Sheltering from Climate Risks

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Urgency of climate risks

Figure: Erftstadt-Blessem, Germany, July 2021

Germany, 2021: €33bn of losses

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> "**Only 52 percent** *of houses in Germany are still* **insured** *[against floods]* "...
>
> *"If we do not consistently* **implement prevention and adaptation to climate change**, *we estimate that premiums for residential building insurance in Germany could double within the next ten years as a result of climate damage alone."*

Urgency of climate risks

Figure: Erftstadt-Blessem, Germany, July 2021

Figure: Valencia, Spain, October 2024

Urgency of climate risks

Figure: Erftstadt-Blessem, Germany, July 2021

Figure: Hurricane Helene, US, September 2024

Sheltering from Climate Risks

This paper:

- How will households mitigate climate damages, and what are the broader consequences?

Empirical evidence:

- Administrative data on flood insurance of homeowners in the US
- Insurance vs adaptation via home elevation
- Response to proxy of climate risk awareness

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Results:

- Insurance and adaptation increase
- Sharp differences across incomes
- Higher incomes adapt; lower incomes rely on insurance

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Interpret results via model:

- Embed flood risk to housing into a heterogeneous agent model
- Households can choose to insure and/or invest in adaptation
- Equilibrium response to a gradual rise in *actual* risk

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$\Rightarrow$ Climate damage is larger and more regressive

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Interpret results via model:

- Embed flood risk to housing into a heterogeneous agent model
- Households can choose to insure and/or invest in adaptation
- Model a gradual rise in *actual* risk

Mechanism:

- Financial constraints limit low-income households' investment in long-term adaptation
- Flood insurance subsidies exacerbate reliance on insurance

$\Rightarrow$ Climate damage is larger and more regressive

Literature

- *Macro effects of climate change:* Nordhaus (1977, 1991, 1992), Nordhaus and Boyer (2000), Golosov et al. (2014), Weitzman (2009), Weitzman (2014), Cai and Lontzek (2019), Hsiang and Jina (2014), Dell, Jones, and Olken (2012), Deschênes and Greenstone (2007), Desmet and Rossi-Hansberg (2015), Desmet, Nagy, and Rossi-Hansberg (2018), Desmet, Kopp, et al. (2021), Smith and Krusell (2017), Nath, Ramey, and Klenow (2024), Bilal and Känzig (2024)
- *Natural disaster risk and adaptation:* Deryugina (2017), Deryugina, Kawano, and Levitt (2018), Bakkensen and Barrage (2022), Baldauf, Garlappi, and Yannelis (2020), Ratnadiwakara (2021), McCoy and Walsh (2018), Fried (2021), Hong, Wang, and Yang (2023), Balboni (2019), Bilal and Rossi-Hansberg (2023), Van der Straten (2023), Fairweather et al. (2024)
- *Insurance:* Xu and Box-Couillard (2024), Hu (2022), Ratnadiwakara (2021), Wagner (2022), Bradt, Kousky, and Wing (2021), Sastry (2021), Blickle and Santos (2022), Ouazad and Kahn (2021), Issler et al. (2020), Garbarino, Guin, and Lee (2024)

Empirics - Outline

Question: How do households respond to rising climate risk?

$\rightarrow$ Focus on flood risk in the US

Identification challenges:

1. Gradual change in flood risk
2. Correlation of risk with amenity values
3. Local economic effects of floods

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Identification challenges:

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2. Correlation of risk with amenity values
3. Local economic effects of floods

Approach:

- Evaluate shocks to flood awareness.
- Construct measure of time-varying flood experience of faraway friends.
- Novel panel using administrative data from National Flood Insurance Program
- Adaptation decision: home elevation

Flood insurance in the US

- ∼95% of household flood insurance is provided by the government via the National Flood Insurance Program (NFIP)
- Low uptake despite heavy subsidisation
- Not compulsory except for some houses in flood zones, low compliance.
- The NFIP publishes administrative microdata on insurance policies: >70mn policies, including census block group location and details of home insured, universe of policies since 2009.
- \$1.6bn in claims in FY2022.

Elevation | Elevated prop of houses | Other desc. stats

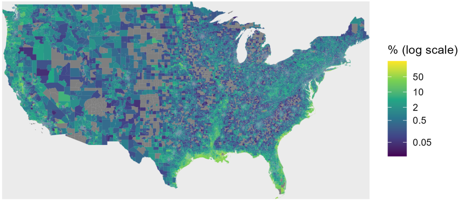

Figure: Insured proportion of all housing units

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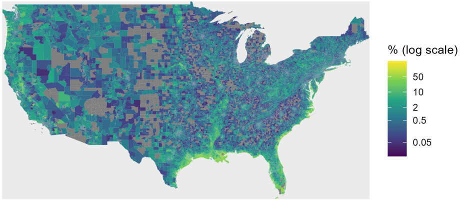

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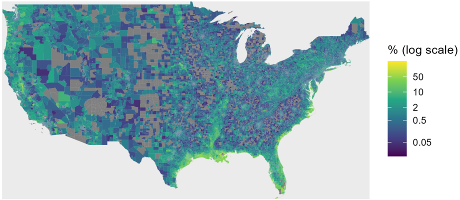

Figure: Insured proportion of all housing units

Elevation

- Another way to reduce your exposure to flood risk is to elevate your building above ground level.
- Flood insurance is cheaper for elevated buildings. Definition of elevation Example rate table
- Elevation is required in some flood zones for new or significantly reconstructed buildings.

Elevation process Elevation map Elevated prop of houses

Figure: Tangier Island, Virgina

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Elevation, insurance and flood risk across incomes

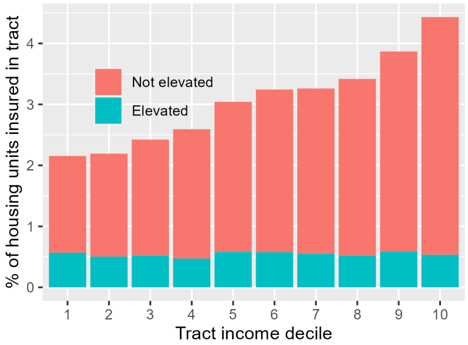

Figure: Share of properties insured and elevated

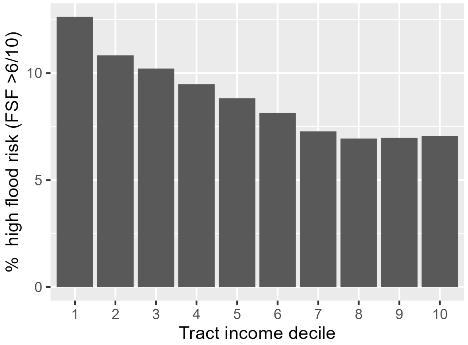

Figure: Share of high flood risk homes

NFIP - constructing panel

NFIP policy microdata is not linked as policies are renewed. However, 90% of flood insurance policies were uniquely identified year-to-year, by:

- Census block group
- Date of renewal of insurance policy and original date of policy issuance
- Date of building construction

And in addition, all but a negligible (<0.1%) of flood insurance claims can be mapped to a flood insurance policy.

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And in addition, all but a negligible (<0.1%) of flood insurance claims can be mapped to a flood insurance policy.

Use this to make a novel panel:

- Almost certainly the same property, repeatedly insured, no insurance claims.
- Track change in elevation status while insured.
- For insurance panel, assume insured if present, uninsured if not.

Identification strategy

- Climate risk is very slow moving
- Use salience of climate risk as a proxy

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  - Rainfall - annual rainfall modelled at 4km resolution, from PRISM Climate Group

Identification strategy

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- Construct a measure of this using average rainfall experienced by friends:
  - Friendship network - Social Connectedness Index from Facebook data, Bailey et al. (2016)
  - Rainfall - annual rainfall modelled at 4km resolution, from PRISM Climate Group
- Use just the experience of far-away ($>$200 miles) friends to remove local effect of flooding

Treatment variable calculation | Social network and non-random exposure to exogenous shocks | SCI details

Event study specification

Specification:

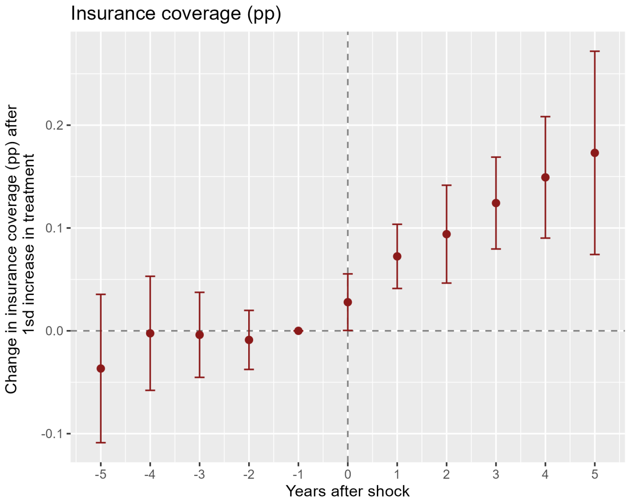
$$y_{i,c,t} = \sum_{k=-4:-2,0:4} \delta_k \Delta z_{c,t-k} + \delta_{-5} z_{c,t+5} + \delta_5 z_{c,t-5} + \alpha_i + \gamma_t + \varepsilon_{i,c,t}$$

Following Freyaldenhoven, Hansen, Pérez, Shapiro (2021)

- $y_{i,c,t}$: Binary variable, elevated/insured $= 1$ for property i in census tract c and year t
- $z_{c,t-k}$: Continuous treatment: census tracts' faraway (200 miles) friends' rainfall experience, annual
- α_i, γ_t: Property and year fixed effects
- SEs clustered by year and census tract
- Sample period: 2009 - 2017

$+$ interact the treatment $z_{i,c,t-k}$ with census tract income in 2000 (above or below median).

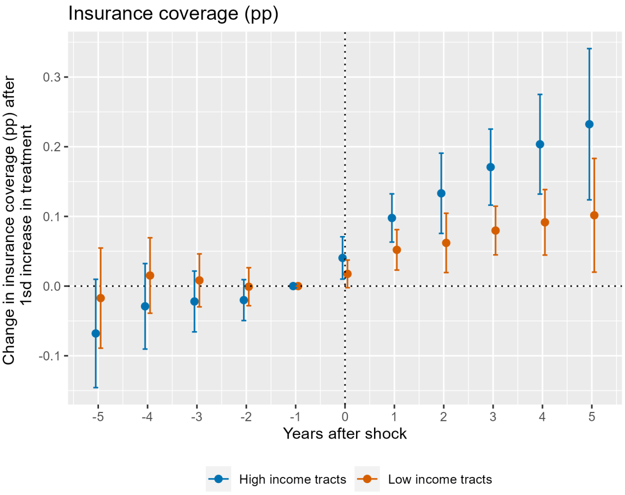
Results - Insurance - Response to flood salience shock



Mean insurance coverage: 39.9 %, Adj R2: 0.2856 , N: 88,658,046 , FE# - i: 9,850,894 , year: 9

Extreme rainfall | Flood claims | Full social network

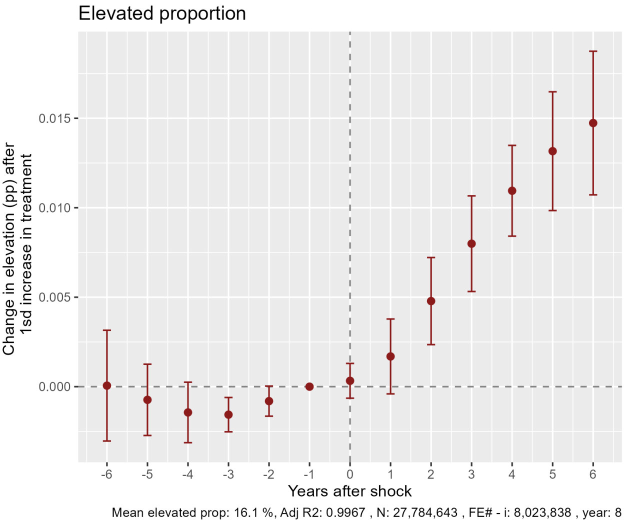
Results - Insurance - Response to flood salience shock



Mean insurance coverage: 39.9 %, Adj R2: 0.286 , N: 88,658,046 , FE# - i: 9,850,894 , year: 9

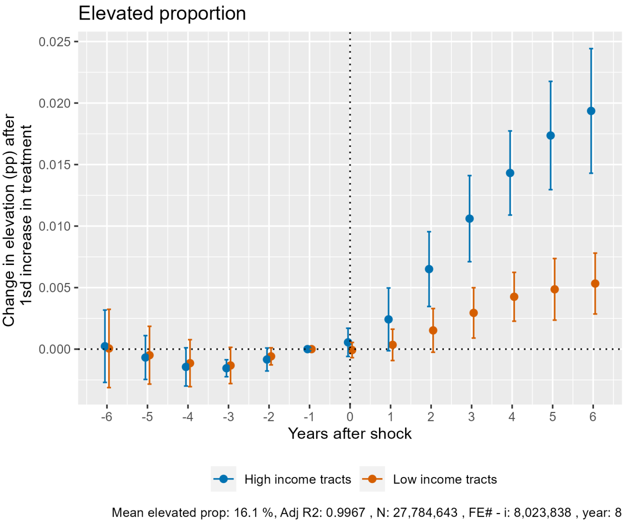
Extreme rainfall | Flood claims | Full social network

Results - Elevation - Response to flood salience shock



Extreme rainfall | Flood claims | Full social network | Elevation vs Migration

Results - Elevation - Response to flood salience shock



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Results - Responses to flood salience shock

Key takeaways:

- Insurance and adaptation rise – insurance 14x more than adaptation
- Low income more reliant on insurance – insurance 25x more than adaptation

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Robustness:

- Migration: high income areas with low levels of relocation drive adaptation Relocation
- Different flood awareness proxy construction Extreme rainfall Flood claims
- Local effects of flooding change results Local flooding Full social network

Model - Outline

Heterogeneous agent model of climate risk:

- Households face flood risk to their housing stock
- Choose to insure or elevate their housing
- Solve transition as flood risk rises

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Key mechanism:

- Idiosyncratic income risk $\times$ borrowing constraint shortens planning horizon
- Adaptation is an illiquid, long-term investment, insurance is short-term and flexible
- Constrained, low income households will adapt less as risk rises

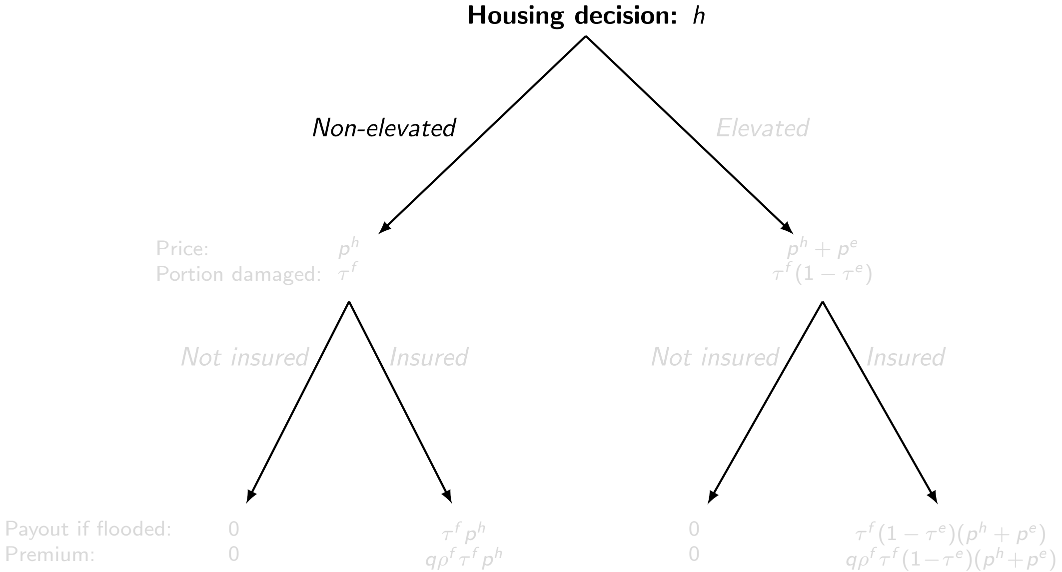
Housing: choose h at price p^h

- Get utility from housing, depreciates at rate δ, subject to adjustment costs.

Flood risk:

- Idiosyncratic, binary risk of a flood f hitting, with probability ρ^f.

Model - Adaptation and Insurance



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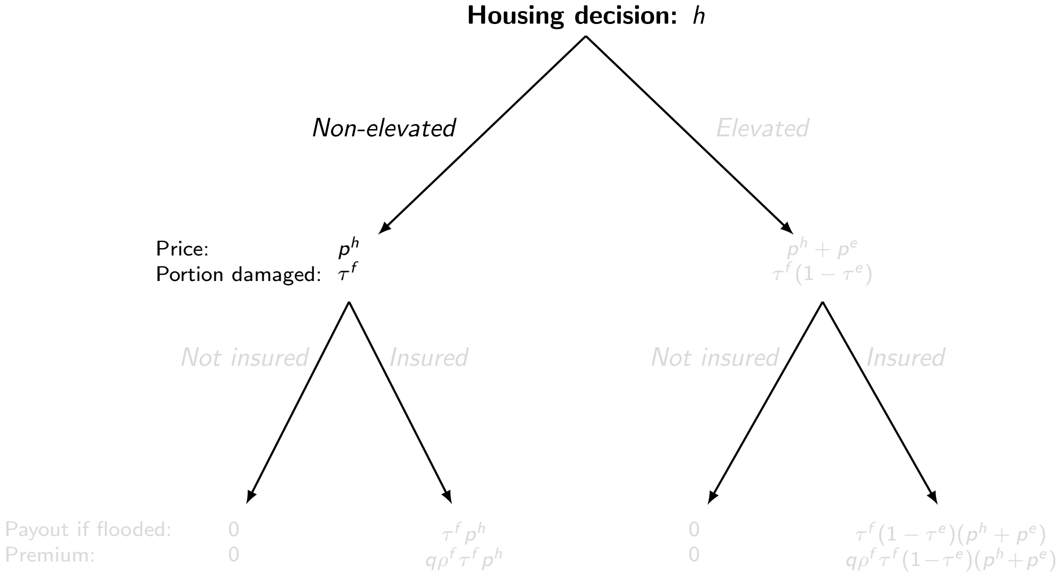

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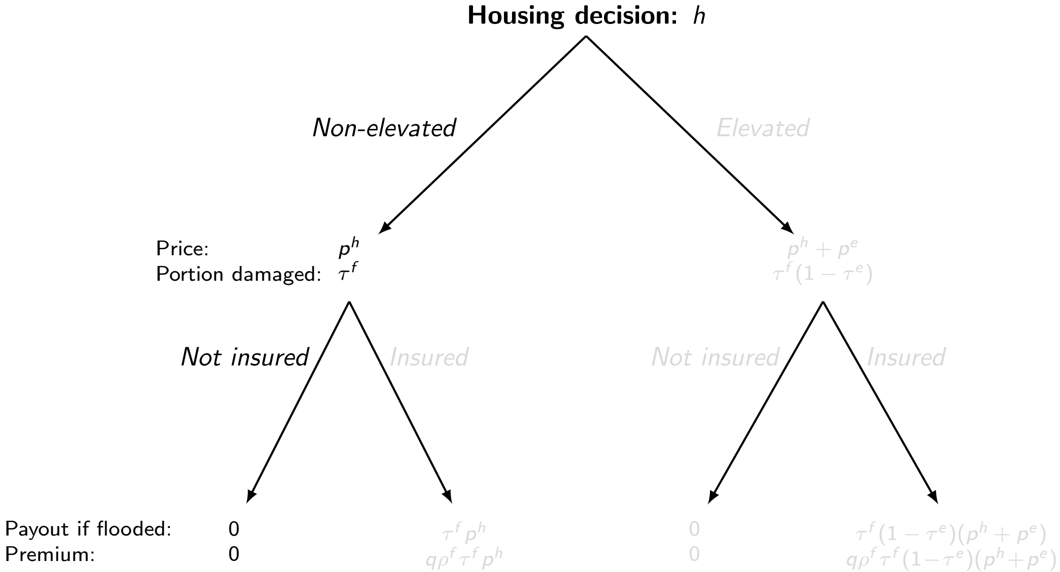

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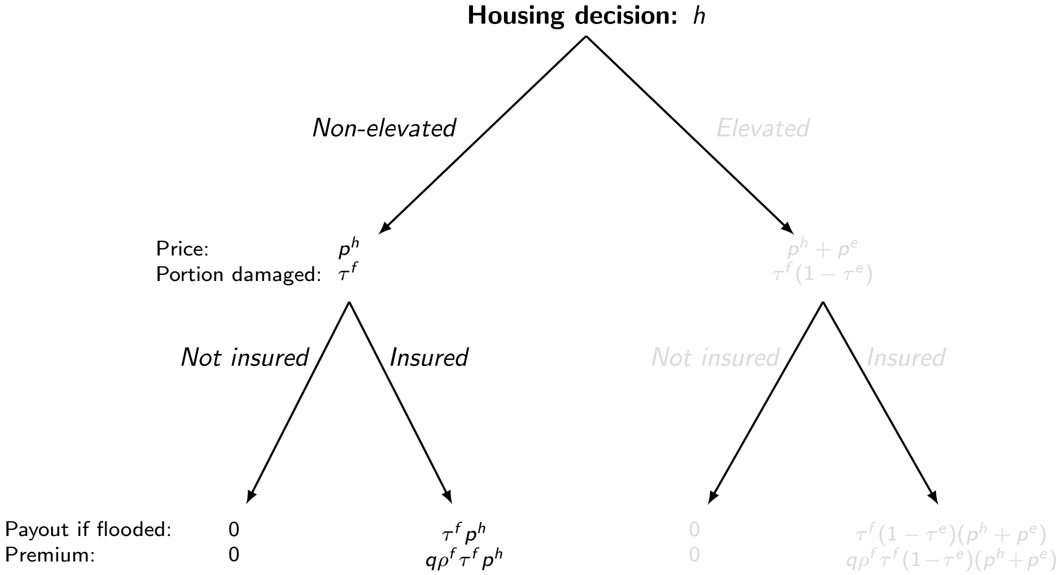

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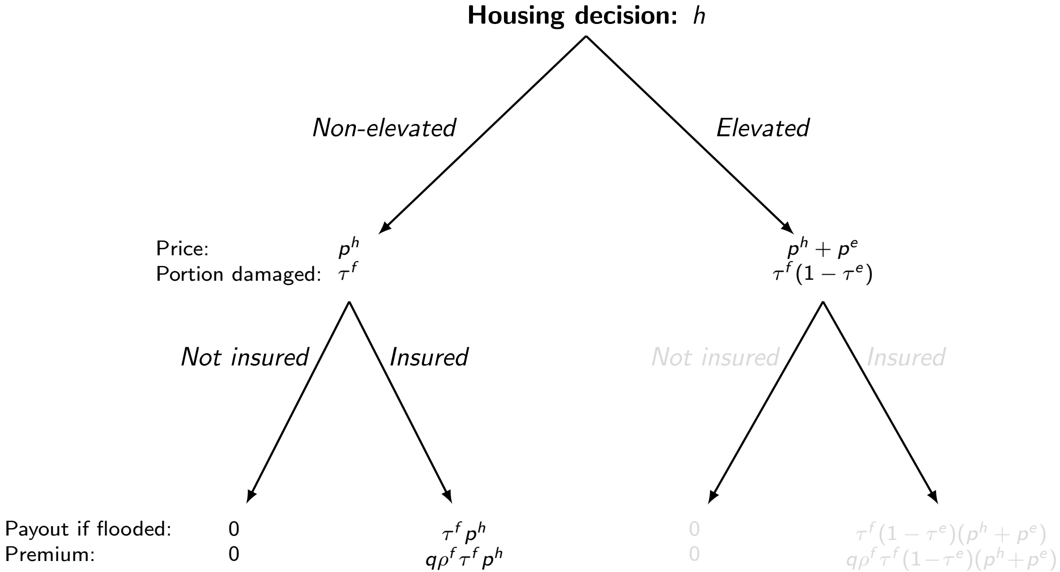

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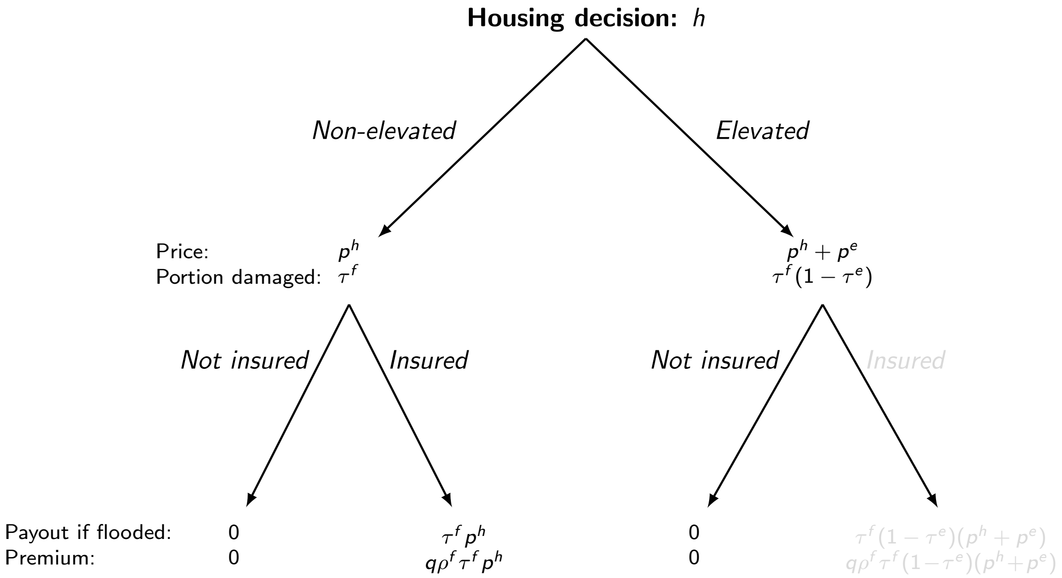

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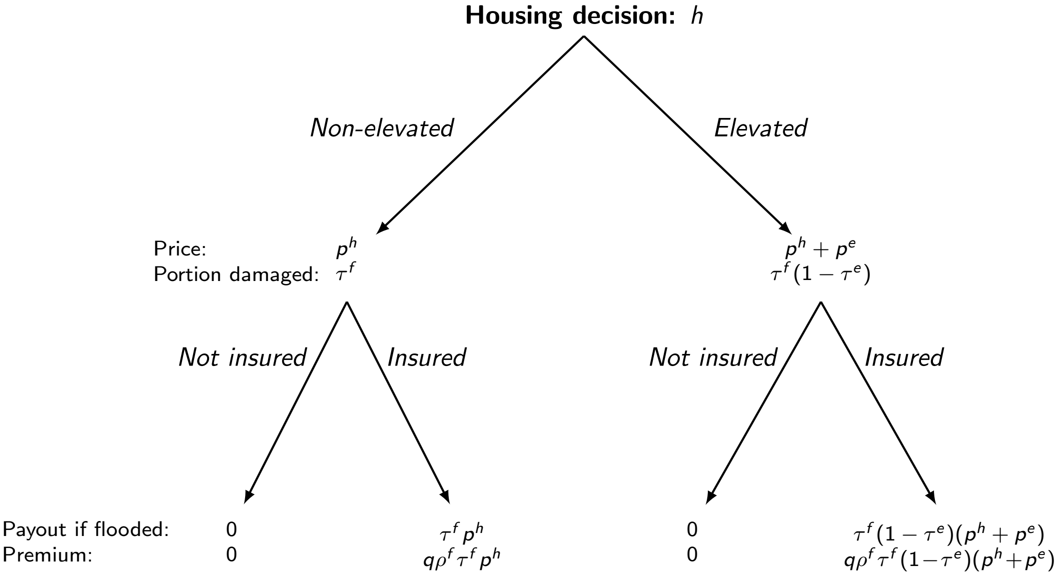


Model - Flood risk and housing

Housing: choose h at price p_h

Flood risk: binary f with probability ρ^f

Elevation ($e \in \{0, 1\}$):

- If households don't elevate, they will suffer loss τ^f to housing stock if flooded.
- Can choose to elevate for premium p^e, reduces flood damage by τ^e.
- Binary choice, subject to adjustment costs.

Model - Flood risk and housing

Housing: choose h at price p_h, illiquid

Flood risk: binary f with probability ρ^f

Elevation: binary e, premium p_e, reduces damage by τ_e, illiquid

Insurance ($i \in \{0, 1\}$):

- Can insure housing for a premium subsidised below fair value (q)
- Utility cost reflecting behavioural frictions
- Net insurance payout:

$$I(h, f, i, e) = i(\underbrace{f\tau^f(1 - \tau^e e)(p^h + p^e e)}_{\text{Insurance payout}} - \underbrace{q\rho^f\tau^f(1 - \tau^e e)(p^h + p^e e)}_{\textit{Premium}})(1 - \delta)h$$

Model - Flood risk and housing

Housing: choose h at price p_h, illiquid

Flood risk: binary f with probability ρ^f

Elevation: binary e, premium p_e, reduces damage by τ_e, illiquid

Insurance: binary i, subsidised, utility cost

Next period housing:

- $H(h, f, i, e) = (1 - f * \tau^f(1 - \tau^e e))(1 - \delta)h$

Model - Timing

Within period timing:

1. Enter period with pre-existing housing stock, elevation status, bonds and productivity
2. Choose whether to insure within that period
3. Hit by exogenous shocks: productivity and flood
4. Make savings, housing and elevation decisions for next period, consume.

Model - Household problem

$$V(b,h,i,e;s,f) = \max_{b',h',i',e'} \{u(c) + \gamma^H u(H(h,f,i,e)) - \gamma^I i V(b,h,i,e;s,f) + \beta\,\mathbb{E}[V(b',h',i',e';s',f')]\}$$

Subject to:

$$\begin{aligned} c &= ws + (1+r)b - b' \\ &\quad + (p^h + p^e e)H(h,f,i,e) - (p^h + p^e e')h' \\ &\quad + I(h,f,i,e) - \Phi^H(h',h) - \Phi^E(e',e,h) \\ b' &\geq \underline{\mathrm{b}} \end{aligned}$$

- b: Risk-free bonds, pay r.
- s: Income state Income risk
- Φ: Adjustment costs for housing and elevation Adj cost specification

Model - Prices

Solve for equilibrium in high flood risk local economies:

Endogenous:

- p^h: Solve for house price that makes housing demand equal to a fixed stock of housing:

$$H^{agg} = H^S$$

- Using sequence-space approach of Auclert, Bardoczy, Rognlie and Straub (2021)

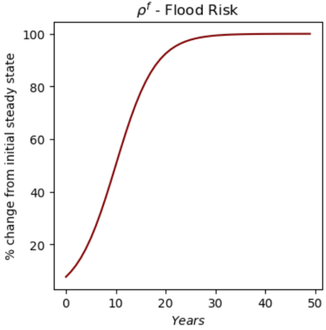
Exogenous

- p^e: set equal to the physical cost of elevating a home c^e
- r: Interest rate

Other model details

Calibration - Flooding

	Value	Description	
ρ^f	0.01	Initial flood risk	Special Flood Hazard Area cut-off.
τ^f	0.25	Flood damage	Kousky and Michel-Kerjan (2017)
q	0.7	Insurance subsidy	Wagner (2022)
γ^I	1e-6	Disutility from insuring	Initial insurance take-up of 46%
p^e	0.15	Cost of elevation	Xian, Lin, and Kunreuther (2017) examples
τ^e	0.5	Damage reduction from elevation	Higher than Kousky and Michel-Kerjan (2017), to accommodate no claims.



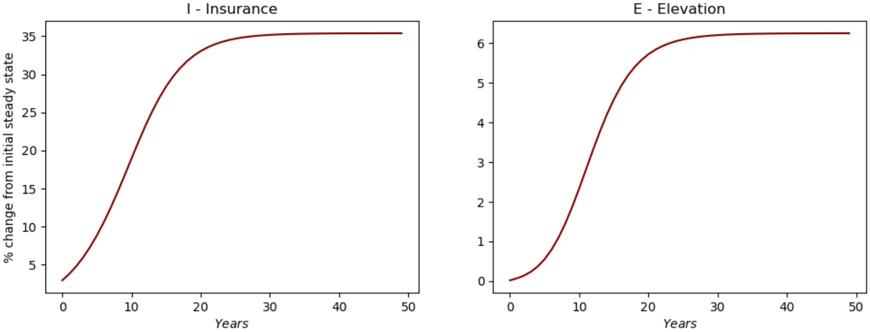
Numerical parameters SS outcomes

Calibration

Parameter	Value	Description
β	0.96	Discount rate
$1/\sigma$	2.5	Intertemporal elasticity of substitution
p^h	1	Price of housing
r	0.02	Bond return
γ^H	0.1	Housing utility
δ	0.025	Depreciation of housing
χ_0	0.25	Housing adjustment parameter
χ_1	0.9	"
χ_2	1.2	"
χ_e	0.01	Elevation adjustment
ρ_z	0.966	Persistence of productivity shocks
σ_z	0.92	Variance of productivity shocks
$\underline{b}$	0.1	Borrowing constraint

Numerical parameters SS outcomes

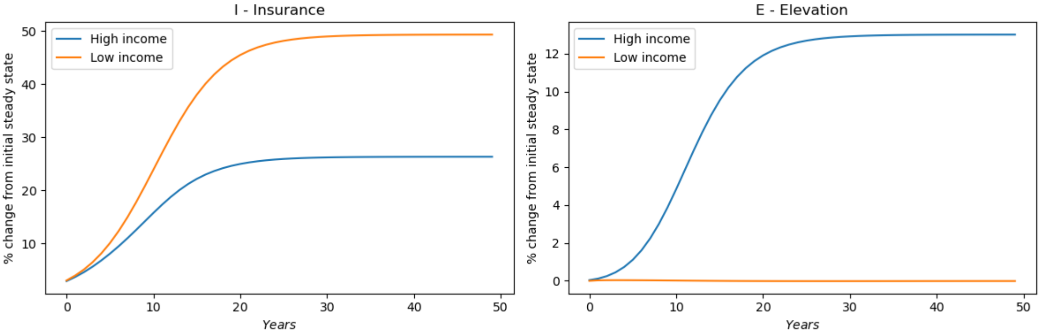
Model results - Transition to higher flood risk



- Insurance increases 6x more than adaptation (14x in data)

Partial equilibrium results | Steady state | Removing insurance subsidies

Model results - Transition to higher flood risk



- High income rely on insurance less
- Low income do not adapt

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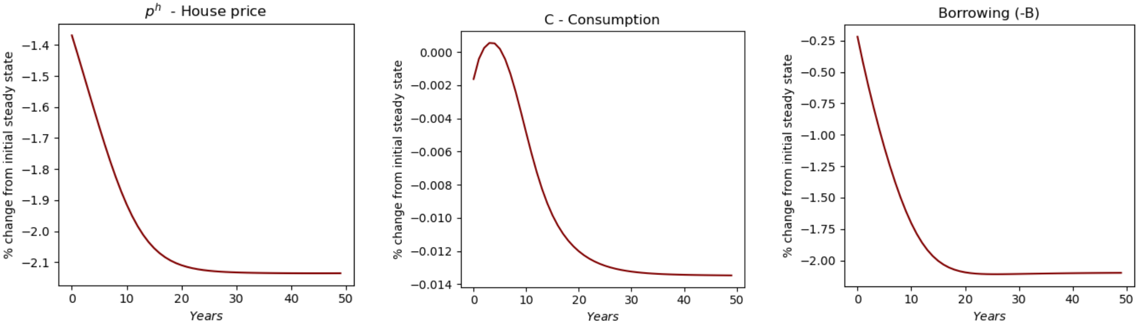
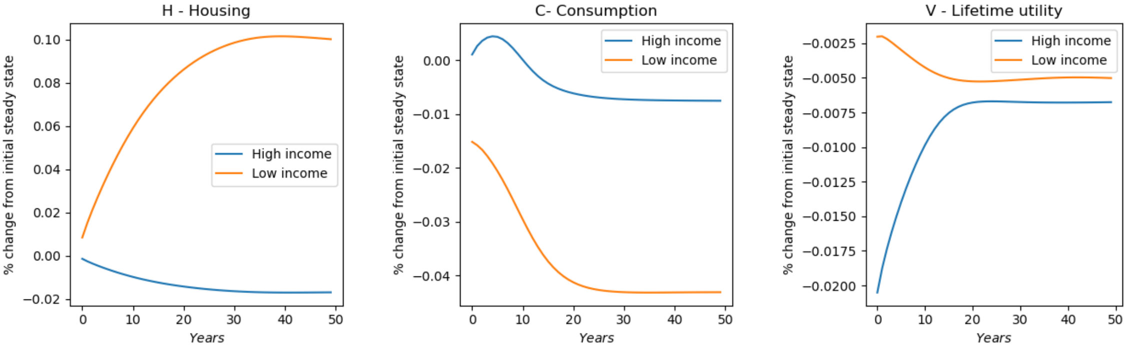
Model results - Transition to higher flood risk



- House prices decline as risk rises

Partial equilibrium results | Steady state | Removing insurance subsidies

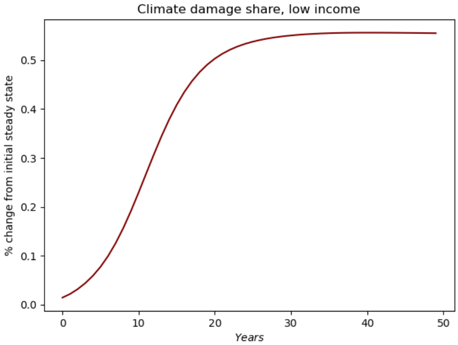
Model results - Transition to higher flood risk

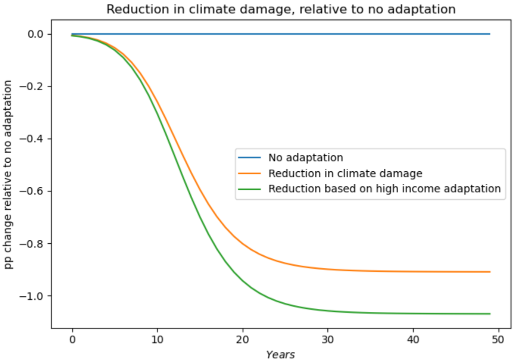


- Low income substitute *toward* housing as house prices decline

Partial equilibrium results | Steady state | Removing insurance subsidies

Model results - Transition to higher flood risk





Low income households' failure to adapt means:

- ... climate damage is more regressive
- ... and larger

$$\textit{Climate damage} = H^{NE}\rho^f\tau^f + H^E\rho^f\tau^f(1-\tau^e)$$

Conclusion

- Empirical responses in micro-data to flood salience shocks suggest:
  - Richer households invest more in adaptation
  - Lower income households are more reliant on insurance
- Heterogeneous agent model of climate risk
  - Demonstrate implications of empirical responses
  - Climate damage is larger and more regressive because low income households fail to adapt
- Policy implications:
  - Removing insurance subsidies would help speed up adaptation Removing insurance subsidies
  - Savings could be redirected to (targeted) adaptation subsidies

Research Agenda

Current papers:

1. 'Non-essential Business Cycles' - with Michele Andreolli and Paolo Surico
   During recessions, households cut non-essential consumption. This hurts earnings within those sectors - which employ low-income, hand to mouth workers - amplifying recessions.
2. 'The Green Energy Transition in a Putty-Clay Model of Capital' - with Simon Gilchrist and Joseba Martinez
   Embedding irreversibility and underutilisation of fossil-fuel reliant investments into an integrated assessment model. The green transition is slower and more economically costly.

Future agenda:

- Increasing un-insurability of climate risks
- Local community coordination in investment in adaptation
- Cyclicality of consumption and keeping up with the Joneses in a world of social media

Research Summary

Research agenda: Macroeconomics and climate change, with a particular focus on the importance of heterogeneity and inequality across households and firms.

Current projects:

1. 'Sheltering from Climate Risks' (JMP)
2. 'The Green Energy Transition in a Putty-Clay Model of Capital' - with Simon Gilchrist (NYU) and Joseba Martinez (LBS)
3. 'Non-essential Business Cycles' - with Michele Andreolli (Boston College) and Paolo Surico (LBS)

Near-term plans:

- Failures in insurance supply in the face of rising climate risks
- Local community investment in adaptation to climate change
- 'Keeping up with the iJones' - reference consumption and social media transmission of information over the business cycle, in a world of social media

(1) Sheltering from Climate Risks

How can households act to mitigate climate risks, and what are the broader consequences?

- Empirical setting, using administrative data on flood insurance in the US
  - High income households more likely to invest in adaptation, when more aware of climate risks
  - Low income households more reliant on insurance

- Develop a heterogeneous agent model of climate risk, incorporating adaptation and insurance
  - Climate damage larger and hits lower income households more
  - Because low income households fail to invest in adaptation.

(2) The Green Energy Transition in a Putty-Clay Model of Capital

with Simon Gilchrist (NYU), Joseba Martinez (LBS)

Climate targets require a shift away from existing fossil-fuel dependent capital (e.g. sunk investments in coal power plants).

We propose a model of the green transition using putty-clay production technology (Gilchrist and Williams (2000), Wei (2003)):

- Once created, investments in capital of a particular vintage are (1) Fixed in nature - factor input ratios can't change, and (2) may be only partially utilised
- Incorporate this into a multi-sector integrated assessment model

Assess the impact of green technology improvements and carbon tax increases:

- A green transition has worse aggregate effects and requires a $\sim$ 40% larger carbon tax increase.

(3) Non-Essential Business Cycles

with Michele Andreolli (Boston College) and Paolo Surico (LBS)

Non-essentials (discretionary/luxury spending):

1. Non-essential consumption declines more during recessions
2. Resulting in declining earnings in non-essential sectors
3. Which disproportionately employ low income, hand-to-mouth workers

This paper:

- New macro time series for essentials and non-essentials, for consumption, prices, earnings
- Document how these respond during recessions and to monetary policy shocks
- Estimate a new-Keynesian model with consumption and labour market heterogeneity
- Demonstrate business cycle amplification and implications for unconventional fiscal policy

Submitted, working on follow-up paper

Research Summary

Future: continue to work at intersection of macroeconomics and climate economics, in addition to other important macro topics. Similar mix of micro-empirical evidence and macro modelling.

Near-term plans:

- Failures in insurance supply in the face of rising climate risks
    - Widespread failures in insurance supply (Florida, wildfires in California) represent broader problems supplying insurance
    - Hard for even large reinsurers to insure larger and more correlated climate risks
    - Document how insurance/reinsurance supply changes after disasters, using reinsurer administrative filings
    - Model reserve requirements in reinsurance to explore implications of fluctuating insurance supply
- Local community investment in adaptation to climate change
- ‘Keeping up with the iJones’ - reference consumption and social media transmission of information over the business cycle, in a world of social media

Research Summary

Future: continue to work at intersection of macroeconomics and climate economics, in addition to other important macro topics.

Near-term plans:

- Failures in insurance supply in the face of rising climate risks
- Local community investment in adaptation to climate change
  - Address coordination (rather than individual level) decisions on adaptation
  - Use Community Rating System of NFIP as case study
  - Are more homogenous/heterogeneous, rich/poor communities more able to co-ordinate adaptation?
- 'Keeping up with the iJones' - reference consumption and social media transmission of information over the business cycle, in a world of social media

Research Summary

Future: continue to work at intersection of macroeconomics and climate economics, in addition to other important macro topics.

Near-term plans:

- Failures in insurance supply in the face of rising climate risks
- Local community investment in adaptation to climate change
- ‘Keeping up with the iJones’ - reference consumption and social media transmission of information over the business cycle, in a world of social media
    - Households’ comparisons are increasingly online via social media, rather than down the street
    - Selective reporting on social media may skew perceptions
    - More conspicuous consumption during booms, less during recessions?
    - Does this contribute to consumption cyclicality, particularly for more ’online’ groups?

Policy implications

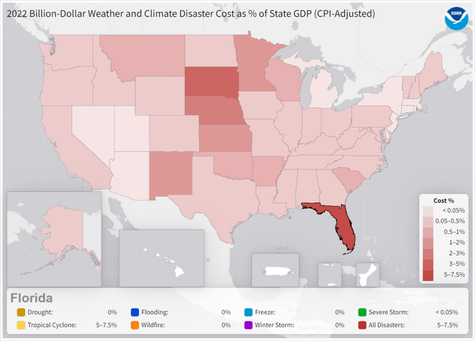
Primarily a positive conclusion: $\rightarrow$ Climate damage is regressive and larger

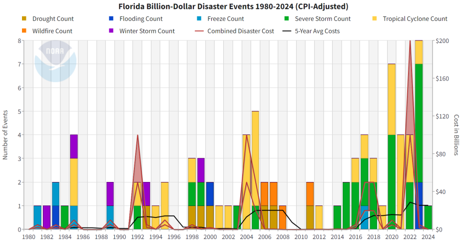
Policy conclusions (some speculative!):

1. Insurance subsidies
   - Seem unwise as they reduce incentives to invest in adaptation
   - Could be reduced (as already being seen) and redirected to (targeted) adaptative subsidies
2. Increased risk $\rightarrow$ self-insurance (decreased borrowing) + more reconstruction
   - Effect on interest rates ambiguous
3. Carbon taxes
   - Larger and more regressive climate damage suggest higher social costs of carbon

Appendix

Economic magnitude of disaster risk





- Swiss RE estimates that insured losses globally have been growing 5-7% per year, and 60% of losses are uninsured.

Elevation definition

NFIP definition of elevated building:
An elevated building is a no-basement building that was constructed so as to meet the following criteria: 1. The top of the elevated floor (all A zones) or the bottom of the lowest horizontal structural member of the lowest floor (all V zones) is above ground level; 2. The building is adequately anchored; 3. The method of elevation is pilings, columns (posts and piers), shear walls (not in V zones), or solid foundation perimeter walls (not in V zones)

Example NFIP rate table

RATE TABLE 3B. REGULAR PROGRAM – POST-FIRM CONSTRUCTION RATES[1,2]

ANNUAL RATES PER $100 OF COVERAGE (Basic/Additional)

FIRM ZONES AE, A1–A30 — BUILDING RATES

ELEVATION OF LOWEST FLOOR ABOVE OR BELOW THE BFE[3,4]	1 FLOOR No Basement/Enclosure/ Crawlspace[5,6]		MORE THAN 1 FLOOR No Basement/Enclosure/ Crawlspace[5,6]		MORE THAN 1 FLOOR With Basement/Enclosure/ Crawlspace[5,6]		MANUFA (MOBILE)
	1-4 Family	Other Residential, Non-Residential Business, Other Non-Residential[9]	1-4 Family	Other Residential, Non-Residential Business, Other Non-Residential[9]	1-4 Family	Other Residential, Non-Residential Business, Other Non-Residential[9]	Single Family
+4	.31 / .09	.28 / .13	.27 / .08	.22 / .08	.24 / .08	.20 / .08	.32 / .16
+3	.35 / .09	.32 / .15	.31 / .08	.25 / .08	.27 / .08	.23 / .09	.37 / .18
+2	.51 / .11	.46 / .20	.44 / .08	.36 / .08	.32 / .08	.28 / .10	.54 / .24
+1	.96 / .17	.84 / .31	.80 / .08	.66 / .09	.46 / .08	.36 / .12	1.02 / .40
0	2.25 / .27	1.92 / .50	1.79 / .08	1.44 / .14	.68 / .08	.58 / .14	2.39 / .71
−1	5.47 / .36	4.58 / .69	4.40 / .08	3.54 / .15	1.17 / .08	.86 / .17	5.83 / 1.13
−2[8]	8.07 / .70	6.88 / 1.35	6.53 / .13	5.25 / .26	***	***	8.61 / 2.19
−3[8]	10.00 / 1.20	8.76 / 2.30	8.32 / .22	6.77 / .47	***	***	10.59 / 3.41
−4[8]	12.06 / 1.80	10.76 / 3.45	10.26 / .36	8.46 / .77	***	***	12.68 / 4.77
−5[8]	13.61 / 2.41	12.34 / 4.60	11.79 / .57	9.88 / 1.16	***	***	14.21 / 6.00
−6[8]	13.96 / 2.96	12.86 / 5.63	12.36 / .84	10.56 / 1.69	***	***	14.51 / 6.84
−7[8]	14.20 / 3.49	13.34 / 6.53	12.87 / 1.11	11.15 / 2.21	***	***	14.85 / 7.50
−8[8]	14.26 / 3.99	13.44 / 7.46	13.23 / 1.40	11.59 / 2.75	***	***	14.89 / 8.04

Figure: Example NFIP rate table (2021)

Building elevation

It is possible to elevate a building without completely reconstructing it:

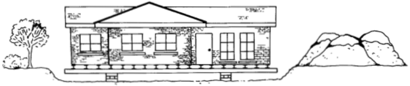


***Figure 2.* 2000 sq. ft. house prepared for elevation.** Approximately 6,500 cu. ft. of dirt will be excavated when all the dirt is removed from beneath the structure. Dirt to be re-used must be kept dry (cover with plastic sheeting). There will be a large hole under the structure until the elevation is complete and fill-dirt has been added. The contractor should be prepared to pump water out of the excavated area in the event of rain.

FEMA Case Study; LSU guide; CNBC 2021 coverage; Example construction company

Elevation

Figure: Holycross, New Orleans (2014)

Figure: Tangier Island, Virgina

Historic elevation

- Long history of elevation as flood defense, particularly in New Orleans:

Figure: New Orleans during the Great Mississippi Flood (1927)

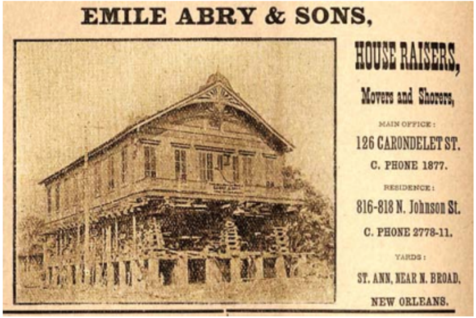


Figure: Advert for building elevation services (1901, New Orleans)

Elevation today

Elevation

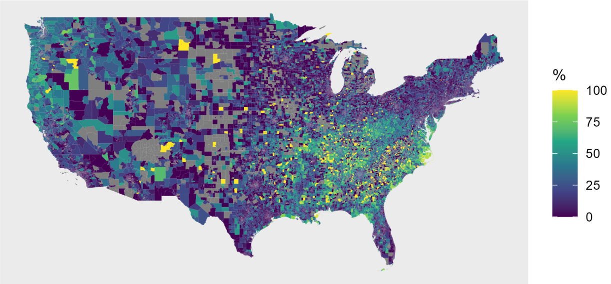


Figure: Elevated proportion of flood insurance policies

Perc. of housing units

Elevation

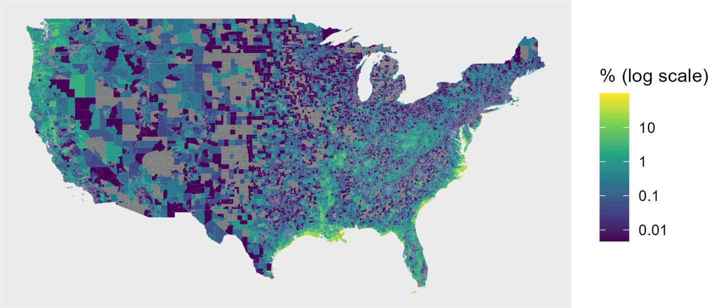


Figure: Elevated proportion of all housing units

Other descriptive statisticss

Table: Summary statistics

By census tract	
No. policies	64
No. housing units	1864
Perc. insured of all housing units	3.2%
Perc. elevated of insured	16.1%
Overall	
Av. policy cost (2015$)	$754

Social Connectedness

Construction of average friend's rainfall, for year t, for zipcode i and friend zipcodes j:

$$\text{Friend rainfall}_{i,t} = \sum_{j=1}^{J} \text{SCI}_{i,j} * (\text{rainfall})_{j,t} \tag{1}$$

This is then mapped from zip codes to census tracts and the treatment variable is the log of this, normalised by the SE.

Social connectedness - representativeness

79% of online adults (68% of all Americans) use Facebook

% of online adults who use Facebook

All online adults	79%
Men	75
Women	83
18-29	88
30-49	84
50-64	72
65+	62
High school degree or less	77
Some college	82
College+	79
Less than $30K/year	84
$30K-$49,999	80
$50K-$74,999	75
$75,000+	77
Urban	81
Suburban	77
Rural	81

Note: Race/ethnicity breaks not shown due to sample size.
Source: Survey conducted March 7-April 4, 2016.
"Social Media Update 2016"

PEW RESEARCH CENTER

Figure: Facebook user demographics (PEW, 2016 survey

- Average distance of friendship connections between zipcodes: 290 miles.
- Correlation between annual rainfall of far-away friends ($>$ 200 miles) and insurance claims in own tract is 0.009 (statistically significant but low).

Borusyak and Hull - Non-Random Exposure to Exogenous Shocks

- The combination of (exogenous) rainfall and (potentially endogenous) social network suggests that my identification strategy could be subject to omitted variable bias of the type described by Borusyak and Hull (2022).
- They recommend (in the case of natural experiments) controlling for a measure of average treatment across shock counterfactuals:

$$\mu_i = \frac{1}{K!} \sum_{\pi(\cdot)\in\Pi_K} f_i(\pi(g); w) \tag{2}$$

- However, they also note that:

  In panel data with $z_{it} = f_{it}(g_t, w_t)$, for example, unit fixed effects generally purge OVB only when the expected instrument is time-invariant, which generally requires the $f_{it}()$ mapping, the value of w_t, and the distribution of g_t to be time-invariant. While plausible in some applications, these conditions (in particular, stationarity of the shock distribution) can be quite restrictive.

  Which could be the case here.

Borusyak and Hull - Non-Random Exposure to Exogenous Shocks

If we assume rainfall in location j and time t can be modelled very simply as:

$$\text{rainfall}_{j,t} = \tau_j + \tau_t + \epsilon_{j,t} \tag{3}$$

With $\epsilon_{j,t}$ iid normal, then $\mu_{i,t}$ becomes:

$$\mu_{i,t} = \sum_{j=1}^{J} \text{SCI}_{i,j} E[\text{rainfall}_{j,t} | w_{j,t}] = \sum_{j=1}^{J} \text{SCI}_{i,j}\tau_j + \tau_t \sum_{j=1}^{J} \text{SCI}_{i,j} = K_i + \tau_t$$

Controlling for a time and location fixed effects is already done in the main specification, so under this assumption there is no OVB.

- However, a more complex process for rainfall in a specific location over time would imply OVB. A better rainfall model to generate an additional $\tilde{\mu}_{i,t}$ to also control for in the regression, as suggested by Borusyak and Hull (2022), could solve this.

NFIP - constructing panel

NFIP policy microdata is not linked as policies are renewed. However, 90% of flood insurance policies were uniquely identified year-to-year, by:

- Census block group
- Date of renewal of insurance policy and original date of policy issuance
- Date of building construction

Furthermore, we can select those that are likely to be unique properties (rather than the same property under different ownership), based on:

- Census block group
- Building construction dates
- Whether policy dates overlap

And in addition, all but a negligible ($<$0.1%) of flood insurance claims can be mapped to a flood insurance policy.

Model - Household heterogeneity

Households face idiosyncratic risk to productivity s_t:

$$log(s_t) = \rho log(s_{t-1}) + \epsilon_t$$

Approximated by a Markov chain using the Rouwenhorst approach.

Households can save in risk-free bonds b with interest rate r, subject to a borrowing constraint:

$$b' \geq \underline{\mathrm{b}}$$

Model - Adjustment costs

Adjustment costs for housing

$$\chi^{h}\left(h_{it}, h_{it-1}\right) = \frac{\phi_1}{\phi_2}\left|\frac{h_{it} - h_{it-1}}{h_{it-1} + \phi_0}\right|^{\phi_2}\left[h_{it-1} + \phi_0\right].$$

Follow the specification in Auclert, Bardoczy, Rognlie and Straub (2021) for illiquid assets.

Adjustment costs for elevation:

$$\chi^{e}(h_{i,t}, e_{i,t}, e_{i,t-1}) = \mathbf{1}(e_{i,t} \neq e_{i,t-1})\phi_3 h_{i,t-1}$$

Calibration

Parameter	Value	Description
n_e	4	Number of productivity states
bmax	10	Maximum bond holdings
bmin	-0.1	Borrowing constraint
hmax	10	Maximum housing holding
kmax	10000	Additional numerical grid calibration
n_b	80	Number of points on bond grid
n_h	110	Number of points on housing grid
Taste shock variance	1e-5	Chosen to ensure it doesn't affect elevation and insurance choice
SS tol	1e-4	Convergence of SS
GE tol	1e-6	Max housing market error in transition

Table: Numerical parameters

Model results - Steady state

Table: Steady state outcomes

Variable	Aggregate value	Low income	High income	Description
C	0.98	0.33	1.63	Consumption
B	-0.05	-0.0997	-0.0082	Bonds
H	0.36	0.11	0.61	Housing
E	0.75	0.77	0.72	Elevation
I	0.46	0.36	0.56	Insurance

Notes: Initial steady state outcomes. Low income and high income values are the averages for above and below median income households.

Model - Steady state

Table: Steady state outcomes

Variable	Aggregate value	Low income	High income	Description
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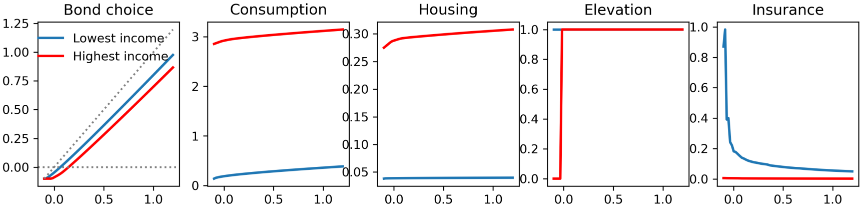
I	0.46	0.36	0.56	Insurance

Variable	Value	Description
Damage	0.0005	Damage each period from flooding in housing units
Low income share of damage	15%	Share of damage absorbed by low income
MPC	0.066	Marginal propensity to consume, income weighted
Φ^H	0.0068	Housing adjustment costs
$\mathbf{1}(e \neq e')$	0.14	Proportion adjusting elevation

Notes: Initial steady state outcomes. Low income and high income values are the averages for above and below median income households.

Model - Steady state, example policy functions



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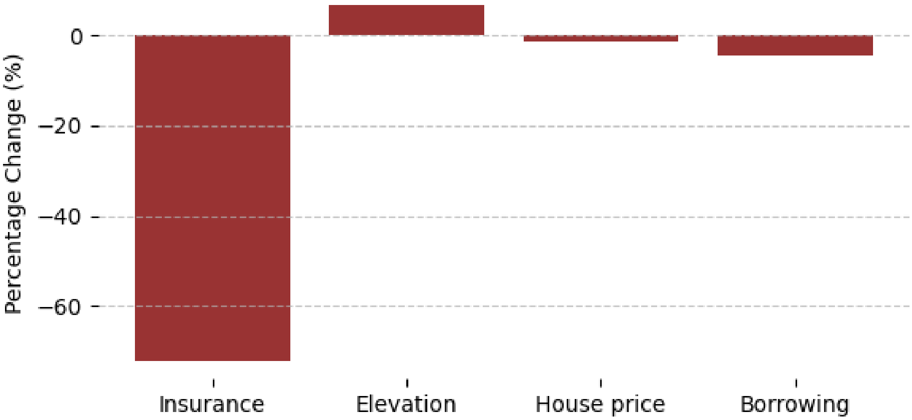
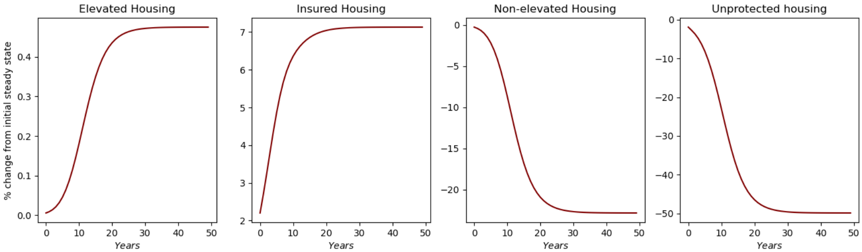
Removal of insurance subsidies



Model results - Transition to higher flood risk



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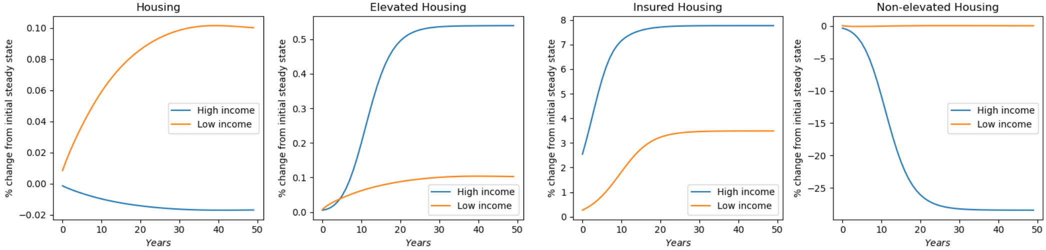
Model results - Transition to higher flood risk



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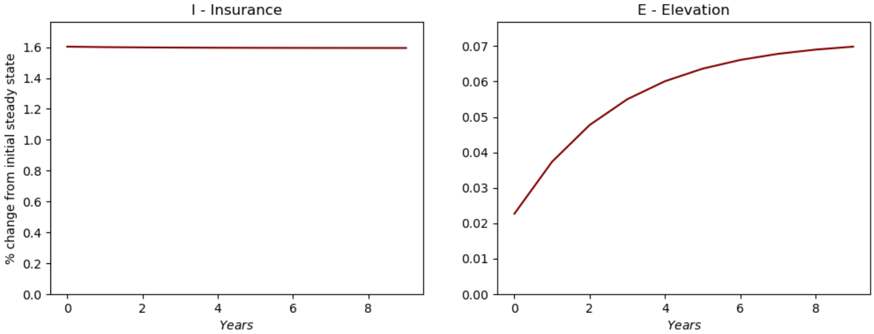
Partial equilibrium responses to a immediate, small (1%) increase in flood risk:



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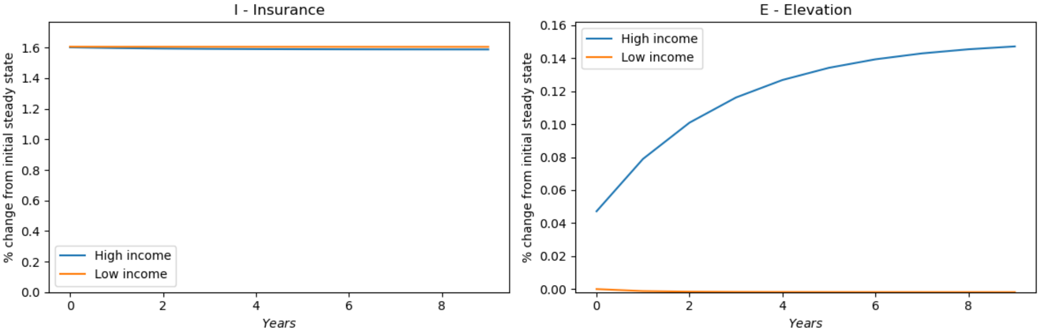
Model results - Partial equilibrium

Partial equilibrium responses to a immediate, small (1%) increase in flood risk:



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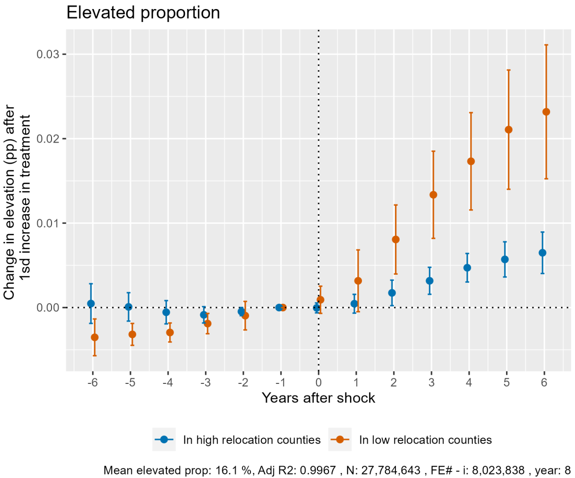
Results - Elevation vs Migration

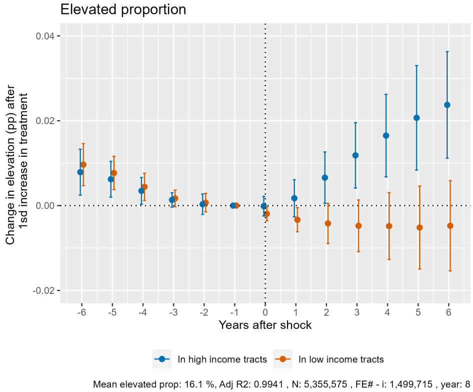


Relocation: number of movers as a proportion of the population in a county. Alternatives Comparison

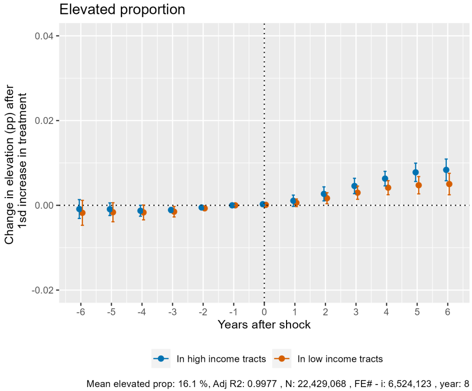
Data: ACS 2006-2010 Migration flows - county level

Results - Elevation vs Migration

Low relocation areas areas:



High relocation areas:

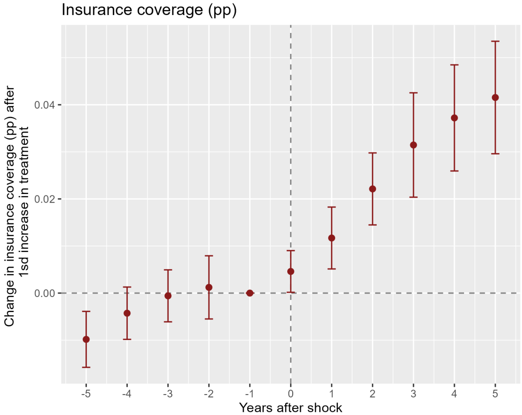


Relocation: number of movers as a proportion of the population in a county. Alternatives Insurance Comparison

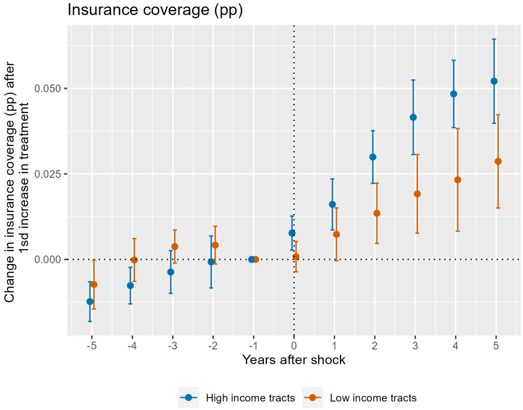
Data: ACS 2006-2010 Migration flows - county level

Results - Insurance - Response to flood salience shock

Alternative shock: number of extreme (>3 inch) rainfall days



Mean insurance coverage: 39.9 %, Adj R2: 0.2857 , N: 93,945,744 , FE# - i: 10,438,416 , year: 9

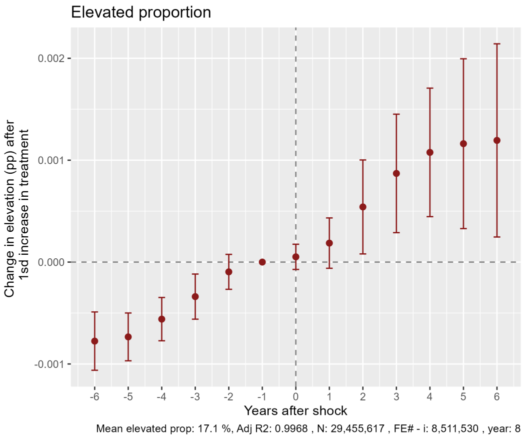


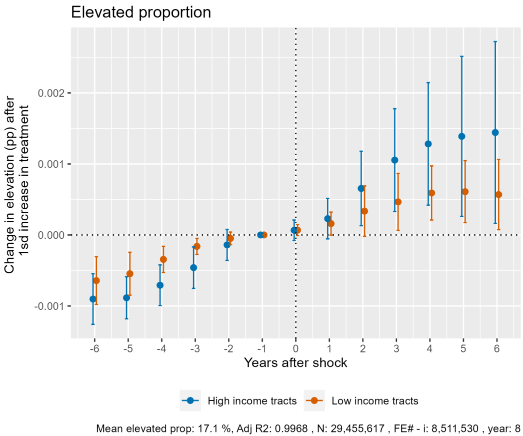
Mean insurance coverage: 39.9 %, Adj R2: 0.286 , N: 93,945,744 , FE# - i: 10,438,416 , year: 9

Back

Results - Elevation - Response to flood salience shock

Alternative shock: extreme (> 3 inch) rainfall days





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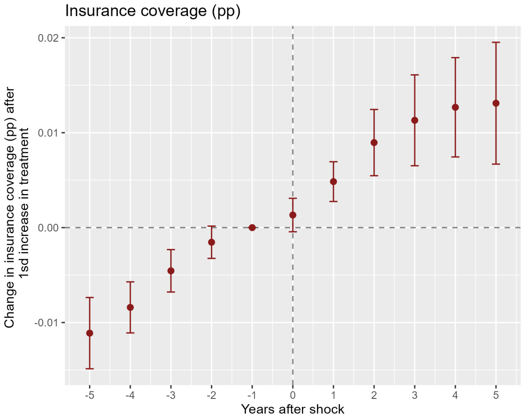
Alternative shock: number of flood claims



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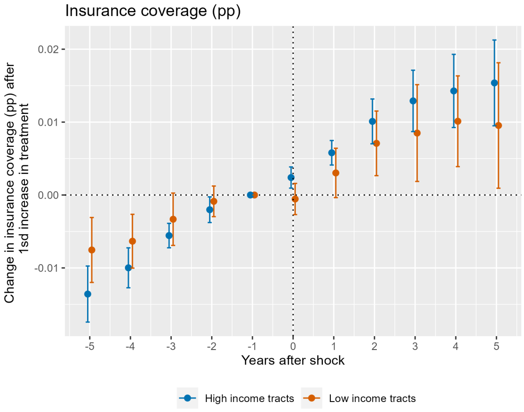

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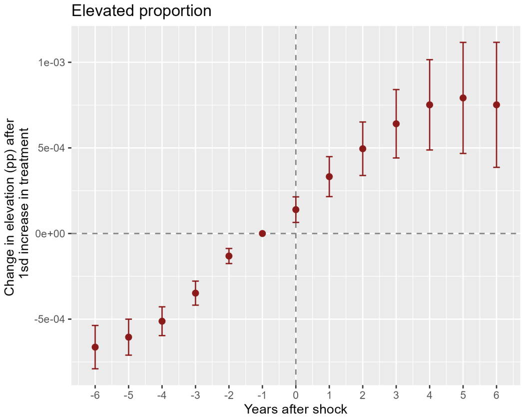
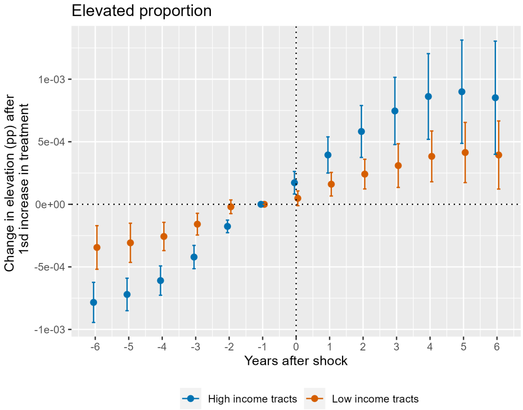
Results - Elevation - Response to flood salience shock

Alternative shock: number of flood claims



Mean elevated prop: 17.1 %, Adj R2: 0.9968 , N: 29,455,617 , FE# - i: 8,511,530 , year: 8



Mean elevated prop: 17.1 %, Adj R2: 0.9968 , N: 29,455,617 , FE# - i: 8,511,530 , year: 8

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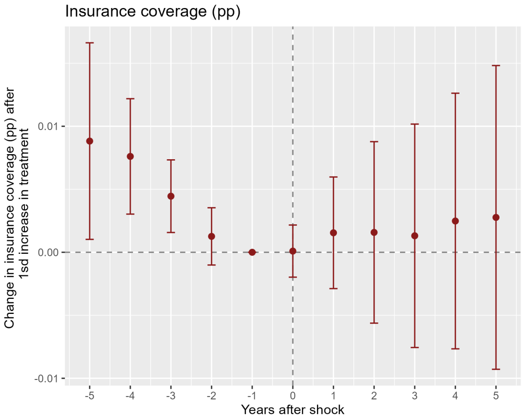
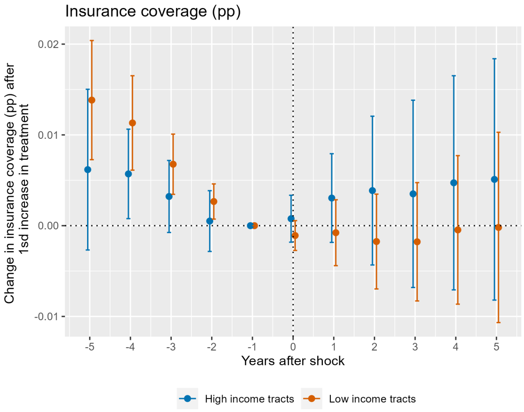
Alternative shock: all friends, including nearby



Mean insurance coverage: 39.9 %, Adj R2: 0.2855 , N: 93,945,744 , FE# - i: 10,438,416 , year: 9



Mean insurance coverage: 39.9 %, Adj R2: 0.286 , N: 93,945,744 , FE# - i: 10,438,416 , year: 9

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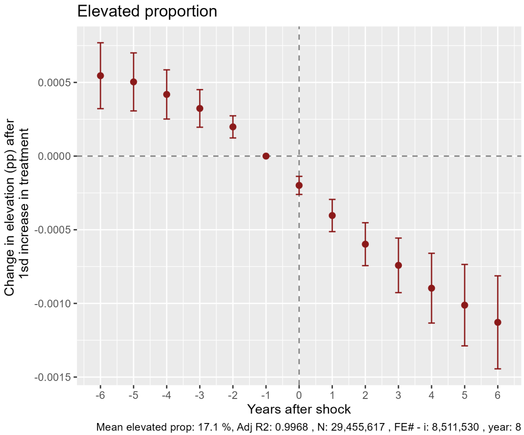
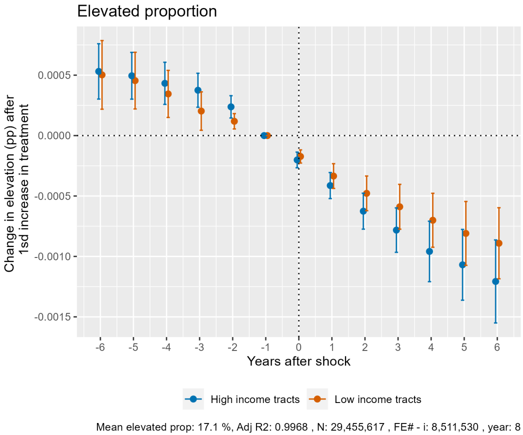
Results - Elevation - Response to flood salience shock

Alternative shock: all friends, including nearby





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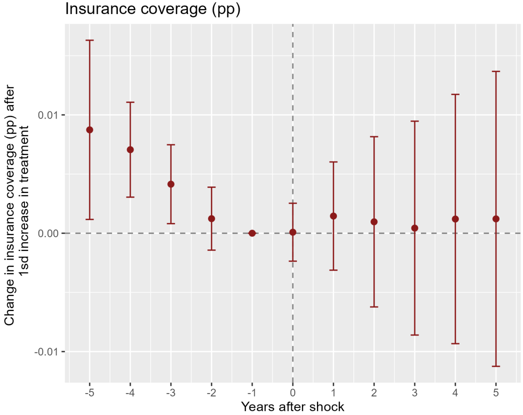
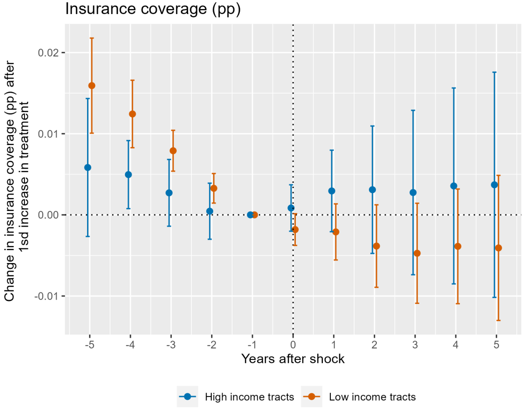
Results - Insurance - Response to local flooding

Alternative shock: local flooding



Mean insurance coverage: 39.8 %, Adj R2: 0.2851 , N: 93,331,863 , FE# - i: 10,370,207 , year: 9



Mean insurance coverage: 39.8 %, Adj R2: 0.285 , N: 93,331,863 , FE# - i: 10,370,207 , year: 9

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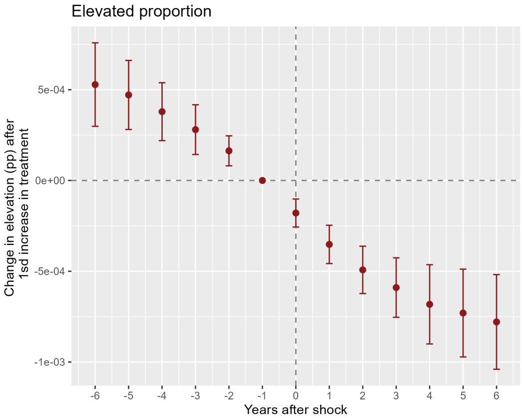
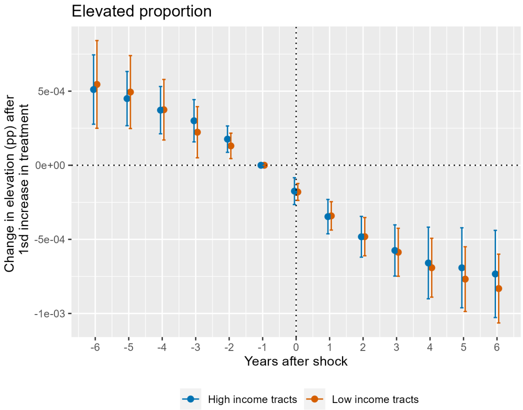
Results - Elevation - Response to local flooding

Alternative shock: local flooding



Mean elevated prop: 17 %, Adj R2: 0.9968 , N: 29,250,326 , FE# - i: 8,460,036 , year: 8



Mean elevated prop: 17 %, Adj R2: 0.9968 , N: 29,250,326 , FE# - i: 8,460,036 , year: 8

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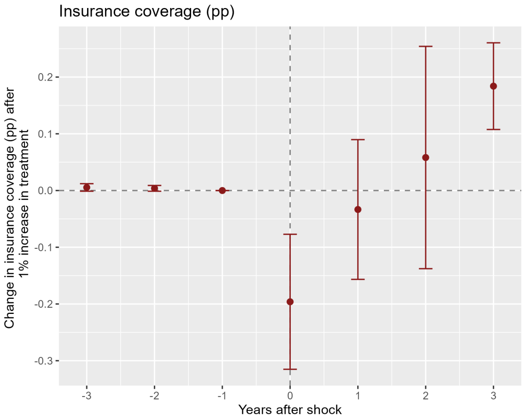
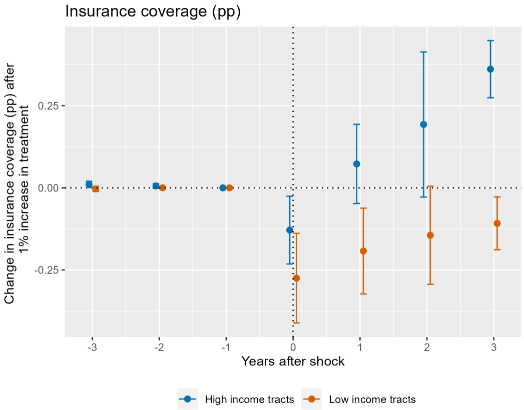
Results - Insurance - Response to insurance price change

Alternative shock: residualised insurance price



Mean insurance coverage: 60.2 %, Adj R2: 0.2973 , N: 32,520,361 , FE# - i: 6,543,291 , year: 5



Mean insurance coverage: 60.2 %, Adj R2: 0.298 , N: 32,520,361 , FE# - i: 6,543,291 , year: 5

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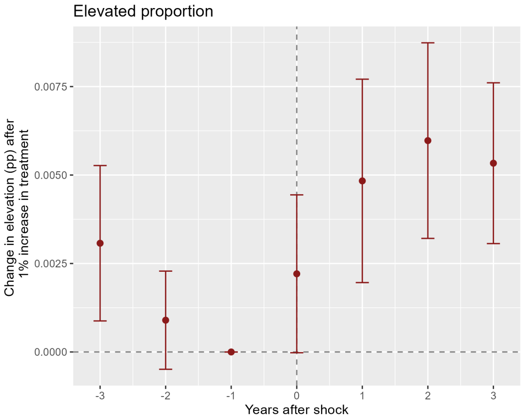
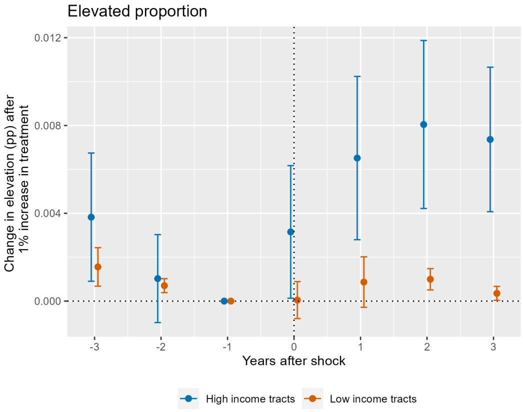
Results - Elevation - Response to insurance price change

Alternative shock: residualised insurance price



Mean elevated prop: 17.2 %, Adj R2: 0.9977 , N: 5,673,766 , FE# - i: 2,142,182 , year: 4



Mean elevated prop: 17.2 %, Adj R2: 0.9977 , N: 5,661,366 , FE# - i: 2,136,917 , year: 4

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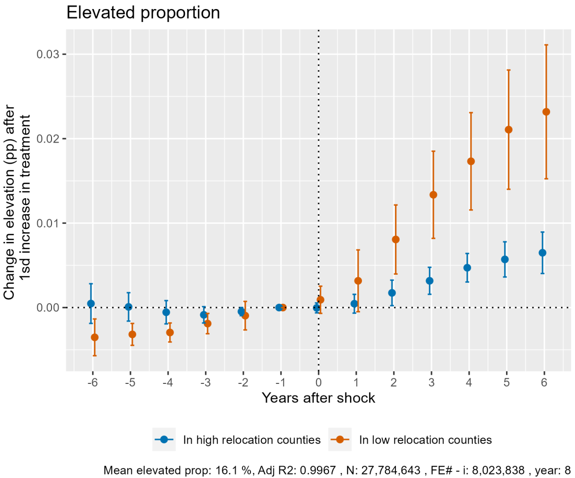
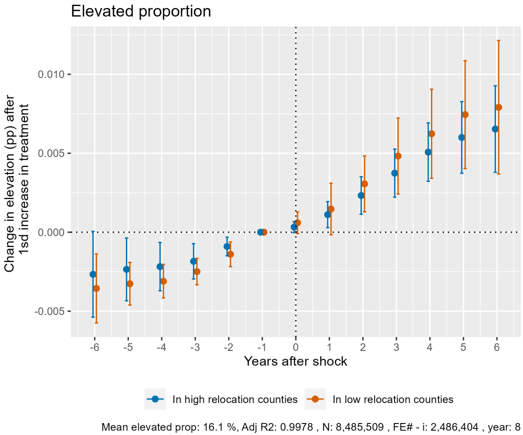
Interaction with migration



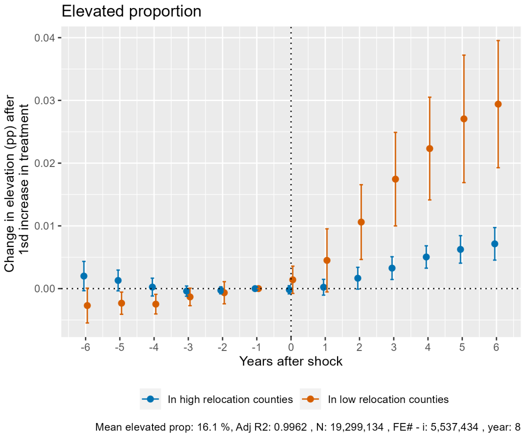
Using ACS 2006-2010 Migration flows - relocation defined by the number of non-movers as a proportion of the population in a county.

Interaction with migration - Inequality

Poor areas:



Rich areas:



Using ACS 2006-2010 Migration flows - relocation defined by the number of non-movers as a proportion of the population in a county.

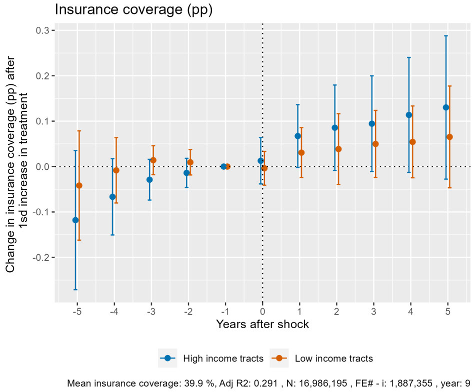
Migration - comparison of areas

	Low relocation	High relocation
Relocation share	0.11	0.18
Net migration share	-0.01	0.01
Median household income	43,532.96	45,005.21
Median age	41.67	38.04
Unemployment rate	7.14	7.63
Labour force participation	0.75	0.73
Share of population with high school or less education	0.38	0.33
Share of population in poverty	0.14	0.14
Share of population in rural areas	0.73	0.46
Share of population in owner-occupied housing	0.75	0.67
Median value, mortgaged houses	131,459.60	151,038.30

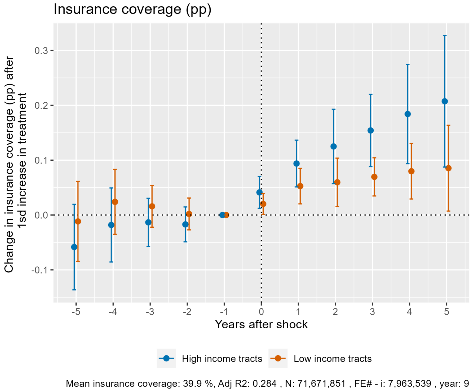
Data: 5y 2010 ACS, 2010 census

Results - Elevation vs Migration

Low relocation areas:



High relocation areas:

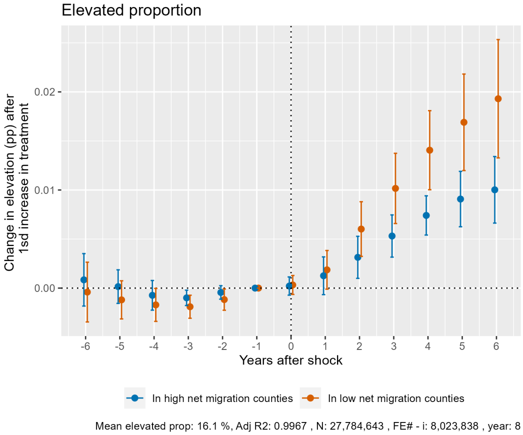


Relocation: number of movers as a proportion of the population in a county. Alternatives Comparison

Data: ACS 2006-2010 Migration flows - county level

Interaction with migration - alternative definitions

Net migration from county:



Outward migration from county: