. Hazard model for RAP without and with climate change (SSP5-8.5)
4. Aggregate to county level for seven Florida counties

PREVIEW OF RESULTS

- Statewide value of mangrove protection to residential property:
  - RAP: $14.3B without climate change, $17.2B with climate change
  - MAP: $18.1B
- Pricing risk matters: state-dependent discounting roughly doubles a conventional expected-damages present value
- RAP and MAP diverge sharply by county
  - Collier, Lee, Miami-Dade: market value *below* modeled value
  - Pinellas, Manatee, Hillsborough: market value *far above* modeled value
- Per property: up to $103K, 13% (RAP) and $23K–$117K, 20% (MAP)

RELATED LITERATURE

- Rare disasters and housing in consumption-based models

  (Rietz, 1988; Barro, 2006; Piazzesi, Schneider & Tuzel, 2007; Gabaix, 2012; Wachter, 2013)

- Climate risk is (partially) priced in real-estate markets

  (Bernstein, Gustafson & Lewis, 2019; Baldauf, Garlappi & Yannelis, 2020; Keys & Mulder, 2020; Giglio et al., 2021)

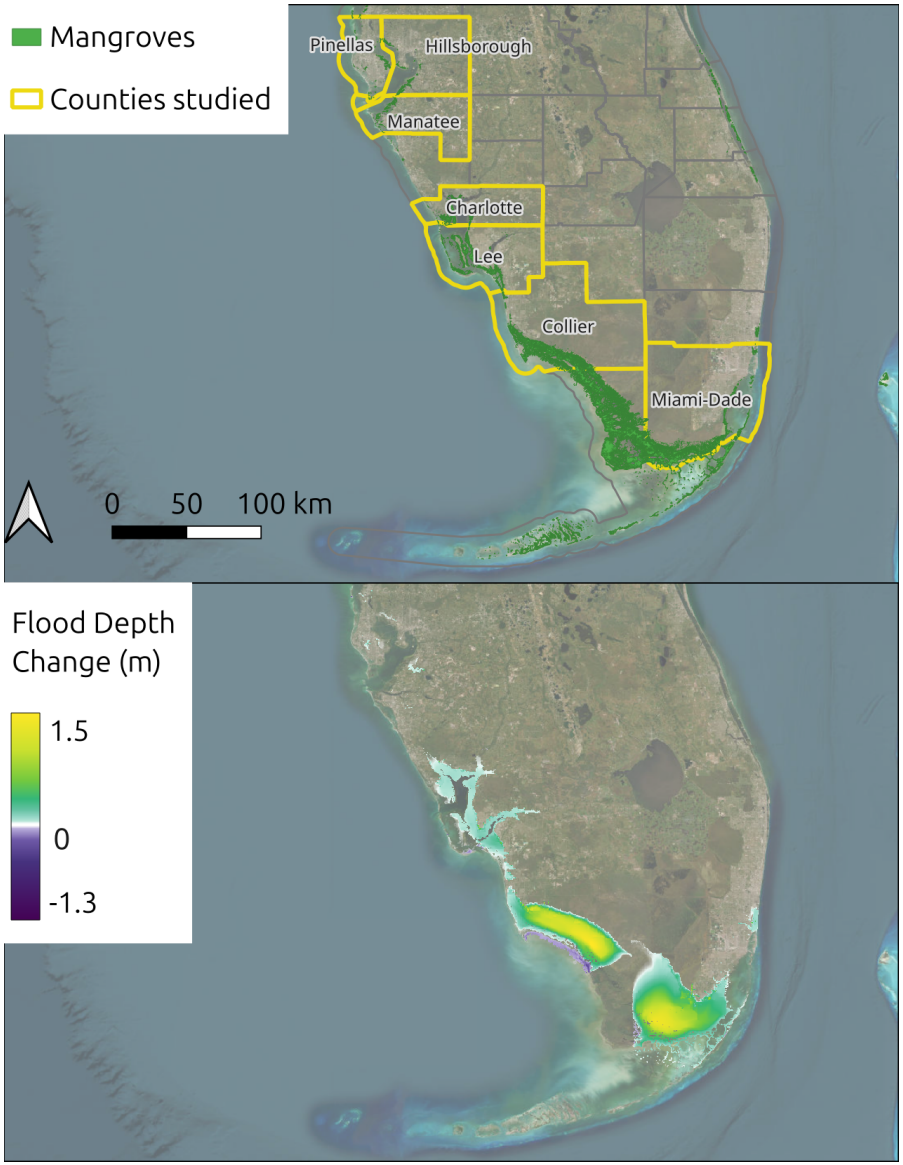
- Catastrophe-risk valuation of nature-based protection — avoided damages (Menéndez et al., 2020; Beck et al., 2022; Narayan et al., 2025)

- Hedonic valuation of coastal risk; nature finance

  (Bin & Polasky, 2004; Kousky et al., 2020; Liu et al., 2026; Flammer et al., 2025; Giglio et al., 2026)

Contributions: • engineering ("how much damage is prevented?") and market ("what should private agents pay for protection?") evidence in *one* asset-pricing framework; • accounting for second moments; • SDF

STUDY AREA: SEVEN FLORIDA COUNTIES



- **Top:** mangrove extent (Global Mangrove Watch 2020) and the seven counties — almost all of Florida where mangroves protect people and property
- **Bottom:** increase in flood depth (m) if mangroves are removed, RP50
- Up to 1.5 m deeper flooding behind the large mangrove belts of Collier and Miami-Dade

WORKING WITH RETURN PERIODS

- A return period (RP) is a quantile of the annual hazard distribution
- RPN event = intensity exceeded with probability $1/N$ in any given year

	RP10	RP25	RP50	RP100
Annual probability	10%	4%	2%	1%

- Engineers deliver flood maps at these four points of the distribution
- For us: four discrete disaster states, each with its own damage and consumption shock
- (Not in this paper) Four points are enough to fit a Pareto distribution

FROM STORMS TO DOLLAR DAMAGES: THE PHYSICAL PIPELINE

- **Storm forecast:** as a function of sea level with and without climate change => storm surge + waves
- **Hazard:** hydrodynamic model: terrain (10m grid) $\longrightarrow$ flood depth
- **Exposure:** every building (USACE National Structure Inventory + Microsoft footprints), values in 2025$ (“book” values, not market)
- **Vulnerability:** FEMA Hazus depth–damage curve by occupancy, foundation, stories $\Rightarrow$ % of structure value lost
- **Input into asset pricing model**

Note: not using FEMA flood maps

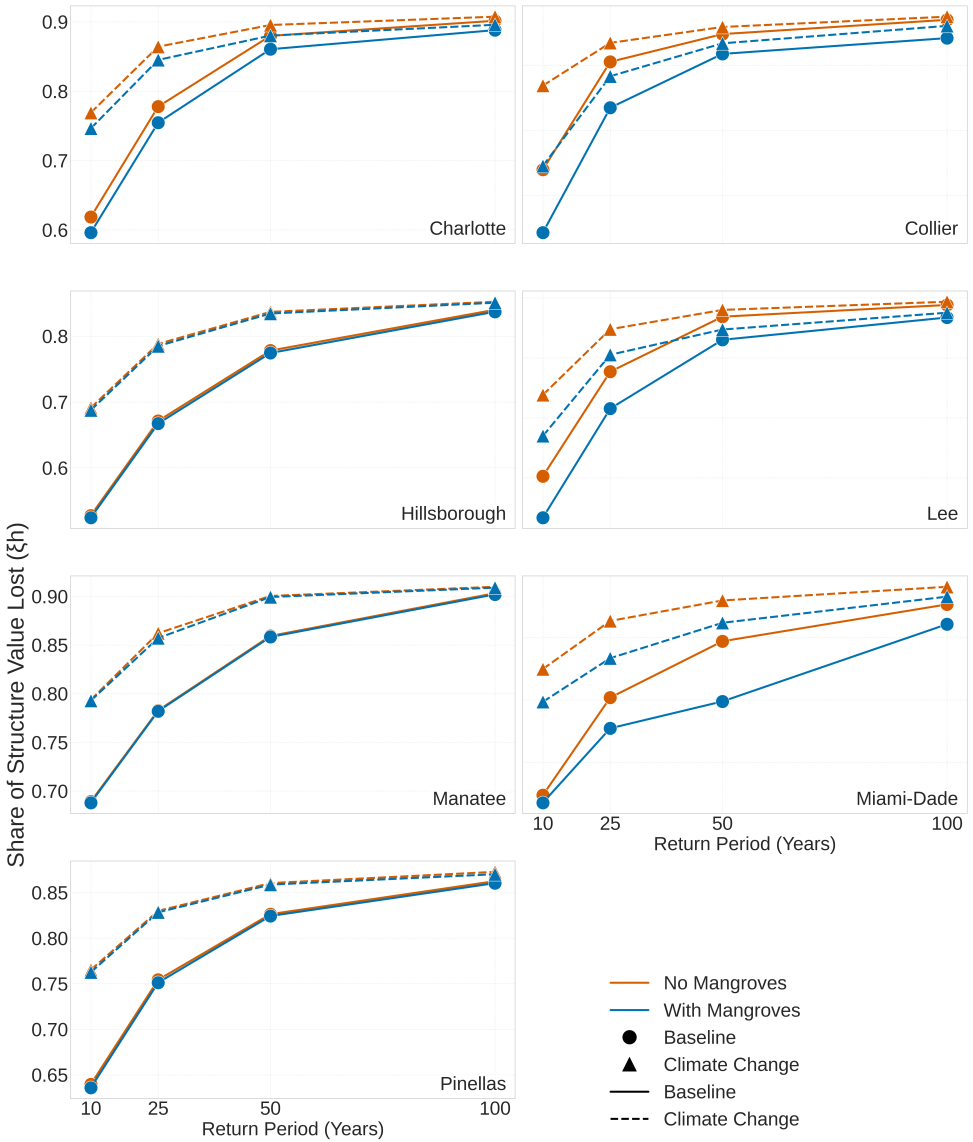
THE FLOOD MODEL

The flood model (SFINCS):

$\mapsto$ flood depth = f(water level, waves, terrain, surface friction)

- **Inputs:** extreme sea levels and storm shapes + synthetic cyclones (COAST-RP, ERA5, STORM); lidar terrain (USGS 3DEP, NOAA CUDEM)
- Mangroves enter as friction: roughness $n = 0.14$; (without $n = 0.02$)
- Climate (SSP5-8.5): higher sea level + projected surge changes
- **Output**: 2 (I(mangrove)) $\times$ 4 RPs $\times$ 2 climate scenarios = 16 flood maps

DIRECT LOSS PARAMETER ξ_h



- $\xi_h = \frac{1}{N} \sum_i \text{damage}_i / \text{value}_i$
- Large (0.5–0.9): *conditional on flooding*, *structure only*; >1.3 m of water ⇒ near-total loss
- Mangroves act on two margins:
  - **intensive**: shallower water
  - **extensive**: fewer homes flood, $\xi_h^m \cdot N_{fl}^m / N_{fl}^0$
- Orange–blue gap is what matters: largest in Collier, Lee, Miami-Dade
- Climate (dashed): higher losses; gap often narrows (overtopping)

STOCHASTIC DISCOUNT FACTOR WITH STORM DISASTERS

Representative household, CRRA utility, storm state $s_t \in \{0, 1\}$:

$$m_{t+1} = \beta \left(1 + g_c\right)^{-\gamma} \left(1 - s_{t+1}\, \xi_c\right)^{-\gamma}$$

- g_c — trend consumption growth; ξ_c — consumption drop when a storm hits
- Rare-disaster logic (Rietz; Barro; Wachter), but regional disasters: ξ_c = 1%, 2%, 4%, 8% for RP10–RP100, vs. 10–60% in macro-disaster calibrations
- Calibrated below developing-country hurricane evidence (7–11%) and spanning Norwegian evidence with full insurance (3–5%)
- Mangroves do not affect ξ_c — income disruption, displacement, regional effects occur regardless of one's own structure

HOUSE PRICE

Housing services $d_t = \delta H_t$; storm damage ξ_h:

$$H_t = \mathbb{E}_t\left[m_{t+1}\left(1+\delta\right)\left(1-s_{t+1}\,\xi_h\right)H_{t+1}\right]\left(1-s_t\,\xi_h\right)$$

Iterating forward:

$$H_t = \mathbb{E}_t\left[\sum_{j=1}^{\infty}(1+\delta)^j\prod_{k=1}^{j}m_{t+k}\left(1-s_{t+k}\,\xi_h\right)\right]\left(1-s_t\,\xi_h\right)$$

- A storm enters twice: **value loss** $\left(1-s\,\xi_h\right)$ and **SDF** $\left(1-s\,\xi_c\right)^{-\gamma}$

MANGROVES AFFECT THE LOSS PARAMETER

$$\xi_h^m = \xi_h \cdot \big(1 - a(d,w)\big), \qquad 0 < a(d,w) < 1, \quad \frac{\partial a}{\partial d} < 0,\ \frac{\partial a}{\partial w} > 0$$

- $a(d,w)$: adaptation benefit of a mangrove belt of width w at distance d
- Value of mangroves for a representative property as a share of value: $V^m = \big(\mathbb{E}[H^m] - \mathbb{E}[H]\big)/\mathbb{E}[H]$
- **Same model, two loss inputs:**
  - RAP: $(\xi_h,\ \xi_h^m)$ from the flood/damage pipeline
  - MAP: $(\hat{\xi}_h,\ \hat{\xi}_h^m)$ inferred from observed post-storm price changes
- County total = $V^m \times$ value of the *at-risk* stock: homes that flood in a 100-year storm without mangroves

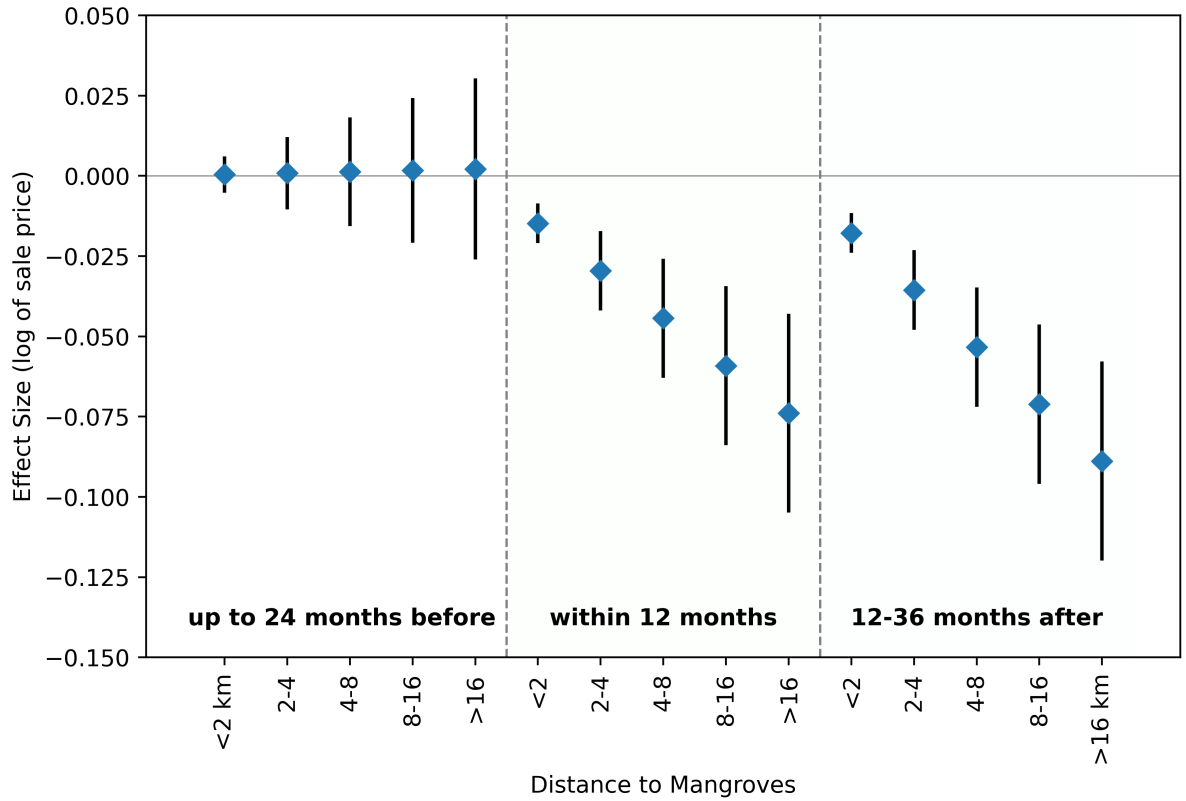
CALIBRATION

Preferences	$\beta = 0.95, \gamma = 2, g_c = 2.5\%$ (Florida > US ~2%)
Rental yield (δ)	7% — BEA PCE housing services / Florida housing stock; Zillow metro rent-to-price ratios average 6.8%
Consumption shock (ξ_c)	1% / 2% / 4% / 8% for RP 10 / 25 / 50 / 100
Storm probabilities	10% / 4% / 2% / 1%, independent Bernoulli by RP; *same* in both climate scenarios => max 4 storms / year
Climate change	Deeper and wider flooding
RAP loss ξ_h	Flood/damage pipeline, county × RP × climate scenario
MAP loss $\hat{\xi}_h$	Liu et al. (2026): pooled $\hat{\xi}_h^{100} = 0.074$ (no mangroves), 0.015 (with mangroves) + county-level estimates
Simulation	1,000 Monte Carlo storm paths, 2024–2100

PRIOR WORK — LIU ET AL. (ROF,2026): HEDONIC EVIDENCE

- Question: how do housing markets price the storm-protection value of mangroves *conditional on hurricanes*?
- Data: Zillow ZTRAX transactions (>1M), Florida 1993–2018 + Global Mangrove Watch + FEMA flood zones + NHC hurricane tracks
- Design:
  - Pre- vs. post-hurricane price changes for the same property
  - Repeated-sales regression with property fixed effects
  - Distance-to-mangrove bins: 0–2 km, 2–4, 4–6, 6–8, 8+
  - Identified from properties outside FEMA high-risk zones ⇒ less distorted by subsidized NFIP insurance and regulation

PRIOR WORK — KEY FINDINGS FROM LIU ET AL. (ROF,2026)



- Level effect: 0–2 km properties see post-hurricane price declines up to 6 ppts smaller than those located further
- Robust to distance-to-coast controls, sales-frequency reweighting, excluding 2007–09 crisis, insurance / climate-beliefs controls

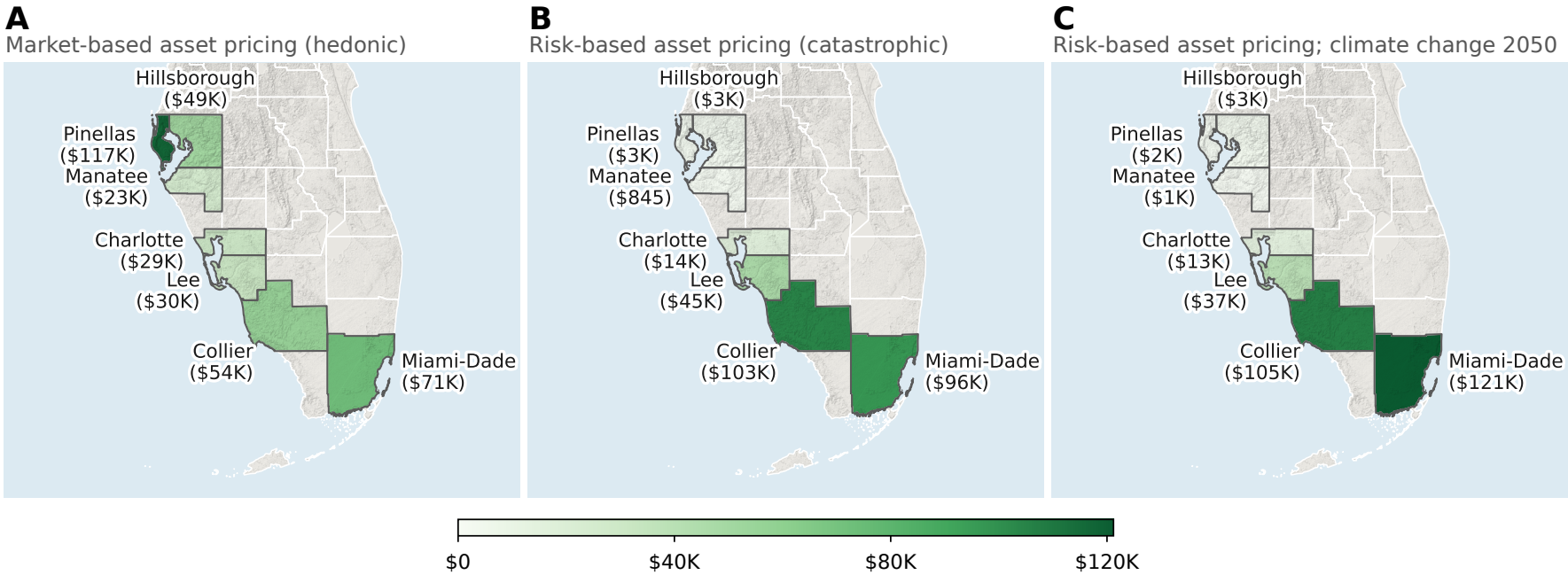
MAP LOSS PARAMETER

- Liu et al. (2026) estimate the price response to a 100-year storm ($\hat{\xi}_h$)
- In our model, $H_{t_0}/H_{t_0-1} = 1 - \hat{\xi}_h$ (risk is already priced)
- Smaller storms:
  linear rule $\hat{\xi}_h(\text{RP}) = \frac{\text{RP}}{100}\,\hat{\xi}_h^{100}$ — the most conservative rule we tried

County	Coef. (SE)
Hillsborough	-0.065^{***} (0.007)
Manatee	-0.036^{***} (0.009)
Miami-Dade	-0.032^{***} (0.004)
Pinellas	-0.116^{***} (0.007)
Charlotte, Collier, Lee	Pooled (0.074)

VALUE PER PROPERTY

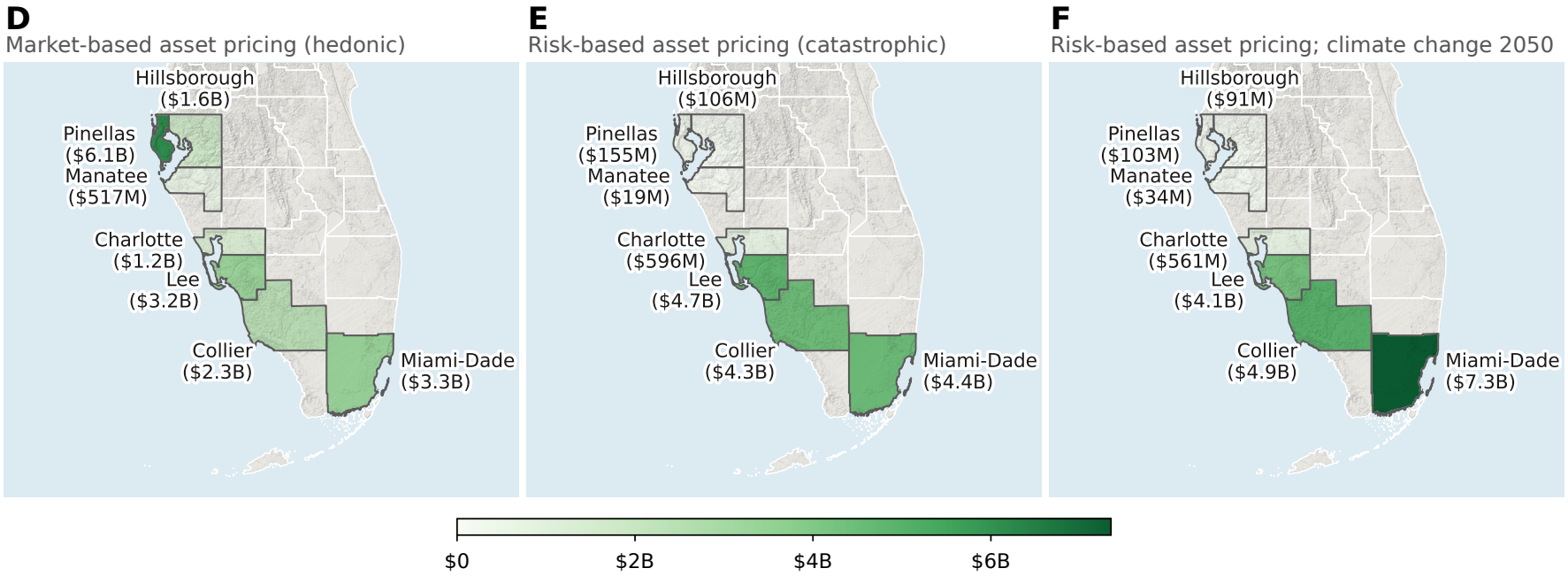
Mangrove protection value per property



- RAP ranges from a few hundred dollars (Manatee) to $103K (Collier)
- MAP is more compressed, $23K–$117K: 6.9% of value where the pooled estimate applies; 4.5–4.6% Manatee/Miami-Dade; 20% Pinellas
- MAP and RAP are not highly correlated across counties

COUNTY TOTALS

Mangrove protection value, county total



- Only homes *at risk of flooding* are aggregated — exposure shares differ a lot across counties
- RAP: $19M (Manatee) to $4.7B (Lee); MAP: $0.5B (Manatee) to $6.1B (Pinellas)
- Relative to total county housing value:
  RAP up to 7.6% (Collier), 5.5% (Lee); MAP up to 7.3% (Pinellas), 4.7% (Charlotte)

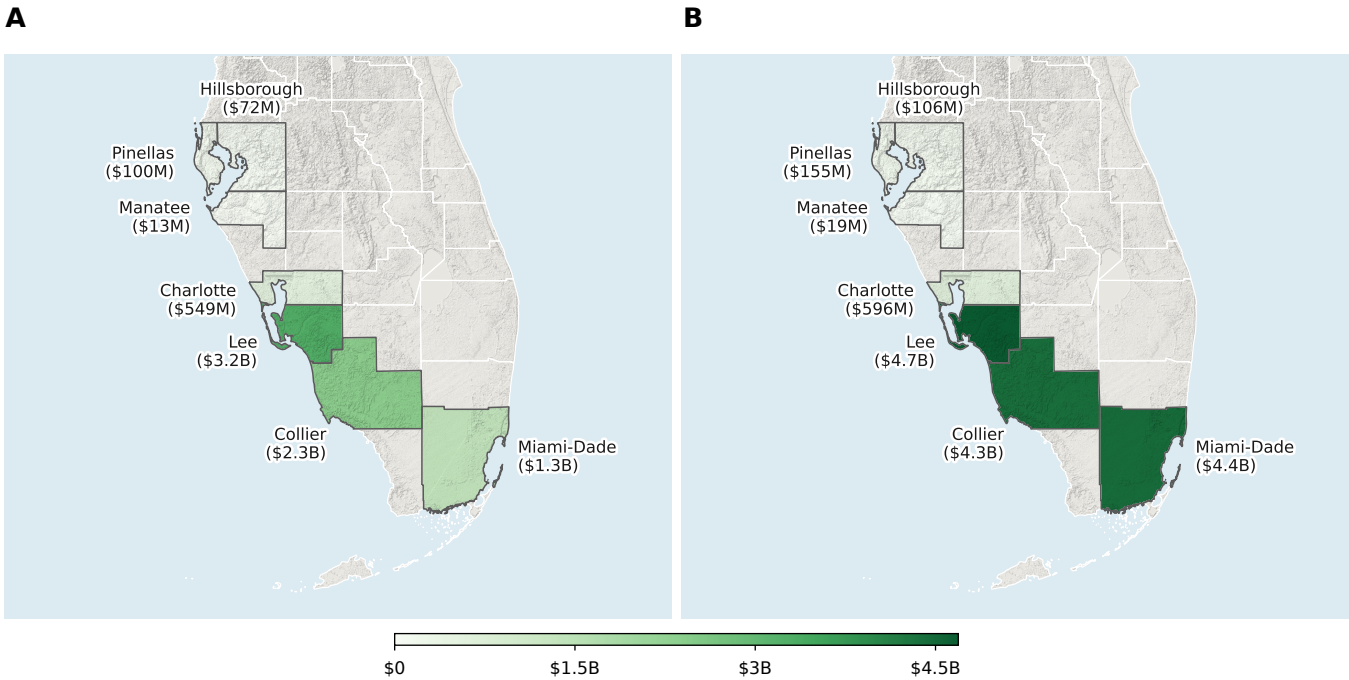
SIMILAR TOTALS, VERY DIFFERENT GEOGRAPHY

	RAP ($B)		MAP ($B)	MAP / RAP
County	No CC	CC		No CC
Charlotte	0.60	0.56	1.20	2.0
Collier	4.35	4.86	2.29	0.5
Hillsborough	0.11	0.09	1.58	14.9
Lee	4.69	4.15	3.18	0.7
Manatee	0.02	0.03	0.52	27.4
Miami-Dade	4.41	7.35	3.27	0.7
Pinellas	0.15	0.10	6.05	39.1
Total	**14.32**	**17.15**	**18.08**	1.3

CLIMATE CHANGE RAISES THE VALUE OF PROTECTION

- Statewide RAP value: $14.3B → $17.2B with 2050s flood hazard
- Two forces:
  - More exposure: at-risk homes rise from 341K to 380K
  - Saturation: deeper water overtops mangroves; protection per home falls slightly (6.1% → 5.8% of value)
- County pattern:
  - Rises: Miami-Dade ($4.4B → $7.3B), Collier, Manatee
  - Falls: Lee, Charlotte, Pinellas, Hillsborough

RAP VS. EXPECTED DAMAGES ($r = 5\%$)



- Statewide: ≈$7.5B (expected damages) vs. $14.3B (RAP)
- RAP > ED in *every* county
- Collier: $67M/yr avoided loss (Narayan et al. (2025)) ⇒ ED = $0.9B; RAP = $4.3B; MAP = $2.3B

SOURCES OF THE MAP–RAP GAP

Why MAP could exceed RAP

- Indirect losses: relocation, jobs, public infrastructure, business disruption, amenity loss
- Wind protection
- Insurance availability and cost
- Households internalize protection's value

Why MAP could be less than RAP

- Under-appreciation of (future) flood risk
- Subsidized NFIP insurance (mitigated: hedonic sample is outside high-risk zones)
- Market-implied losses spread over several years, not just the storm year

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We measure the gap but *cannot attribute* it to one mechanism.

Implication: MAP < RAP (Collier, Lee, Miami-Dade), private markets may underprice protection => public funding; otherwise, private funding of mangrove protection

LIMITATIONS

- Hard infrastructure (seawalls, bulkheads, living shorelines) not modeled explicitly — data largely unavailable
- Representative CRRA household with rational expectations; no loss aversion, ambiguity aversion, or heterogeneous beliefs
- Hedonic loss identified only for 100-year storms; linear scaling to smaller storms is conservative (alternatives raise MAP in every county)
- Flood protection value only: no carbon, habitat, erosion co-benefits; no restoration costs ⇒ not a full cost–benefit analysis

TAKEAWAYS AND IMPLICATIONS

- Mangrove flood protection has a large private value for Florida homeowners: $14–17B (risk-based) and $18B (market-based)
- Asset pricing approach roughly doubles conventional expected-damage values
- **Finance implications:** quantified private value could be a baseline for resilience bonds, public–private partnerships to pay for preservation
  - Charlotte, Collier, Lee: high value *and* high exposure — private aggregate contributions up to $1.2B, $2.3B, $3.2B (MAP)
- Framework transfers to valuing reefs, marshes, dunes as nature-based adaptation solutions as well as to gray infrastructure values

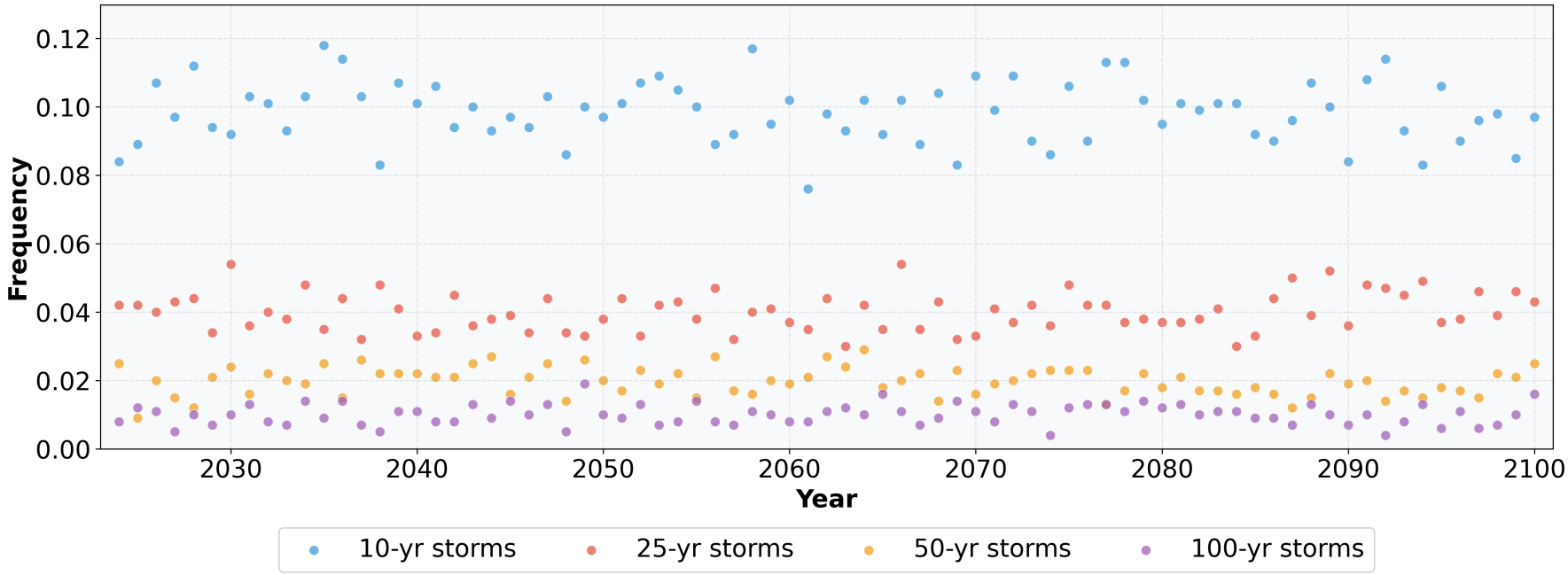
Thank you

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Code and calibration inputs:

`github.com/tengtedliu/mangrove-asset-pricing`

BACKUP: SIMULATED STORM PATHS



Realized annual storm frequency across 1,000 paths, by return period. A year can draw several storm types; the most severe one sets that year's shocks. Frequencies are identical across climate scenarios — climate change shifts the *damage* at each RP, not the draw.

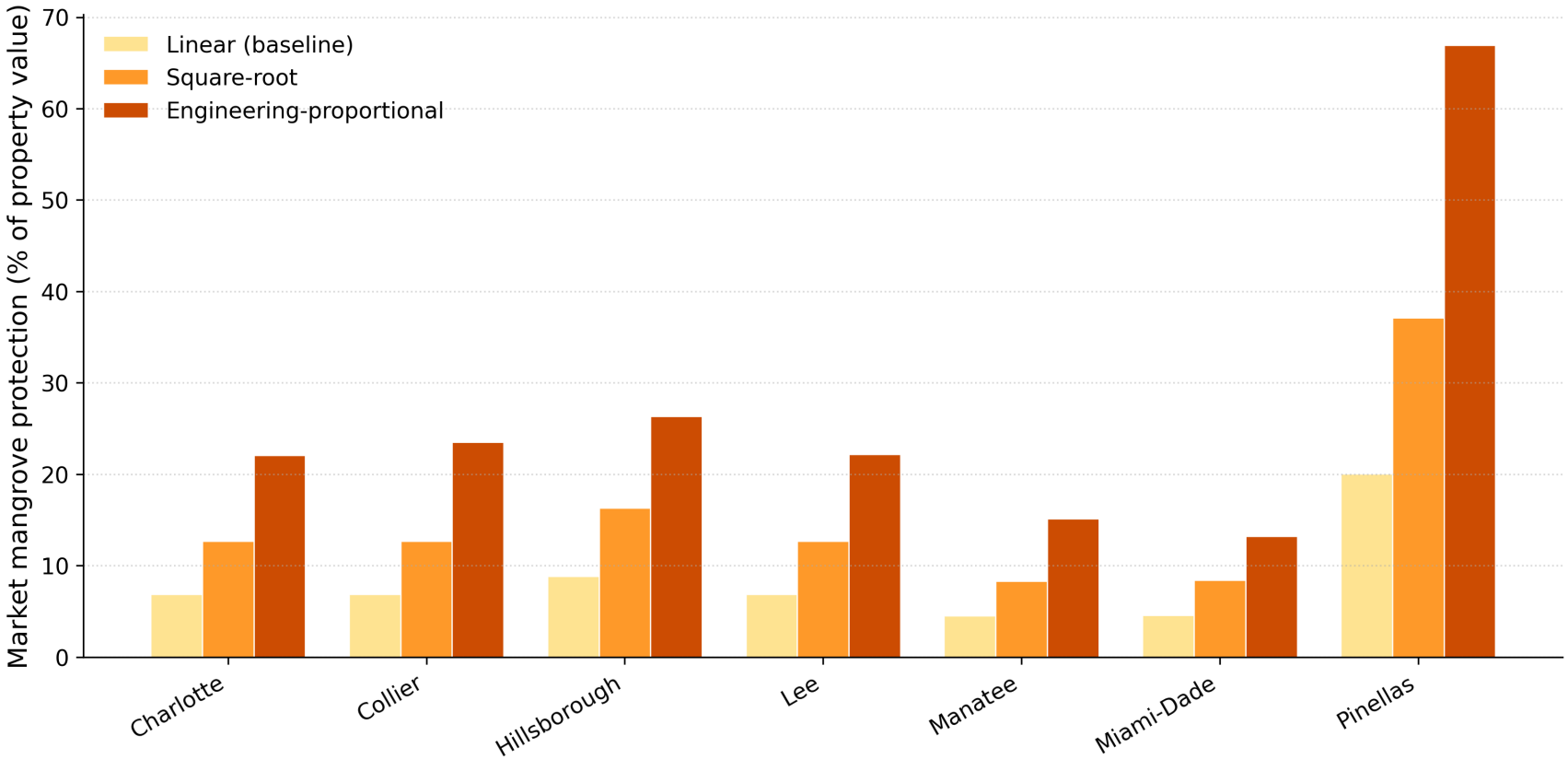
BACKUP: CONSUMPTION-SHOCK CALIBRATION

- **Macro rare disasters:** 10–60% consumption drops (Barro, 2006; Barro & Ursúa, 2009) — far too large for a regional storm
- **Developing economies:** Philippines typhoons −7.1% (Anttila-Hughes & Hsiang, 2013); Chennai flood −11% (Agarwal et al., 2024); Vietnam ∼ −7% (Bui et al., 2014)
- **Advanced economy with full insurance:** Norway, cumulative consumption decline ≈ 33% of direct damages, 3–5% over four years, driven by housing-wealth effects (Espegren et al., 2025)
- **US:** little direct consumption evidence; income losses largely transitory (Deryugina et al., 2018), but NFIP take-up <50% even in high-risk areas
- **Our choice:** $\xi_c = 1/2/4/8\%$ for RP10/25/50/100 — conservative; Florida insurance disruption suggests larger shocks

BACKUP: RENTAL YIELD δ

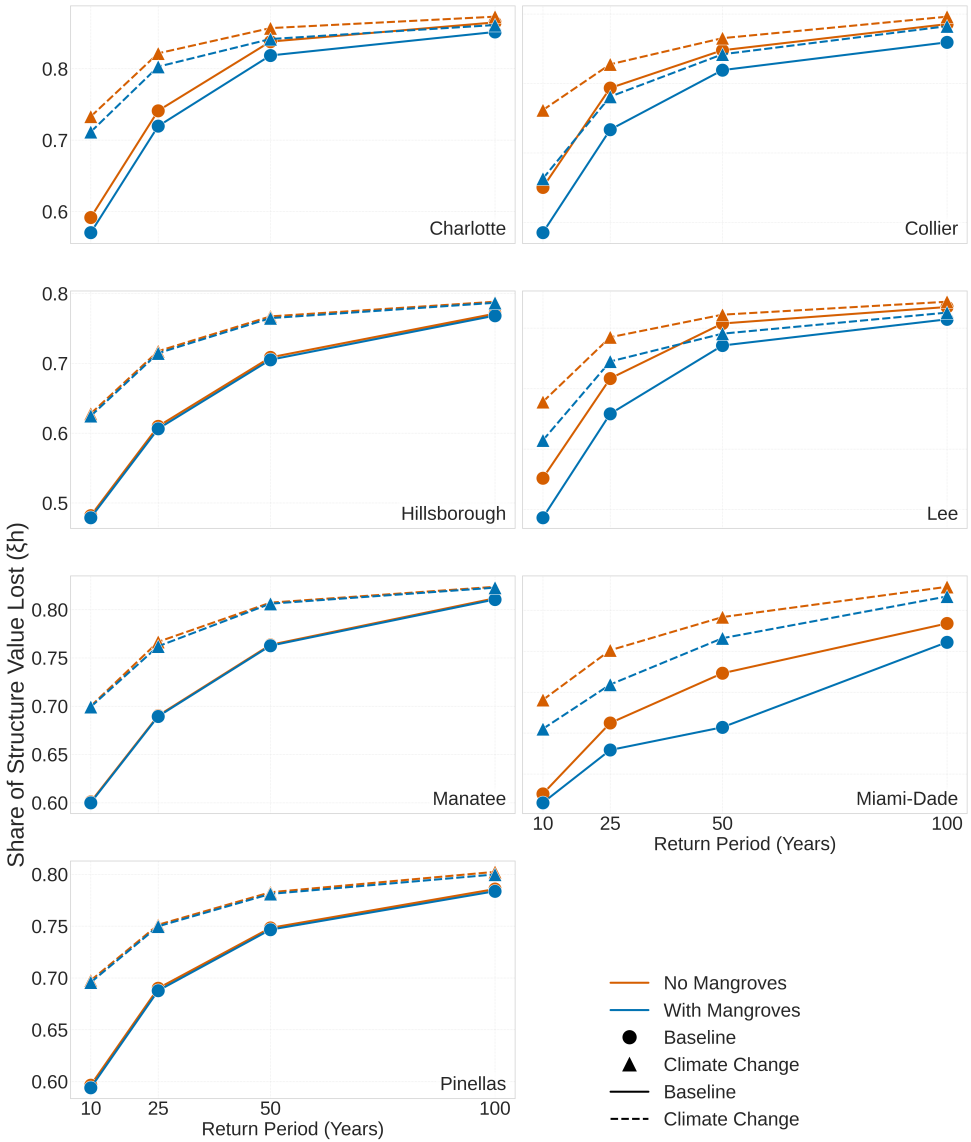
- Following Piazzesi, Schneider & Tuzel (2007): δ = housing service flow / housing stock value
- National housing PCE share 2024: \$3,603.6B / \$21,615.1B = 16.67%
- Florida: 16.67% $\times$ \$1,463.5B PCE = \$244.0B housing services; stock $\approx$ 10.0M units $\times$ \$350K = \$3,500B
- $\Rightarrow \delta = 244.0/3{,}500 = 6.97\% \approx 7\%$
- Cross-check, Zillow June 2024 rent-to-value: Miami 7.37%, Tampa–St. Petersburg 6.75%, Orlando 6.35% (avg. 6.82%)
- National implied δ in PST (2007) $\approx$ 5.0–5.5%; Florida premium of 1.5–2 ppt

BACKUP: SENSITIVITY TO THE RETURN-PERIOD SCALING RULE



Linear (baseline): $\hat{\xi}_h(\mathrm{RP}) = \frac{\mathrm{RP}}{100}\hat{\xi}_h^{100}$; square-root: $\sqrt{\mathrm{RP}/100}\,\hat{\xi}_h^{100}$; engineering-proportional: RP profile of ξ_h. Both alternatives load more loss onto frequent storms and *raise* MAP in every county.

BACKUP: VALUE-WEIGHTED LOSS PARAMETER



- Alternative aggregation: ratio of means

$$\xi_h^{vw} = \frac{\sum_i \text{damage}_i}{\sum_i \text{value}_i}$$

- Equivalent to weighting by structure value — expensive homes count more
- Full pipeline re-run; main qualitative conclusions unchanged (SI)

BACKUP: HEDONIC MAPPING DERIVATION

Storm at t_0, none at $t_0 - 1$. Split off the first term of H_{t_0-1}:

$$H_{t_0-1} = \mathbb{E}_{t_0-1}\left[(1+\delta)\, m_{t_0}(1 - s_{t_0}\xi_h)\right](1+\Phi_{t_0}),$$

$$\Phi_{t_0} \equiv \mathbb{E}_{t_0}\left[\sum_{j\geq 1}(1+\delta)^j \prod_{k=1}^{j} m_{t_0+k}(1 - s_{t_0+k}\xi_h)\right]$$

After the storm, $H_{t_0} = \Phi_{t_0}(1-\xi_h)$. With i.i.d. storms, $\Phi_{t_0} = \frac{(1+\delta)\mu}{1-(1+\delta)\mu}$, $\mu \equiv \mathbb{E}[m(s)(1 - s\,\xi_h)]$, so

$$\frac{H_{t_0}}{H_{t_0-1}} = \frac{\mu\,(1-\xi_h)}{\mathbb{E}_{t_0-1}[m_{t_0}(1 - s_{t_0}\xi_h)]} = 1 - \xi_h$$

under rational expectations ($\mathbb{E}_{t_0-1}[\cdot] = \mu$). Hence the observed repeat-sales price change identifies $\hat{\xi}_h$.

BACKUP: COUNTY-SPECIFIC HEDONIC PARAMETERS

County	Coef. (SE)	Parameter used	MAP (% of value)
Hillsborough	-0.065^{***} (0.007)	County-specific	8.8
Manatee	-0.036^{***} (0.009)	County-specific	4.5
Miami-Dade	-0.032^{***} (0.004)	County-specific	4.6
Pinellas	-0.116^{***} (0.007)	County-specific	20.0
Charlotte, Collier, Lee	opposite-signed	Pooled (0.074)	6.9

County $\times$ post-hurricane mangrove-proximity interactions from Liu et al. (2026). Wrong-signed estimates (near-mangrove homes *appreciating* after storms) likely reflect waterfront amenities or post-storm redevelopment.