Virtual Seminar on Climate Economics

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Glenn Rudebusch (Brookings, NYU, CEPR)

Flooded House or Underwater Mortgage?

Yasmine van der Straten
Nova SBE

CEPR Virtual Seminar on Climate Economics

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Motivation

The Guardian. "Climate crisis: 50 photos of extreme weather around the world – in pictures (2021)".

Motivation

- Climate risks loom as mitigation efforts lag behind.
- Growing literature studies macroeconomic effects of adaptation,

  (See e.g. Fried 2022, Albert et al. 2021, Bilal and Rossi-Hansberg 2023, Hovekamp and Wagner 2023, Hong et al. 2023, Burke et al. 2024).

  → Role of finance remains underexplored.

Motivation

- Climate risks loom as mitigation efforts lag behind.
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  (See e.g. Fried 2022, Albert et al. 2021, Bilal and Rossi-Hansberg 2023, Hovekamp and Wagner 2023, Hong et al. 2023, Burke et al. 2024).
- Physical risks directly impact house prices and lending and insurance decisions.

  (See e.g. Baldauf et al. 2020, Bernstein et al. 2019, Bakkensen and Barrage 2021, Giglio et al. 2021, Wagner 2022, Ge et al. 2022, Sastry 2026).

  → Unclear how these financial incentives shape private adaptation efforts.

Motivation

- Climate risks loom as mitigation efforts lag behind.
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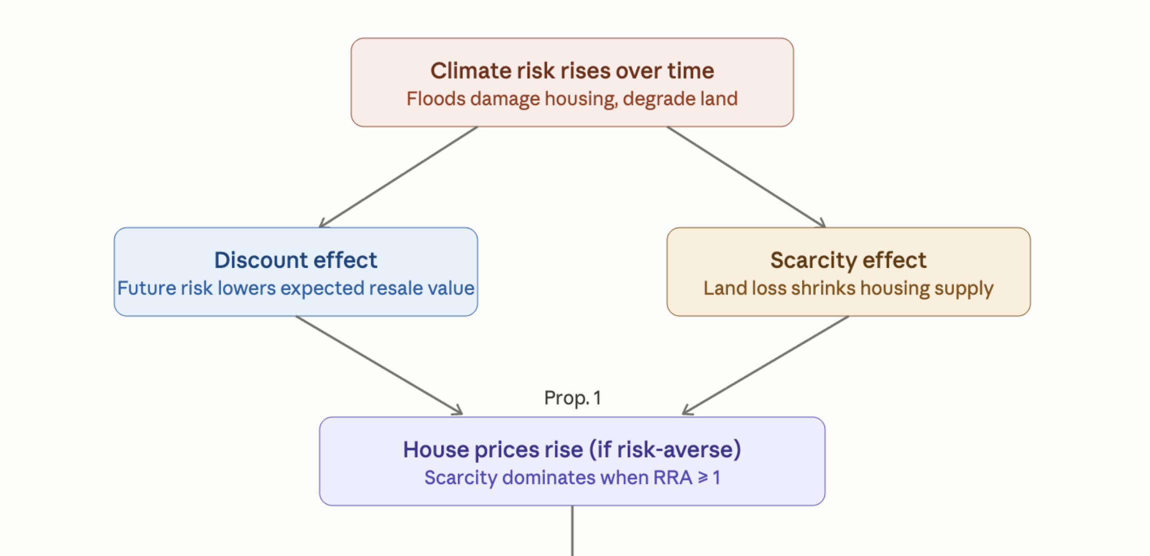
- What are the macrofinancial implications of climate change and adaptation?
  - What is the direct effect of climate change on house prices?
  - Do we adapt efficiently given price signals?
  - Are there any indirect feedback effects due to financial constraints?

Flooded House or Underwater Mortgage?

- General equilibrium framework with overlapping generations
- Households consume housing and a non-durable good; either of low- or high-income type.
- Economy is **exogenously** exposed to *idiosyncratic* physical climate risk.
- Physical climate risks lead to property damages and degrade land, reducing habitat.
- Households **endogenously** adapt, creating resilience against climate risk.

This paper



Climate risk rises over time
Floods damage housing, degrade land

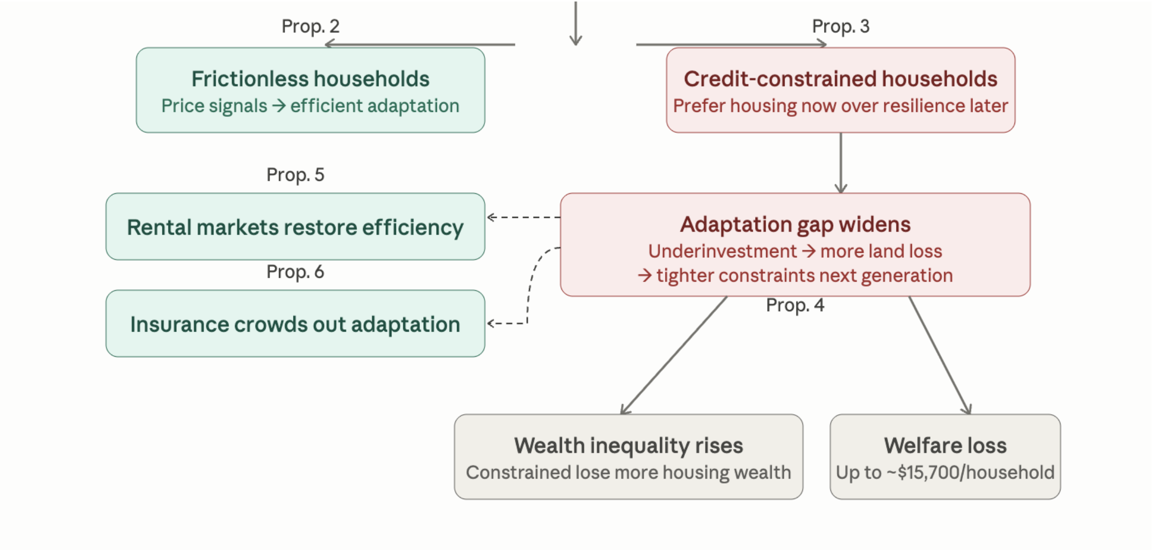
Discount effect
Future risk lowers expected resale value

Scarcity effect
Land loss shrinks housing supply

Prop. 1

House prices rise (if risk-averse)
Scarcity dominates when RRA ≥ 1

This paper (cont.)



Prop. 2

Prop. 3

Frictionless households
Price signals → efficient adaptation

Credit-constrained households
Prefer housing now over resilience later

Prop. 5

Rental markets restore efficiency

Prop. 6

Insurance crowds out adaptation

Adaptation gap widens
Underinvestment → more land loss
→ tighter constraints next generation

Prop. 4

Wealth inequality rises
Constrained lose more housing wealth

Welfare loss
Up to ~$15,700/household

Related literature

- **Pricing of physical climate risk in housing markets:** e.g., Harrison et al. (2001), Bin et al. (2008), Gibson et al. (2017), Keenan et al. (2018), Bernstein et al. (2019), Bosker et al. (2019), Keys and Mulder (2020), Murfin and Spiegel (2020), Baldauf et al. (2020), Giglio et al. (2021), Bakkensen and Barrage (2021).

  → Climate damages raise house prices through scarcity, with safe housing becoming relatively more valuable.
- **Macroeconomic effects of climate change adaptation:** e.g., Muis et al. (2015), Fried (2022), Albert et al. (2021), Bradt and Aldy (2023), Hsiao (2023), Hong et al. (2023), Balboni et al. (2023), Bilal and Rossi-Hansberg (2023), Cruz and Rossi-Hansberg (2024), Balboni (2025).

  → Finance shapes private adaptation: credit-constrained households systematically underinvest in resilience.
- **Impact of physical climate risk on lending and insurance decisions:** e.g., Issler et al. (2019), Bakkensen et al. (2022), Wagner (2022), Ge et al. (2022), Sastry et al. (2023), Keys and Mulder (2024), Boomhower et al. (2024), Kahn et al. (2024), Sastry (2026).
- **Investment and capital reallocation with financing constraints:** e.g., Kiyotaki and Moore (1997), Rampini (2019), Lanteri and Rampini (2023).

  → Adaptation gap widens endogenously as underinvestment tightening future constraints.

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Households

- General equilibrium framework with overlapping generations.
- Households are either of low- or high-income type (exogenous).
  - Households are of a high (prob. ϕ) or low (prob. $(1-\phi)$) income type.
  - Earn wage $y \in \{q, w\}$, respectively, with $q > w$.
- Households consume a non-durable good $c_{i,t+1}$ and demand housing, $L_{i,t}$.

$$U_i = c_{i,t+1} + v\left(L_{i,t}\right) \qquad v' > 0, v'' < 0$$

Housing capital and climate risk

- Economy is exposed to physical climate risks from extreme weather events (e.g., floods, wildfires, hurricanes) or gradual changes like sea-level rise.
  - $\gamma_t \in (0, 1)$: Probability that a *given* household suffers losses.
  - $\xi_{i,t} \in (0, 1)$: Idiosyncratic losses suffered by household i in period t.
  - $\xi_{i,t} \sim F(\xi_{i,t})$, i.i.d. across households, with $\mathbb{E}(\xi_{i,t}|\text{Hit}) = \mu \in (0, 1)$.

$$\mathbb{E}\left(\xi_{i,t}\right) = \mu\gamma_t \quad L_{i,t+1} = L_{i,t}(1 - \xi_{i,t+1})$$

Climate change and land degradation

- Climate change degrades over a quarter of the Earth's ice-free land, reducing its usability e.g., erosion, subsidence, landslides, soil salinity, desertification, flooding, *(IPCC 2019)* .
- Land is in inelastic supply in the LT *(Ricardo, 1817; Nichols, 1970 AER; Hansen & Prescott, 2002 AER; Saiz, 2010 QJE; Grossman et al., 2025 JEEA).*
- Supply of habitable land follows law of motion:

$$\begin{aligned}\bar{L}_{t+1} &= \int_0^1 \left(1-\xi_{i,t+1}\right) di \cdot \bar{L}_t \\ &\overset{\text{LLN}}{=} \left(1-\mu\gamma_{t+1}\right)\cdot \bar{L}_t\end{aligned}$$

- **Broadly:** $\bar{L}_{t+1} < \bar{L}_t$ captures *any* mechanism that reduces effective supply of *habitable* land after climate events
  e.g., land abandoned after repeat flooding, zoning and building restrictions in flood plains, insurers withdrawing from high-risk areas, lenders tightening mortgage availability.

Los Angeles after the fires: 'You can only live in a disaster zone for so long'

The city is pushing to rebuild areas devasted by wildfires. But the costs and the mounting risks of future disasters are hard to overcome

▸ Habitat Loss ▸ IPCC (2019)

Mortgage market

- Households with positive savings ($S_{i,t} > 0$) lend to others.
    - Mortgage debt backed by housing capital.
- Sufficiently large damages lead to an 'underwater mortgage':

$$p_{t+1} L_{i,t+1} \leq (1 + \hat{r}_{t+1})(-S_{i,t})$$
$$\xi_{i,t+1} \geq 1 - LTV_{i,t+1} = \hat{\xi}_{i,t+1}$$

- Mortgage debt earns the risky rate of return, $\hat{r}_t \geq r$, with r the risk-free rate of return.
    - Idiosyncratic damages and risk neutrality $\Longrightarrow$ creditors price mortgages at r.
- Insurance intermediaries: covered in an extension.

▸ No arbitrage

Household optimization

$$\max_{L_{i,t}} \mathbb{E}_t\left(c_{i,t+1}\right) + v(L_{i,t})$$

$$s.t. \quad y_i \leq p_t L_{i,t} + S_{i,t} \qquad \text{(budget constraint)}$$

$$c_{i,t+1} \leq \max\left\{p_{t+1}(1-\xi_{i,t+1})L_{i,t} + (1+r)S_{i,t}, 0\right\} \qquad \text{(limited liability constraint)}$$

$$c_{i,t+1}, L_{i,t} \geq 0 \qquad \text{(no negative consumption constraint)}$$

▸ No arbitrage

How does climate change affect house prices?

- House prices are given by:

$$
\begin{aligned}
p_t &= \frac{(1-\mu\gamma_{t+1})\,p_{t+1} + v'(\bar{L}_t)}{(1+r)} \\
&= \sum_{j=t}^{\infty} \left(\frac{1}{1+r}\right)^{j-t} \left[v'(\bar{L}_j)\right] \cdot \prod_{i=t}^{j-1} (1-\mu\gamma_{i+1})
\end{aligned}
$$

How does climate change affect house prices?

- House prices are given by:

$$p_t = \frac{\overbrace{(1-\mu\gamma_{t+1})}^{\text{SLR discount}} p_{t+1} + v'(\bar{L}_t)}{(1+r)}$$

$$= \sum_{j=t}^{\infty} \left(\frac{1}{1+r}\right)^{j-t} \left[v'(\bar{L}_j)\right] \cdot \prod_{i=t}^{j-1} (1-\mu\gamma_{i+1})$$

  - Direct effect: House prices *discounted* for exposure to future climate risk.

    see e.g.,Gibson et al. (2017), Bernstein et al. (2019), ?), ?), Keys and Mulder (2020), Baldauf et al. (2020), Giglio et al. (2021), Bakkensen and Barrage (2021).
  - **Long run**: Realized climate damages *raise* the shadow value of owning housing.

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\end{aligned}
$$

Proposition

House prices rise in climate risk if households are sufficiently risk-averse regarding their housing consumption:

$$\underbrace{-\left(v''(\bar{L}_j) \cdot \bar{L}_j\right) / \left(v'(\bar{L}_j)\right)}_{RRA} \geq 1$$

Extensions

- **Low vs. high risk regions**: model isolates the scarcity channel conditional on local demand.
  - Suppose a region contains housing with both low- and high-risk exposure.
  - Differences in risk exposure generate implicit price segmentation.
  - Relative price of safe housing rises as effective scarcity reallocates demand.
- **Land vs. structures**: effective housing services combine land and structures (Combes et al. 2021).
  - As land becomes scarcer, households build taller or denser, partially offsetting land loss.
  - For $RRA > 1$, *house* prices rise, inducing greater structure intensity on surviving land.
  - Scarcity is attenuated but not eliminated, unless housing supply is sufficiently elastic.

▸ Regions ▸ Structures

Climate change adaptation

- **Climate change adaptation**: ”Adjustments in ecological, social or economic systems in response to actual or expected climatic impacts ... to reduce vulnerability to potential climate damages” (UNFCCC).
- **Why private?**
  - Individuals better understand unique risks faced.
  - Private measures can be tailored where public policy is too blunt or too slow.
- **Adaptation $\neq$ insurance:**
  - Adaptation reduces damages *ex ante*: less land degrades, more housing stock preserved.
  - Insurance compensates losses *ex post*: does not slow land degradation.

▸ Examples

Adaptation reduces idiosyncratic losses

- Private choice of adaptation by household i in period t denoted by $x_{i,t} \in [0,1)$.
- Adaptation shifts distribution of losses to the left:

$$\mathbb{E}\left(\xi_{i,t+1}\right) = (1 - x_{i,t})\mu\gamma_{t+1}$$

- Adaptation endogenizes the rate at which the supply of inhabitable houses shrinks:

$$\bar{L}_{t+1} = \left(1 - \left(1 - \int_0^1 x_{i,t}\, di\right)\mu\gamma_{t+1}\right)\bar{L}_t$$

- Investment costs incurred upon purchase of housing: $\psi_{i,t} = \frac{1}{2} L_{i,t} {x_{i,t}}^2$.

Do households adapt efficiently?

- With adaptation, house prices are given by:

$$p_t = \frac{\left(1 - (1 - \int_0^1 x_{i,t} di)\mu\gamma_{t+1}\right) p_{t+1} + v'(\bar{L}_t)}{(1+r)} - \frac{1}{2}\int_0^1 x_{i,t} di^2$$

- Unconstrained private choice of adaptation is given by:

$$x_{i,t} = \frac{\mu\gamma_{t+1} \cdot p_{t+1}}{(1+r)}$$

- Future price $=$ value of an additional unit of housing for next generations.

Proposition

In frictionless markets, unconstrained households adapt efficiently.

▸ Household Problem ▸ Social Planner Problem ▸ Discount debate

Mortgage creditors anticipate climate risks

- Lenders price default risk but adaptation direct affects the value of pledged housing capital.
- Adaptation investments are non-contractible ex-post.
- Mortgage debt is limited by expected liquidation value of collateral:
  (Kiyotaki and Moore 1997, Sastry 2026) .

$$(1+r)(-S_{i,t}) \leq \left(1-\left(1-\mathbb{E}\left(\bar{x}_{l,t}\right)\right)\mu\gamma_{t+1}\right) p_{t+1} L_{i,t}$$

▸ Limits to adaptation

Financial constraints lead to suboptimal adaptation

- Credit constrained households can buy less housing.
- Optimal choice of adaptation of constrained, low-income household, $x^*_{l,t}$

$$x^*_{l,t} = \frac{\mu \gamma_{t+1} \cdot p_{t+1}}{(1+r)(1+\lambda_{l,t})}$$

with $\lambda_{l,t} \geq 0$ the shadow value of the constraint.

Proposition

Credit constrained households underinvest in adaptation.

Financial constraints lead to suboptimal adaptation

- Credit constrained households underinvest in adaptation.
- **Wealth Inequality**: Constrained HHs remain more vulnerable to physical impacts.
- **Spillovers**: Unequal adaptation further reduces habitat of future generations.

Financial constraints lead to suboptimal adaptation

- Credit constrained households underinvest in adaptation.
- **Wealth Inequality**: Constrained HHs remain more vulnerable to physical impacts.
- **Spillovers**: Unequal adaptation further reduces habitat of future generations.
- **Amplification:** Constraints bind increasingly harder over time

Proposition

Under CRRA utility in housing $(v(\cdot))$*, the "private adaptation gap" widens over time.*

▸ Optimization

Renting vs buying

- Could financially constrained households rely on landlords with deeper pockets?
- In a perfectly competitive rental markets, the rental price (per unit of L_t) is

$$R_t = v'\left(L_t^*\right)$$

- Landlords bear investment cost, capture returns through rent and preserved resale value.

Proposition

If perfectly competitive, rental markets lead to more effective adaptation.

Insurance markets

- Insurance plays a key role in mitigating the impact of climate change on household wealth.
- Insure damages to the house due to extreme weather events:
  - $\pi_t \in (0, 1]$: Institutionally determined coverage rate (per unit of housing) at time t.
  - Expected payout per unit of housing capital insured: $\xi_{i,t+1} \cdot p_{t+1}$.
  - Insurance priced at its actuarial value, with premium, z_t for full coverage

$$z_t = \frac{(1 - \mathbb{E}(x_{i,t}))\mu\gamma_{t+1} \cdot p_{t+1}}{(1 + r)}$$

  - Insurers cannot fully condition contracts on adaptation *(Wagner 2022)* .

▸ Institutional Context ▸ Optimization

Insurance leads to moral hazard in adaptation

- With insurance provision, the private choice of adaptation becomes:

$$x_{i,t} = \frac{(1 - \pi_t) \cdot \mu \gamma_{t+1} \cdot p_{t+1}}{(1 + r)}$$

- Home equity effect provides a countervailing force *(Mayers and Smith Jr 1983)* , but never dominates in equilibrium

Proposition

The provision of climate risk insurance crowds out private adaptation.

- **Insurance and adaptation are not substitutes:** expanding coverage alone undermines long-run resilience, as insurance only compensates losses *ex post*.

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Long run simulation

- Parameterization based on the US economy, simulation for Florida's coastal area.
  - 30 years: 64,000 homes in FL at risk (12,000 in Miami Beach).
  - End of century: 1 million homes that at risk.

    → +40% of U.S. homes at risk *(Dahl et al. 2018)*.
- Run forward from 2000-2150, time period: 30 years.
- Counterfacutal analysis based on ▸ IPCC (2023) projections.

Probability of idiosyncratic risk

- γ_t: Fraction of houses at risk of flooding for given rise in sea levels.
- Utilize aggregate property exposure to (1-10ft) SLR in Florida based on Bernstein et al. (2019).
- Projections on SLR for Miami Beach area between 2000 - 2150 based on IPCC (2023).[1]
  - Projected SLR for the Miami beach area by 2100 under an intermediate scenario: 0.71m.
  - Other cities in Florida: between 0.64-0.73m of SLR.
- Consider a low GHG emission-scenario (SSP1-1.9, SSP1-2.6), an intermediate GHG emission-scenario (SSP2-4.5) and a GHG emission-scenario (SSP3-7.0).

▸ NOAA ▸ NASA ▸ Other Parameters

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[1] *Garner et al. (2021), Fox-Kemper et al. (2021), Garner et al. (in prep.).*

How much do we adapt?

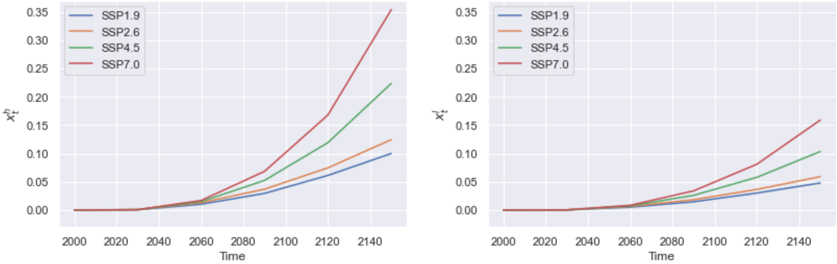


Figure: Evolution of the unconstrained private choice of adaptation, $x_{h,t}$, (left) and constrained private choice of adaptation, $x_{l,t}$, (left) (right), under the SSP 1-1.9, 1-2.6, 2-4.5, 3-7.0 and trajectory.

Welfare Implications

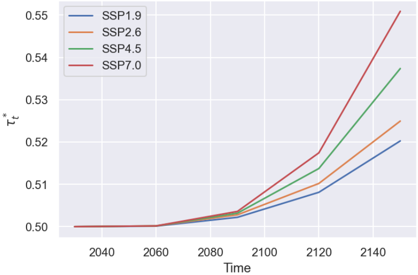
	SSP1–1.9	SSP1–2.6	SSP2–4.5	SSP3–7.0
A. Marginal value of housing saved through adaptation				
Consumption equivalent	0.038	0.047	0.083	0.127
Relative to consumption (%)	3.690	4.509	7.724	**11.726**
Relative to income (%)	3.971	4.909	8.679	13.393
Relative to house value (%)	4.464	5.641	10.731	17.921
B. Utility cost of housing lost through the underinvestment				
Consumption equivalent	0.002	0.003	0.010	0.0247
Relative to consumption (%)	0.192	0.295	0.929	2.288
Relative to income (%)	0.207	0.321	1.044	2.613
Relative to house value (%)	0.232	0.369	1.290	**3.497**

Table: Marginal value of adaptation under the SSP 1-1.9, 1-2.6, 2-4.5, 3-7.0 and trajectory.

- The welfare loss due to the underinvestment in adaptation equals $ 15,700 per household.

Rental Markets and Frictions

- Rental markets foster more effective adaptation, but theory relies on rental markets being frictionless.
- Suppose rental market frictions reduce effective adaptation by fraction $\tau \in [0, 1]$, capturing inefficiencies such as agency problems, transaction costs or regulatory constraints.
- How large must τ be to overturn the efficiency result?
- For any $\tau < \tau^*$, adaptation under renting remains higher than under constrained homeownership.



Conclusion

- Climate risk lowers prices in physically exposed areas, while land scarcity increases the relative price of safer housing.
- Forward-looking prices can incentivize efficient private adaptation in frictionless markts.
- Financially constrained households underinvest in resilience.
- Private adaptation gap widens as households become more constrained.
- Implication: Shifting toward landlord-based ownership can improve adaptation efficiency.

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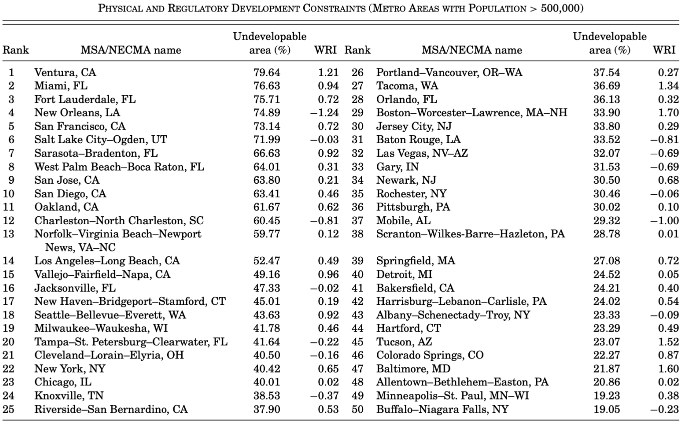
Undevelopable Land in Coastal Areas



PHYSICAL AND REGULATORY DEVELOPMENT CONSTRAINTS (METRO AREAS WITH POPULATION > 500,000)

Rank	MSA/NECMA name	Undevelopable area (%)	WRI	Rank	MSA/NECMA name	Undevelopable area (%)	WRI
1	Ventura, CA	79.64	1.21	26	Portland–Vancouver, OR–WA	37.54	0.27
2	Miami, FL	76.63	0.94	27	Tacoma, WA	36.69	1.34
3	Fort Lauderdale, FL	75.71	0.72	28	Orlando, FL	36.13	0.32
4	New Orleans, LA	74.89	−1.24	29	Boston–Worcester–Lawrence, MA–NH	33.90	1.70
5	San Francisco, CA	73.14	0.72	30	Jersey City, NJ	33.80	0.29
6	Salt Lake City–Ogden, UT	71.99	−0.03	31	Baton Rouge, LA	33.52	−0.81
7	Sarasota–Bradenton, FL	66.63	0.92	32	Las Vegas, NV–AZ	32.07	−0.69
8	West Palm Beach–Boca Raton, FL	64.01	0.31	33	Gary, IN	31.53	−0.69
9	San Jose, CA	63.80	0.21	34	Newark, NJ	30.50	0.68
10	San Diego, CA	63.41	0.46	35	Rochester, NY	30.46	−0.06
11	Oakland, CA	61.67	0.62	36	Pittsburgh, PA	30.02	0.10
12	Charleston–North Charleston, SC	60.45	−0.81	37	Mobile, AL	29.32	−1.00
13	Norfolk–Virginia Beach–Newport News, VA–NC	59.77	0.12	38	Scranton–Wilkes-Barre–Hazleton, PA	28.78	0.01
14	Los Angeles–Long Beach, CA	52.47	0.49	39	Springfield, MA	27.08	0.72
15	Vallejo–Fairfield–Napa, CA	49.16	0.96	40	Detroit, MI	24.52	0.05
16	Jacksonville, FL	47.33	−0.02	41	Bakersfield, CA	24.21	0.40
17	New Haven–Bridgeport–Stamford, CT	45.01	0.19	42	Harrisburg–Lebanon–Carlisle, PA	24.02	0.54
18	Seattle–Bellevue–Everett, WA	43.63	0.92	43	Albany–Schenectady–Troy, NY	23.33	−0.09
19	Milwaukee–Waukesha, WI	41.78	0.46	44	Hartford, CT	23.29	0.49
20	Tampa–St. Petersburg–Clearwater, FL	41.64	−0.22	45	Tucson, AZ	23.07	1.52
21	Cleveland–Lorain–Elyria, OH	40.50	−0.16	46	Colorado Springs, CO	22.27	0.87
22	New York, NY	40.42	0.65	47	Baltimore, MD	21.87	1.60
23	Chicago, IL	40.01	0.02	48	Allentown–Bethlehem–Easton, PA	20.86	0.02
24	Knoxville, TN	38.53	−0.37	49	Minneapolis–St. Paul, MN–WI	19.23	0.38
25	Riverside–San Bernardino, CA	37.90	0.53	50	Buffalo–Niagara Falls, NY	19.05	−0.23

Saiz, 2010.

▸ Back

Land erosion and loss

Figure: Tuvalu minister to address COP26 knee deep in water to highlight climate crisis and sea level rise. "Where I was standing and filming, as you can see behind me, there's that concrete base that was actually built by the Americans during World War Two. As you can imagine, this base used to be on land and it's now in the middle of the sea, about 20 or 30 metres from the land. So we are experiencing land erosion. Certain parts of the island are underwater during high tide. These are just a few examples of the threats that we are facing".

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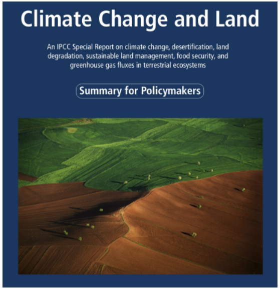
IPCC special report on climate change and land

- Human use directly affects **more than 70% (likely 69–76%) of the global, ice-free land surface** *(high confidence)*. Land also plays an important role in the climate system.
- Land degradation affects people and ecosystems **throughout the planet** and is both affected by climate change and contributes to it.
- Land degradation adversely affects people's livelihoods (very high confidence) and **occurs over a quarter of the Earth's ice-free land area** *(medium confidence).*



Climate Change and Land

An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems

Summary for Policymakers

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IPCC special report: land degradation

- Climate change exacerbates the rate and magnitude of several ongoing land degradation processes and introduces new degradation patterns *(high confidence)*.
- Soil loss from conventionally tilled land **exceeds the rate of soil formation by more than 2 orders of magnitude** *(medium confidence)*.
- Sea level rise has exacerbated coastal erosion *(medium confidence)*. Global warming beyond present day will **further exacerbate ongoing land degradation processes** through increasing floods *(medium confidence)*, drought frequency and severity *(medium confidence)*, intensified cyclones *(medium confidence)*, and sea level rise *(very high confidence)*, with outcomes being modulated by land management *(very high confidence)*.
- **Erosion of coastal areas because of sea level rise will increase worldwide** *(high confidence)*. **Even with adequate implementation of measures to avoid, reduce and reverse land degradation**, there will be residual degradation in some situations *(high confidence)*. **Exceeding the limits of adaptation will trigger escalating losses or result in undesirable changes**, such as forced migration, conflicts, or poverty.
- Examples of potential limits to adaptation due to climate-change-induced land degradation are coastal erosion (where **land disappears**, collapsing infrastructure), and extreme forms of soil erosion.

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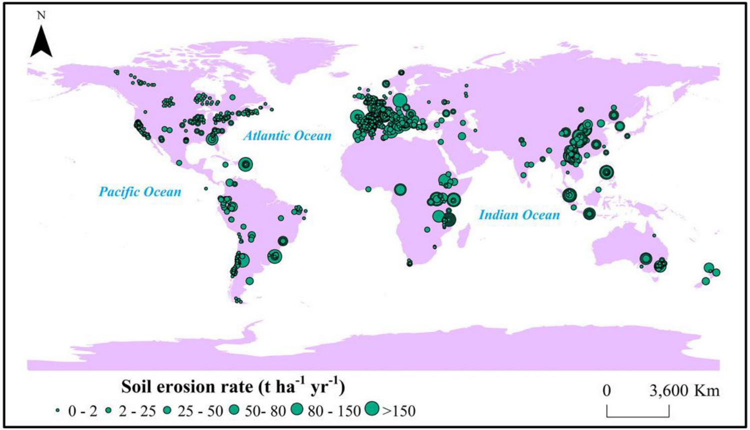
Soil erosion at the global scale



IPCC (2019)

Household optimization: solution strategy

- Time t-expectation of household i's consumption in period $t+1$:

$$\mathbb{E}_t\left(c_{i,t+1}\right) = F\left(\hat{\xi}_{i,t+1}\right)\left(p_{t+1}\left(1-\mathbb{E}\left(\xi_{i,t+1}|\xi_{t+1}\leq\hat{\xi}_{i,t+1}\right)\right)L_{i,t} + (1+\hat{r}_{t+1})S_{i,t}\right)$$

- No arbitrage requires

$$\begin{aligned}(1+r)(-S_{i,t}) = F\left(\hat{\xi}_{i,t+1}\right)(1+\hat{r}_{t+1})(-S_{i,t})\\ + \left(1-F\left(\hat{\xi}_{i,t+1}\right)\right)p_{t+1}\left(1-\mathbb{E}\left(\xi_{i,t+1}|\xi_{i,t+1}>\hat{\xi}_{i,t+1}\right)\right)L_{i,t}\end{aligned}$$

- Households maximize:

$$\begin{aligned}&\mathbb{E}_t\left(U(c_{i,t+1},x_{i,t},L_{i,t})\right) = (1+r)(S_{i,t}) + p_{t+1}\left(1-\mathbb{E}\left(\xi_{i,t+1}\right)\right)L_{i,t} + v(L_{i,t})\\ &= (1+r)(y_i - p_t L_{i,t}) + p_{t+1}\left(1-\mu\gamma_{t+1}\right)L_{i,t} + v\left(L_{i,t}\right)\end{aligned}$$

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Different housing stocks in a region

▸ Back

Different types of housing stocks

- Suppose there are two different types of housing stocks in the given region
  - Houses on low elevation ($\bar{L}_{\bar{\mu}}$), for which $\bar{\mu}$ (fraction $(1 - f(\gamma_t))$).
  - Houses on high elevation ($\bar{L}_{\underline{\mu}}$), for which $\underline{\mu}$ (fraction $f(\gamma_t)$).
- In unsegmented markets, house prices will be given by

$$p_t^{low} = \frac{(1 - \bar{\mu}\gamma_{t+1})\, p_{t+1} + v'(\bar{L}_t)}{(1 + r)}$$

$$p_t^{high} = \frac{\left(1 - \underline{\mu}\gamma_{t+1}\right) p_{t+1} + v'(\bar{L}_t)}{(1 + r)}$$

i.e. the differences in risk exposure results in implicit price segmentation.

Corollary

The relative price of safe housing rises as climate change shrinks housing supply and reallocates demand.

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Land vs structures

- Effective housing services, H_t, are given by the Cobb–Douglas aggregator combining L_t and structure intensity, K_t (Combes et al. 2021):

$$H_t = K_t^{\alpha} L_t^{1-\alpha}$$

- Structure intensity is adjusted to its static optimum given remaining land, with a per unit per period user cost of maintaining a given intensity level of q.
- Housing services are delivered competitively, with developers choosing structure intensity to maximize the value of housing services net of intensity costs.

Corollary

Effective housing services decline with land loss if and only if the elasticity of housing prices with respect to land supply, $\epsilon_{p,\bar{L}}$*, satisfies*

$$\epsilon_{p,\bar{L}} \equiv \frac{\partial log(p_t)}{\partial log(\bar{L}_t)} > -\frac{(1-\alpha)}{\alpha}.$$

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Adaptation to hurricane risk in Florida (Naples, 2022)

Dixie Whatley
@bothcoasts · Follow

We live on the beach in Naples, Florida. We stayed through the Hurricane Ian. Thought I'd share a rather notable photo from the experience...

8:29 PM · Oct 1, 2022

Back

Household optimization with adaptation

$$
\begin{aligned}
\max_{L_{i,t}, x_{i,t}} \ & \mathbb{E}_t \left(c_{i,t+1} \right) + v(L_{i,t}) \\
s.t. \quad y_{i,t} &\leq \left(p_t + \frac{1}{2} x_{i,t}^2 \right) L_{i,t} + S_{i,t} \\
c_{i,t+1} &\leq \max \left\{ p_{t+1}(1 - \xi_{i,t+1}) L_{i,t} + (1 + \hat{r}_{t+1}) S_{i,t}, 0 \right\} \\
c_{i,t+1}, L_{i,t}, x_{i,t} &\geq 0.
\end{aligned}
$$

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Social planner problem

- The unconstrained social planner maximizes Utilitarian welfare:

$$\max_{x_t} \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^{t} \left[-(1+r)\frac{1}{2}x_t^2 \bar{L}_t + v(\bar{L}_t)\right]$$

subject to

$$\bar{L}_j = \bar{L}_t \prod_{i=t}^{j-1} (1-(1-x_i)\mu\gamma_{i+1})$$

- Efficient level of adaptation, x_t^*:

$$x_t^* = \frac{\mu\gamma_{t+1}}{(1+r)} \cdot \underbrace{\sum_{j=t+1}^{\infty} \left(\frac{1}{1+r}\right)^{j-(t+1)} \left[-(1+r)\frac{1}{2}x_j^2 + v'(\bar{L}_j)\right] \prod_{i=t+1}^{j-1} (1-(1-x_i)\,\mu\gamma_{i+1})}_{p_{t+1}}$$

▸ Back

Discounting debate

- Choice of the social discount rate at the heart of the debate in climate change economics *(e.g., Stern 2007, Nordhaus 2007, Weitzman 2007)*.
- Ramsey rule: $r^* = \varrho + \zeta \cdot g^*$ with ϱ the pure rate of time preference, g the growth rate of per capita consumption and ζ the elasticity of consumption.
  - Stern (2007): $\varrho = 0.1\%$, $\zeta = 1$ and $g^* = 1.3\% \implies r^* = 1.4$.
  - Nordhaus (2007): $\varrho = 1.5\%$, $\zeta = 2$, and $g^* = 2\% \implies r^* = 5.5$.
  - Weitzman (2007): $\varrho = 2\%$, $\zeta = 2$ and $g^* = 2\% \implies r^* = 6\%$.
- While small, difference in proposed social discount rates lead to large disparities between recommended intensity of climate change *(Heal and Millner 2014)*.

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Choice of social discount rate crucial for optimality

- Private choice of adaptation and social optimum only coincide the case in which market discount rates are used to evaluate the welfare of future generations.
- Suppose the welfare of future generations is evaluated with a discount rate $r^{SP} \in [0, 1]$ with $r^{SP} < r$.
- Define the social adaptation gap, Ω, as the difference between the private choice of adaptation and the social optimum.

Corollary

Unconstrained households underinvest in adaptation. Specifically, in a given period, t, the size of the social adaptation gap is given by

$$\Omega_t = \frac{\mu\gamma_{t+1}}{(1+r)} \cdot \sum_{j=t+1}^{\infty} \left(\left(\frac{1}{1+r^{SP}} \right)^t - \left(\frac{1}{1+r} \right)^t \right) \left[-(1+r)\frac{1}{2}x_j^2 + v'(L_j) \right] \prod_{i=t+1}^{j-1} \left(1 - (1 - x_i)\,\mu\gamma_{i+1}\right)$$

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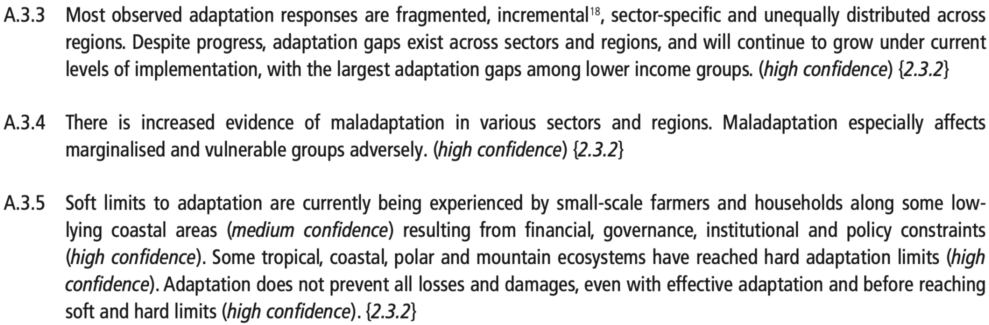
Limits to Adaptation



A.3.3 Most observed adaptation responses are fragmented, incremental[18], sector-specific and unequally distributed across regions. Despite progress, adaptation gaps exist across sectors and regions, and will continue to grow under current levels of implementation, with the largest adaptation gaps among lower income groups. (*high confidence*) {*2.3.2*}

A.3.4 There is increased evidence of maladaptation in various sectors and regions. Maladaptation especially affects marginalised and vulnerable groups adversely. (*high confidence*) {*2.3.2*}

A.3.5 Soft limits to adaptation are currently being experienced by small-scale farmers and households along some low-lying coastal areas (*medium confidence*) resulting from financial, governance, institutional and policy constraints (*high confidence*). Some tropical, coastal, polar and mountain ecosystems have reached hard adaptation limits (*high confidence*). Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits (*high confidence*). {*2.3.2*}

IPCC (2023)

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Change in the Adaptation Gap

- For the private adaptation gap, Λ_t, to rise in γ_{t+1}, it must hold that:

$$\frac{\partial v'\left(L^*_{l,t}\right)}{\partial L^*_{l,t}} \cdot \frac{\partial L_{l,t}}{\partial \gamma_{t+1}} \cdot \frac{1}{v'\left(L^*_{l,t}\right)} - \frac{\partial v'\left(L^*_{h,t}\right)}{\partial L^*_{h,t}} \cdot \frac{\partial L_{l,t}}{\partial \gamma_{t+1}} \cdot \frac{1}{v'\left(L^*_{h,t}\right)} \geq 0$$

- Using CRRA utility with RRA coefficient ς, this becomes

$$-\varsigma\left(\underbrace{\frac{\partial L_{l,t}}{\partial \gamma_{t+1}}}_{\leq 0} \cdot \frac{1}{L^*_{l,t}} - \underbrace{\frac{\partial L_{h,t}}{\partial \gamma_{t+1}}}_{\leq 0} \cdot \frac{1}{L^*_{h,t}}\right) \geq 0$$

which always holds as credit constraints bind.

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Parameter values

Parameter	Description	Value	Source/Target
A	TFP in final-good production	1	Normalization
$\tilde{h}$	Inelastic supply of high-skilled labour	35	Credit allocation target
$\tilde{l}$	Inelastic supply of low-skilled labour	20	Credit allocation target
$\bar{L}$	Initial stock of houses	1	Normalization
α	Capital share in final-good production	0.32	BEA (2010)
η	Relative productivity of intangible inputs	0.67	Credit allocation target
μ	Fraction of damages to housing capital	1	Normalization
μ_K	Fraction of damages to tangible capital	0.7	Target $\mu/\mu_K = 0.7$ (Fried 2022)
ρ	Substitution parameter	0	Cobb-Douglas Production
ϕ	Fraction of high skilled labour	0.3	U.S. Census Bureau (2010)
ω	Bargaining power of innovators	0.58	Corporate financing target

Target	Description	Data	Model
Credit allocation target	Household debt/(Household + corporate debt)	0.68	0.65
Corporate financing target	Corporate debt/(Corporate debt + equity)	0.26	0.29

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NOAA Sea Level Rise Viewer

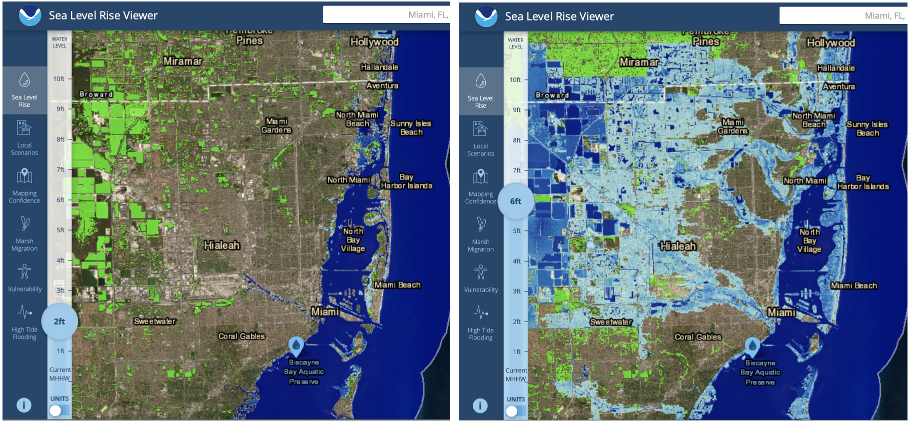

Figure: Interface of the NOAA sea level rise viewer.

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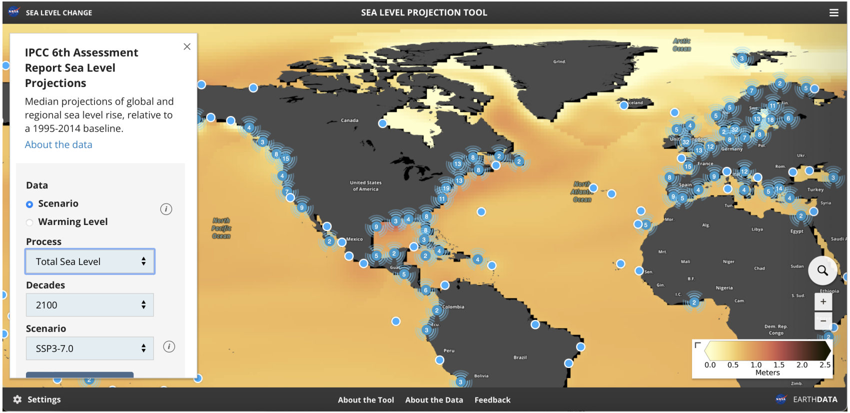
NASA Sea Level Rise Tool



IPCC 6th Assessment Report Sea Level Projections

Median projections of global and regional sea level rise, relative to a 1995-2014 baseline.

About the data

Data

● **Scenario**

○ **Warming Level**

Process

Total Sea Level

Decades

2100

Scenario

SSP3-7.0

Figure: Interface of the NASA sea level rise tool.

Back

Sea level rise projections: Miami Beach

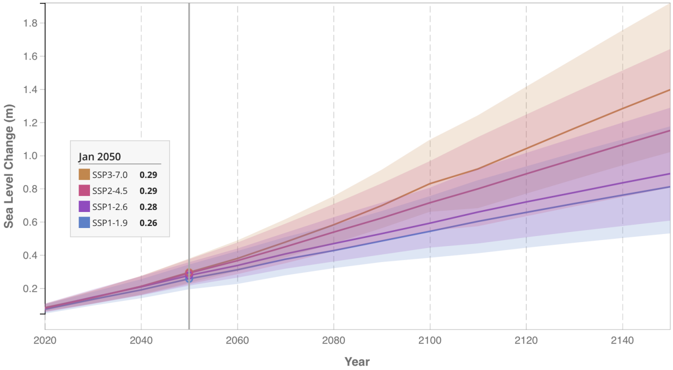


Figure: Sea level rise projections for Miami Beach, based on the NASA sea level rise tool.

Institutional context

- Real estate climate risk is born by:
    - Homeowners
    - Mortgage lenders (also: GSEs, MBs)
    - Flood insurers providers (public, private, reinsurance)
    - FEMA

▸ Back

Institutional context

- Real estate climate risk are backstopped by federal government.
- Not legally required to have flood insurance, but mortgage lenders often require it.
  → Gov-backed lenders mandate it for properties in "Special Flood Hazard Areas".
- Flood insurance is provided by National Flood Insurance Program (NFIP).
  - Federally-backed initiative administered by the government.
  - Eligibility requirements.
  - Coverage: 250,000 US dollars for buildings.
  - Average annual cost: 760 US dollars.
  - Average claim payout: 29,000 US dollars.

- Not legally required to have flood insurance, but mortgage lenders often require it.
  → Gov-backed lenders mandate it for properties in "Special Flood Hazard Areas".

▸ Back

Institutional context

- Real estate climate risk are backstopped by federal government.
- Not legally required to have flood insurance, but mortgage lenders often require it.
- Flood insurance is provided by National Flood Insurance Program (NFIP).
- Disaster assistance provided by FEMA.
  - Requires Presidential Disaster Declaration.
  - Average disaster relief payment in Florida: 5,100 US dollars.

▸ Back

Institutional context

- Real estate climate risk are backstopped by federal government.
- Not legally required to have flood insurance, but mortgage lenders often require it.
- Flood insurance is provided by National Flood Insurance Program (NFIP).
- Disaster assistance provided by FEMA.
- Additional flood coverage is available through private insurers.
  → Private insurance becomes increasingly harder to obtain! *(Sastry et al. 2023, Boomhower et al. 2024)*

▸ Back

Household optimization with insurance

$$
\begin{aligned}
&\max_{L_{i,t},x_{i,t}} \mathbb{E}_t\left(c_{i,t+1}\right) + v(L_{i,t}) \\
s.t. \quad & y_{i,t} \leq \left(p_t + z_t\pi_t + \frac{1}{2}x_{i,t}^2\right) L_{i,t} + \ + S_{i,t} \\
& c_{i,t+1} \leq \max\left\{p_{t+1}(1-(1-\pi_t)\xi_{i,t+1})L_{i,t} + (1+r)S_{i,t}, 0\right\} \\
& c_{i,t+1}, L_{i,t}, x_{i,t} \geq 0.
\end{aligned}
$$

▸ Back

Insurance crowds out private adaptation

1. Suppose that $\frac{\partial p_{t+1}}{\partial \pi_t} \cdot \frac{1}{p_{t+1}} > 1$.
2. Then, insurance provision encourages private adaptation, $\frac{\partial x_t}{\partial \pi_t} > 0$.
3. This implies that $\frac{\partial \bar{L}_j}{\partial \pi_t} > 0$.
4. But then, we have that $\frac{\partial p_{t+1}}{\partial \pi_t} < 0$.
5. And it must be that $\frac{\partial x_t}{\partial \pi_t} < 0$.
6. This implies that $\frac{\partial \bar{L}_j}{\partial \pi_t} < 0$, which is a contradiction.

Proposition

The provision of climate risk insurance crowds out private adaptation investments.

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