Mandatory versus Voluntary Adaptation to Natural Disasters: The Case of Wildfires in the United States

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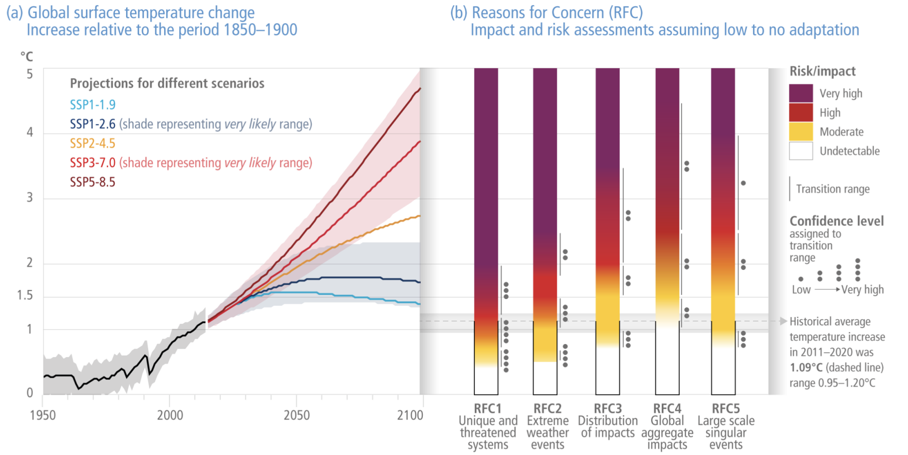
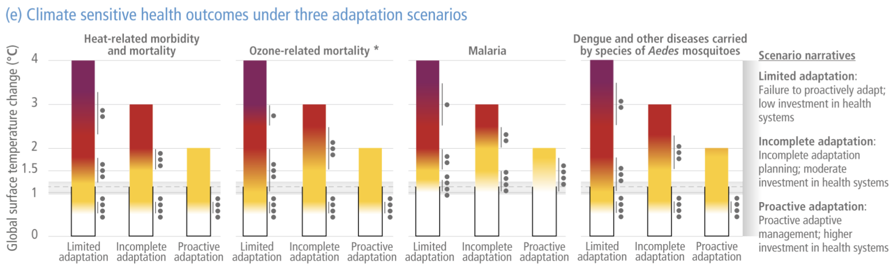
Sixth IPCC Report



Yesterday’s IPCC report

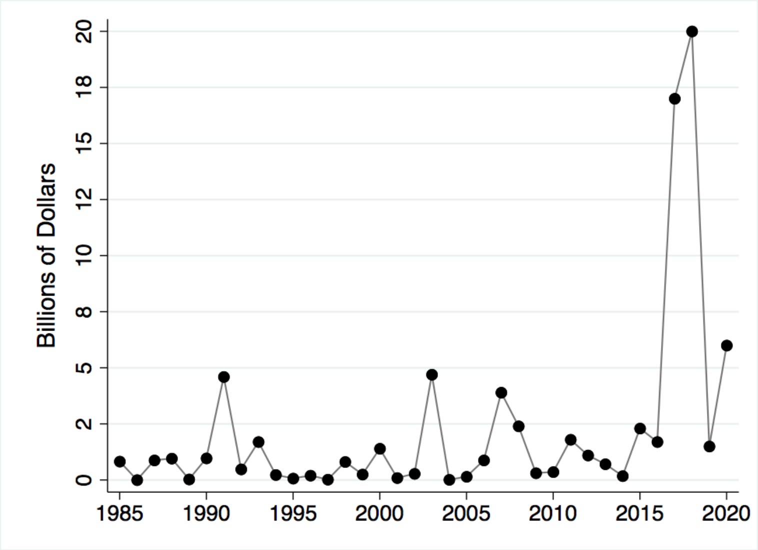


How should governments support adaptation to worsening weather catastrophes?

- Takeup of protective technologies/behaviors hampered by
  - Myopia
    - [Hallstrom and Smith, 2005, Donovan et al., 2007, Gallagher, 2014, McCoy and Walsh, 2018, Bakkensen and Barrage, Forthcoming]
  - Moral hazard & insurance market failures
    - [Kunreuther and Michel-Kerjan, 2011, California Department of Insurance, 2018, Deryugina, 2017, Baylis and Boomhower, 2019, Wagner, Forthcoming]
  - Externalities
    - [Shafran, 2008, Costello et al., 2017]
- Two options to address these frictions
  1. Offer information and subsidies
  2. Mandate adaptive investment
- Important differences in economic implications, but little evidence about outcomes under these different regimes

We consider wildfire building codes in California

- Wildfires have caused $40+ billion of property damage in the United States in the past 5 years, mostly in California.



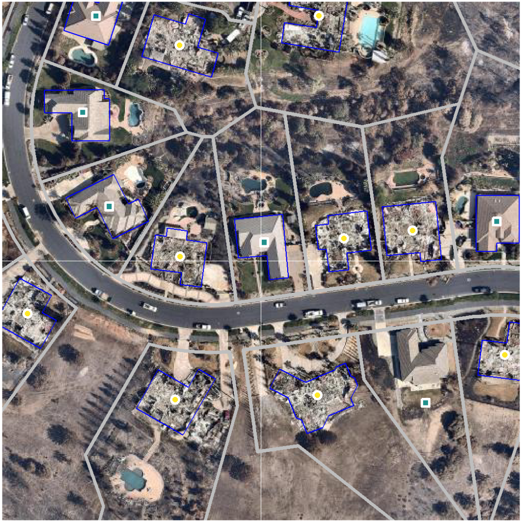
Patterns of structure loss

Tubbs Fire, Santa Rosa, CA. Aerial imagery from NearMap.

We evaluate the effect of building codes on survival of own- and neighboring structures.

- Assemble parcel-level damage data representing almost all U.S. homes destroyed by wildfire since 2003.
- Merge to the universe of assessor data for destroyed and surviving homes inside fire perimeters.
- Use differences in code requirements to measure the effects of building codes on structure survival.
- Measure spillover benefits of mitigation for neighboring properties due to reduced structure-to-structure spread.
- Develop economic model to calculate net social benefits of wildfire building codes.

Why do homes burn during wildfires?



"Unlike a flash flood or an avalanche, in which a mass engulfs objects in its path, fire spreads because the requirements for combustion are satisfied at locations along the path... A wildland fire cannot spread to homes unless the homes and their adjacent surroundings meet those combustion requirements." [Cohen, 2000]

Local governments may face split incentives

- Hazard designations are unpopular with incumbent homeowners
- Local governments internalize a small share of mitigation benefits (Baylis and Boomhower, 2019).
- Incomplete adoption of local govt FHSZ maps (Troy, 1998; Miller et. al., 2020)

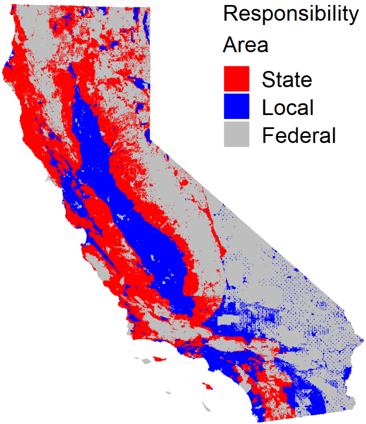
- *Sacramento Bee* on rebuilding Santa Rosa after 2017:

Burned-out California town ignores stricter building codes, even with wildfire threat

Timeline of California wildfire building codes

- Mid-1990's reforms following Oakland Firestorm
  - A.B. 337, 1992 ("Bates Bill")
  - A.B. 3819, 1995 (Fire resistant roofing materials)
  - A.B. 423, 1999 (Outlaws untreated wood shingles)
- Strengthened via "Chapter 7A" requirements in 2008
- Standards have historically been mandatory in State Responsibility Area, and opt-in in Local Responsibility Area (hundreds of localities).

Wildfire code requirements depend on jurisdiction and mapped fire hazard



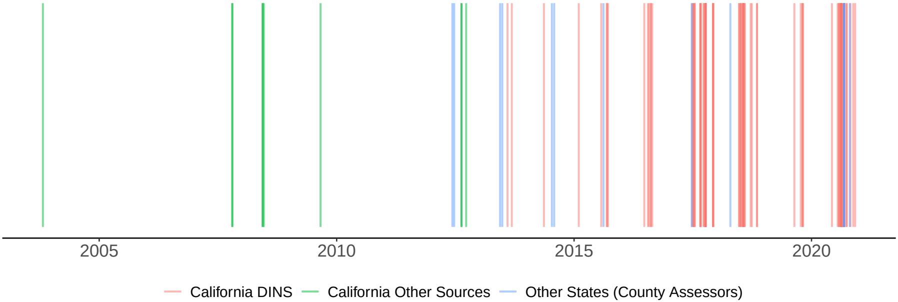
Code zone (adoption requirement)

1. CA SRA (mandatory)
2. CA LRA VHFHSZ (decided by municipality)
3. CA LRA Not VHFHSZ and Non-CA (decided by homeowner)

Mandatory codes in all state-managed areas, with opt-in adoption in local government areas (hundreds of municipalities and counties).

We compile near-comprehensive data on U.S. homes destroyed by wildfire over two decades.

- Damage censuses for 112 wildfires, 2003–2020
    - CA, AZ, CO, OR, WA
    - Assembled from CAL FIRE DINS, CAL FIRE archives, individual county assessors
- Property tax assessment data for all U.S. properties
    - Limit to single family homes inside wildfire perimeters



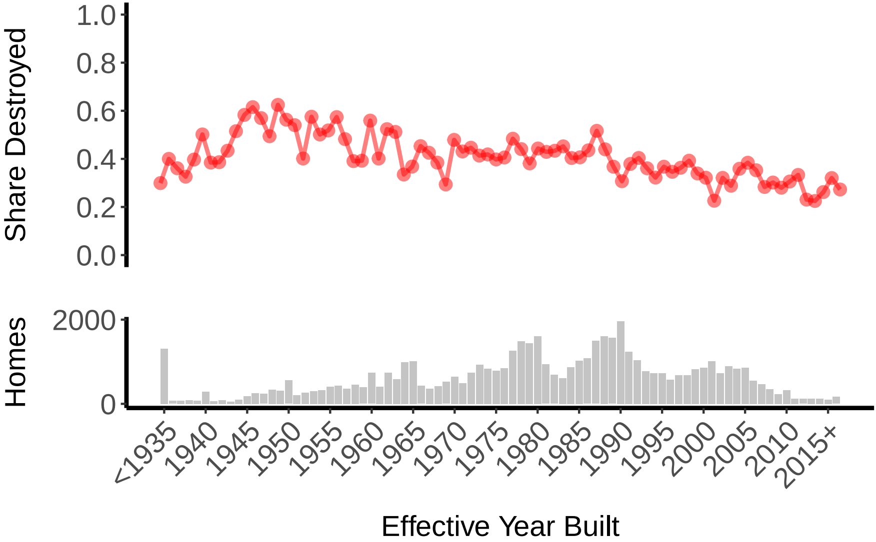
We merge to the universe of properties inside wildfire perimeters and leverage additional spatial data.

- Property tax assessment data (ZTRAX)
  - Universe of U.S. properties
    - Year built, effective year built, assessed value by year, etc.
    - Limit to single family homes inside wildfire perimeters.
  - Merge to damage data based on assessor parcel number.

- Additional spatial datasets
  - Parcel boundaries (county assessors).
  - High-res aerial imagery to validate locations & damage reports.
  - Building footprints

Summary of the final merged dataset (all states)

- 55,408 homes exposed to wildfires, 39% destroyed.



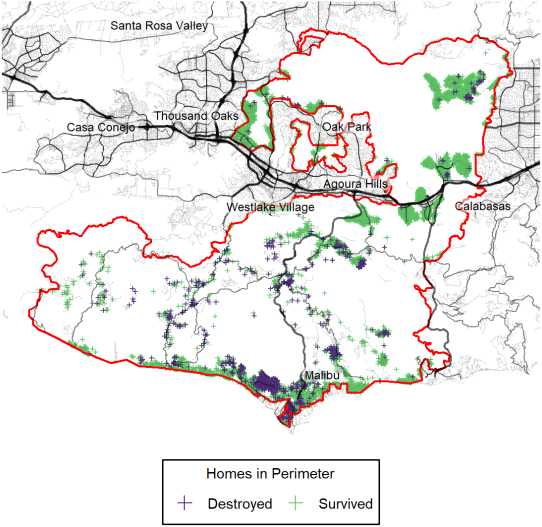
Assigning rooftop locations

Redding, CA before the Carr Fire (2018)

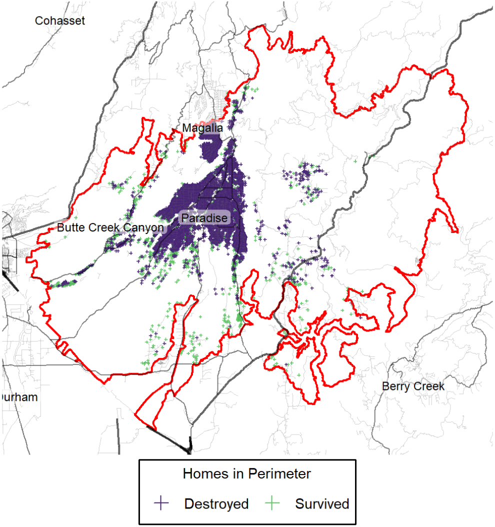
Validating damage reports

Redding, CA after the Carr Fire (2018)

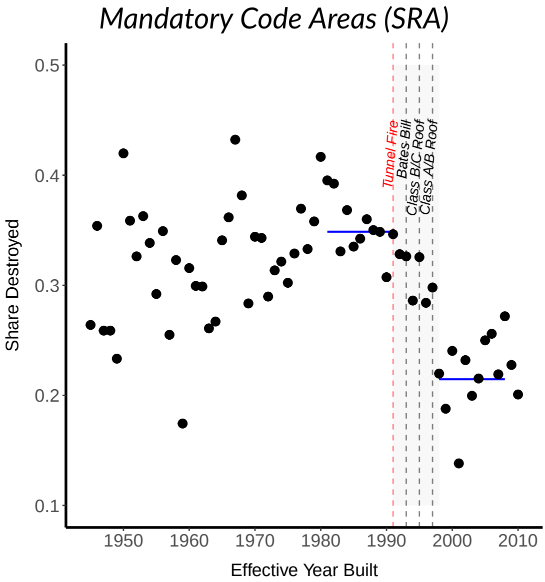
Woolsey Fire (2018)



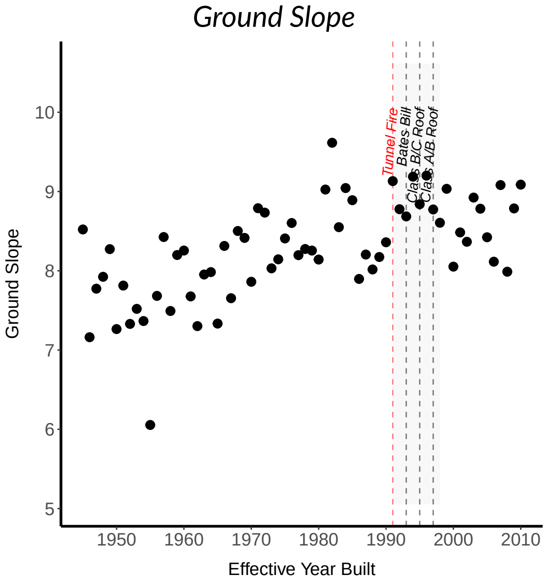
Camp Fire (2018)



Homes built after 1995 in mandatory code areas are more likely to survive.



Other home characteristics do not change in 1995.



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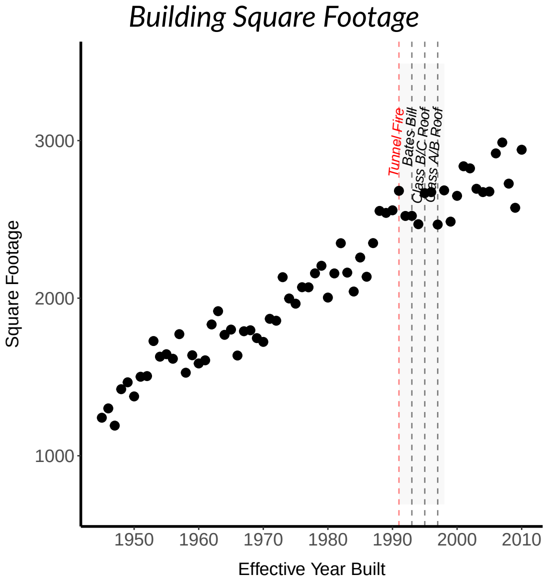


The empirical strategy compares survival for homes on the same street built in different years.

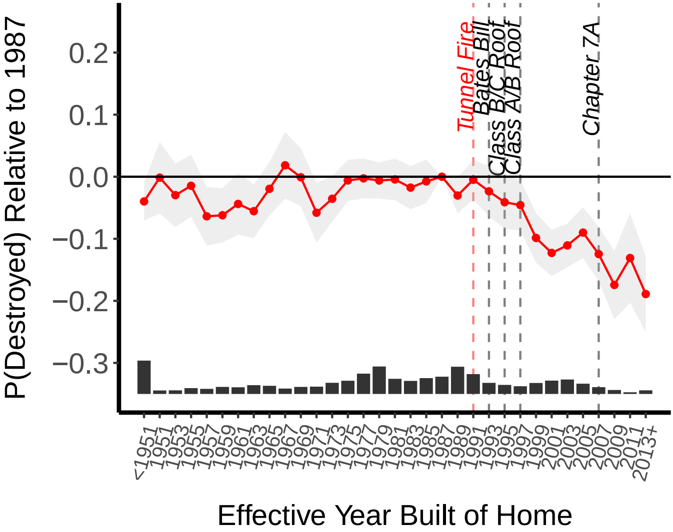
$$1[Destroyed]_{isf} = \sum_{v=v_0}^{v=V} \beta_v D_i^v + \gamma_{sf} + X_i \alpha + \epsilon_i \quad (1)$$

- V vintage bins
- γ_{sf} are **street-by-fire** fixed effects
- X_i includes controls for ground slope, vegetation, building square footage, and number of bedrooms.

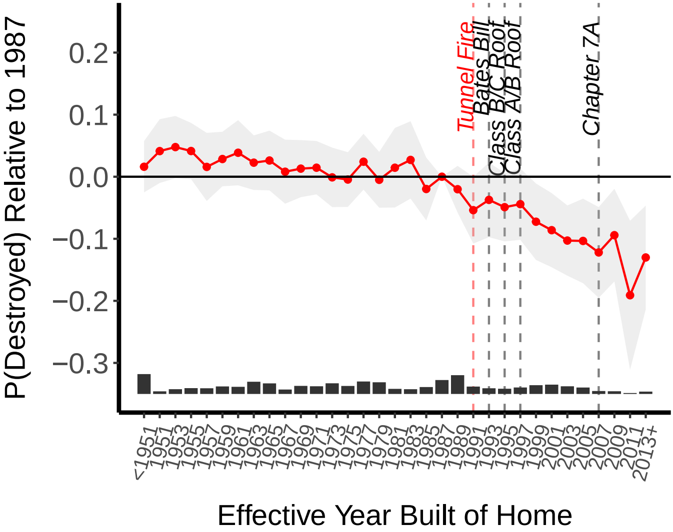
1. Estimate Equation 1 separately by jurisdiction.
2. DiD specification that interacts vintage bins with jurisdiction.

Street-by-fire fixed effects isolate variation along streets.

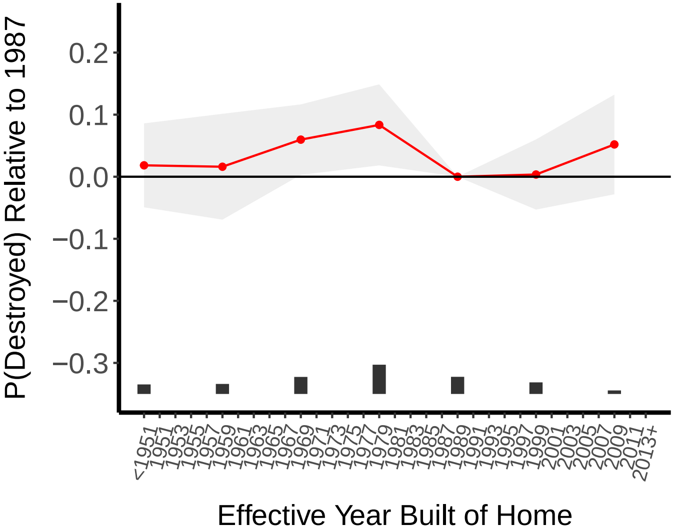
Vintage effects in mandatory code areas (SRA)



Vintage effects in opt-in code areas (LRA-VHFHSZ)



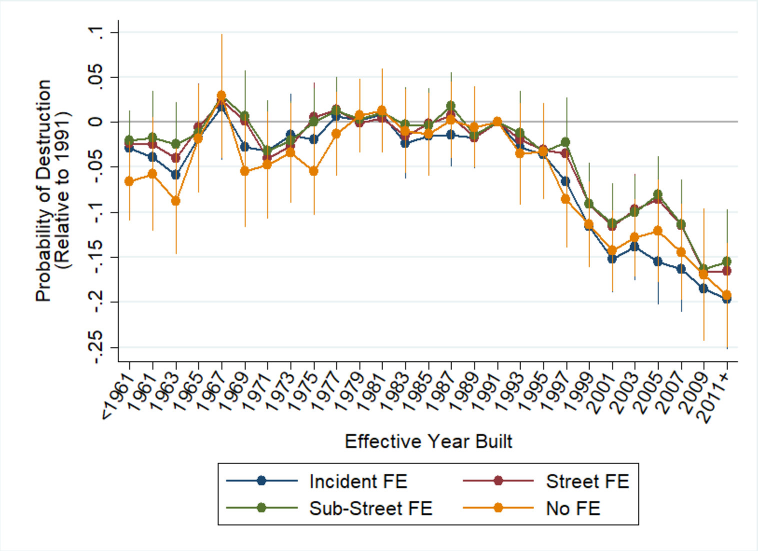
Vintage effects for other CA areas plus OR, WA, AZ



Difference in differences estimates

	(1)	(2)
Comparison Group × 1998–2007	-0.023	-0.009
	(0.026)	(0.026)
Comparison Group × 2008–2016	-0.003	0.019
	(0.033)	(0.038)
SRA × 1980–1997	-0.007	-0.046
	(0.033)	(0.041)
SRA × 1998–2007	-0.096***	-0.137***
	(0.034)	(0.042)
SRA × 2008–2016	-0.137***	-0.187***
	(0.036)	(0.043)
LRA VHFHSZ × 1980–1997	-0.024	-0.049
	(0.032)	(0.049)
LRA VHFHSZ × 1998–2007	-0.108***	-0.140***
	(0.033)	(0.048)
LRA VHFHSZ × 2008–2016	-0.144***	-0.176***
	(0.037)	(0.050)
Ground slope (deg)		0.005***
		(0.001)
Lot Size (Acres)		-0.000
		(0.000)
Building Square Feet		-0.000
		(0.000)
Bedrooms		-0.000
		(0.003)
Street FEs	Yes	Yes
Fuel Model FEs	No	Yes
Aspect FEs	No	Yes
Observations	48,213	38,386
R^2	0.62	0.63

Alternative fixed effects specifications



Structure to Structure Spread

Calculating distances between structure walls

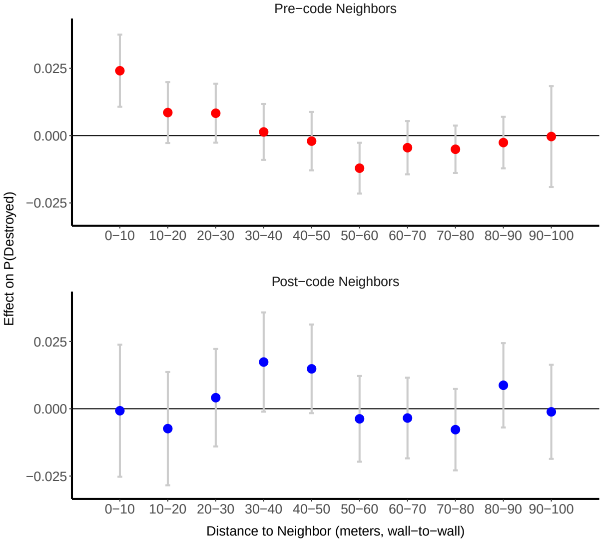
Homes before the Thomas Fire (2017)

Empirical Design for Structure to Structure Spread

- Effects of pre- vs. post-code neighbors at various distances
- Further-away neighbors as a useful placebo check

$$1[Destroyed]_{isf} = \sum_{j=1}^{J} \rho_j NoCode_j + \sum_{j=1}^{J} \phi_j Code_j + \sum_{v=v_0}^{V} \beta_v D_i^v + \gamma_{sf} + X_i \alpha + \epsilon_{isf}$$

Effects of any neighbor at various distances



Effects by number of neighbors

	Destroyed			
	(1)	(2)	(3)	(4)
1 pre-code nearby homes	0.020***	0.023***	0.026***	0.027***
	(0.007)	(0.007)	(0.007)	(0.007)
2+ pre-code nearby homes	0.031***	0.039***	0.050***	0.051***
	(0.009)	(0.010)	(0.009)	(0.009)
1 post-code nearby home	0.001	0.002	0.010	0.001
	(0.013)	(0.013)	(0.012)	(0.013)
2+ post-code nearby homes	-0.001	0.001	0.003	-0.009
	(0.016)	(0.018)	(0.018)	(0.021)
Own Year Built	✓	✓	✓	✓
Topography	✓	✓	✓	✓
Street FE	✓	✓	✓	✓
Observations	38,226	23,564	44,923	26,842
R^2	0.64	0.68	0.63	0.68
Distances	Walls	Walls	Centroids	Centroids
Subsample		✓		✓
Dep. Var. Mean	0.40	0.49	0.40	0.51

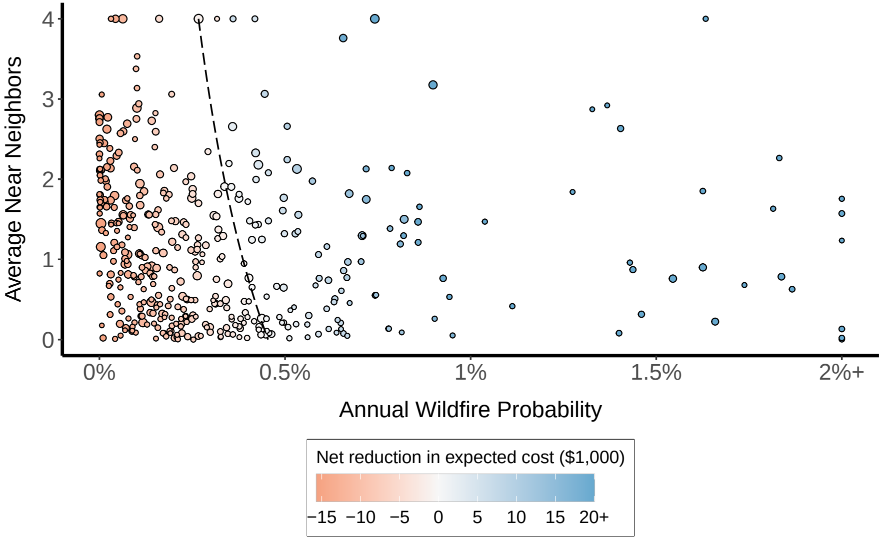
Net social benefits of mandated mitigation

- Our estimates reveal the own- and neighbor- benefits of mitigation.
- Given estimates of mitigation costs and values at risk, we can benchmark the net social benefits of universal mitigation.
- Thought experiment: "What is the minimum annual probability of wildfire exposure that makes WUI building codes cost effective?"
- A lower bound: "Risk-neutral cost effectiveness"

$$\sum_{i=1}^{N}[p^F p_i^D(L^I + L^U)] - \sum_{i=1}^{N}[p^F(p_i^D - \sum_{j=1}^{N}\tau_{ij})(L^I + L^U) + m] \tag{2}$$

- Details in the paper, along with expected utility model

Lower bound net benefits of universal mitigation in 400 California zip codes



A more complete measure: expected utility difference

Expected utility without mitigation

$$p^F p^D U(w_0 - L^U - k) + (1 - p^F p^D) U(w_0 - k) \tag{3}$$

Expected utility with mitigation

$$p^F (p_i^D - \sum_{j=1}^{N} \tau_{ij}) U(w_0 - L^U - \tilde{k} - m) + [1 - p^F (p_i^D - \sum_{j=1}^{N} \tau_{ij})] U(w_0 - \tilde{k} - m) \tag{4}$$

- k's are actuarially fair insurance premiums
- Assume CRRA utility
- Compare certainty equivalents for Equations 3 and 4

Alternative cost-effectiveness calculations

	Insured %	100	67		33	
			$\gamma = 2$	$\gamma = 5$	$\gamma = 2$	$\gamma = 5$
Cost Estimate	Source					
New Home						
$ 0	*HE-Low*	0	0	0	0	0
$ 7,868	*NAHB-Low*	0.19%	0.18%	0.16%	0.15%	0.10%
$15,660	*HE*	0.38%	0.36%	0.33%	0.30%	0.20%
$29,429	*NAHB-High*	0.71%	0.68%	0.63%	0.58%	0.41%
Retrofit						
$62,760	*HE*	1.50%	1.46%	1.40%	1.33%	1.15%

Conclusion

- We assembled data on nearly all homes exposed to wildfires in the United States during 2003–2020.
- We identify remarkable, non-linear vintage effects in survival for California homes.
- We show that these effects are due to state and local building code changes following the 1991 Oakland Firestorm.
- These preventive investments improve survival for neighboring homes.
- Cost effectiveness calculations suggest the building code mandate is cost-effective for new homes.

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