Housing and Mortgage Markets with Climate Risk: Evidence from California Wildfires

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Wildfires in California

- Since 1972, the area burned each year in California has increased 5-fold.
- 2018: 1.8 M acres burned (over $16 B estimated losses and 85 deaths); more than any other U.S. state.
- 2019: 4 wildfires caused losses $>$ $25 B.
- 2020: 9,279 fire events, 4.2 M acres burned, 32 deaths. August Complex, largest ever wildfire in California, burned $>$ 1 million acres.
- 2021: Second largest wildfire in CA history, Dixie fire: 960,335 acres burned.

Purpose of the Study

- To investigate housing market responses to wildfire disasters in California:
  - Post-wildfire residential house-price and size dynamics,
  - Post-wildfire mortgage terminations.
  - Post-wildfire gentrification.

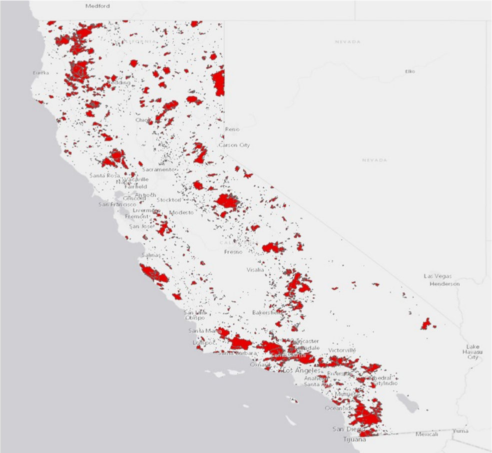
- Our focus:

  1. Exploit a quasi-experimental design identified by fire “treatment” and “control” areas.
     - Burn-areas determined by the random confluence of human actions as well as physical and meteorological forces.
     - Empirical burn-area boundaries are identified post-wildfires by CalFire scientists.

  2. Quantify the wildfire risks to the California housing stock.

  3. Inform policy debate concerning residential fire-insurance regulation in California.

California Wildfire Incidence and Questions of Interest



1. **Housing markets.**
   - Are there changes in housing quality and prices after large urban wildfires?
2. **Residential mortgages.**
   - Is there a significant increase in mortgage terminations after an urban wildfire?
3. **Gentrification.**
   - Are there gentrification-related changes in household characteristics after large urban wildfires?
4. **Is the actuarial risk of urban wildfires estimable?**

Simple Game-theoretic Framework

- Consider a neighborhood represented by two homeowners $i \in \{1, 2\}$, each owning one property.
- Housing services are obtained from owning a house and improving it, as well as *neighborhood externalities*.
- The total market value of house i

$$\hat{H}_i = H_i + \lambda H_{3-i}.$$

  - H_i = market value of house i without externalities,
  - λ = a factor of proportionality for neighborhood externalities (e.g. the second house).
- Each homeowner may choose to invest (I) in housing or not to invest (N)
  - c = cost of investing (Assume: homeowner pays if no fire and insurance pays if fire).
- Equilibria of this game uses baseline parameters $H_1 = H_2 = 66.67$ and $\lambda = 0.5$.

Equilibrium in the no-fire case : Classic Prisoner's Dilemma

		H2	
		I	N
H1	I	108, 108	83, 125
	N	125, 83	100, 100

- **Cell (N, N)**: If neither homeowner invests, the houses are each worth

$$H_i + \lambda H_{3-i} = 66.67 + (0.5 \times 66.67) = 100.$$

- **Cell (I, I)**: If investment cost \$67 and house is 75% more valuable (i.e. $1.75 \times 66.67 = 116.67$), then payoff net of costs

$$\hat{H}_i = 116.67 + (0.5 \times 116.67) - 67 \approx 108.$$

- **Cells (I, N), (N, I)**: If only homeowner 1 invests

$$\hat{H}_1 = 116.67 + (0.5 \times 66.67) - 67 \approx 83,$$
$$\hat{H}_2 = 66.67 + (0.5 \times 116.67) \approx 125.$$

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- Both homeowners would prefer to invest, but **not investing is the dominant strategy for each**.

Equilibrium in the fire case: Rebuild cost borne by insurance company

H1 \ H2	I	N
I	175, 175	117, 58
N	58, 117	0, 0

- **Cell (N, N)**: If neither homeowner invests, the (destroyed) houses are worth zero.

- **Cell (I, I)**: If both homeowners invest then house values are the same as no-fire but without subtracting investment cost.

$$\hat{H}_i = 116.67 + (0.5 \times 116.67) \approx 175.$$

- **Cells (I, N), (N, I)**:
  If only H1 invests, we have

$$\hat{H}_1 = 116.67 + (0.5 \times 0) \approx 117,$$
$$\hat{H}_2 = 0 + (0.5 \times 116.67) \approx 58.$$

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- **Fire has overcome the coordination problem: dominant strategy is both invest**.

Inner control region

- Now suppose there are two other homeowners $i \in \{1, 2\}$ in the inner control region, that is, the unburned area closest to the fire area.

- Houses in inner control region experience externalities from the homes in the fire, that is, if homeowners in the fire area invest, then homeowners in the inner control region enjoy additional payoffs equal to λ_{fire} times the average value of the renewed homes in the nearby fire area (\$116.67 each, from above), where $\lambda_{\text{fire}} = 0.15$.

- Therefore, the total market value of house i in the inner control region is

$$\hat{H}_i = \begin{cases} H_i + \lambda H_{3-i} + \lambda_{\text{fire}} \times 116.67 & \text{if at least one homeowner invests,} \\ H_i + \lambda H_{3-i} & \text{if neither homeowner invests.} \end{cases}$$

Inner control region

		H2	
		I	N
H1	I	134, 134	109, 151
	N	151, 109	100, 100

- **Cell (N, N)**: If neither homeowner invests, the houses are worth \$100 each – like no-fire case.

- **Cell (I, I)**: If both homeowners invest, same as no-fire case, \$108, plus externalities from rebuilt fire area,

$$\hat{H}_i = 108 + 0.15 \times 116.67 \approx 134.$$

- **Cells (I, N), (N, I)** If only H 1 invests (and by symmetry for H2),

$$\hat{H}_1 = 83 + 0.15 \times 116.67 \approx 109,$$
$$\hat{H}_2 = 125 + 0.15 \times 116.67 \approx 151.$$

Inner control region

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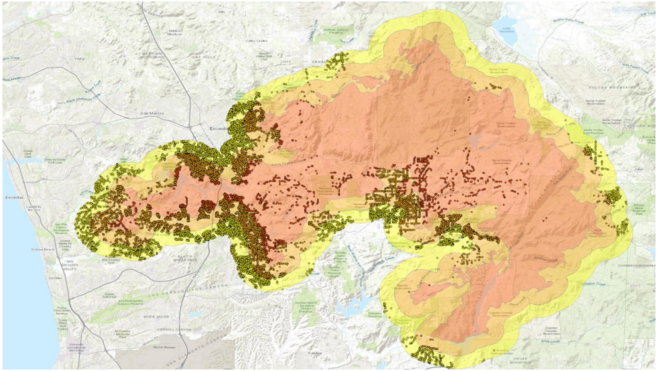
- **Game has a unique symmetric equilibrium: both homeowners invest with prob. 0.35.**

Mortgagor Choices with Fire Insurance

- **Frictionless world:** Insured might be indifferent to wildfires, because insurance company will reimburse the loss up to policy limit.
  - Wildfires should not have any effect on household mortgage decisions.
- **With frictions:**
  - Not clear, a priori, what the post-fire effect on mortgage default would be.
- **Fire casualty insurance coverage (up to policy limits):**
  - If do not rebuild:
    - Pre-fire market value of the structure minus the land value, plus personal property coverage.
  - If rebuild:
    - *Replacement cost value* (RCV) – **must rebuild**.
    - Coverage for additional living expenses – **repayment of expenditures**.
    - Build-to-code upgrades – **must rebuild**.
    - Personal property coverage – **fungible, no itemized replacement required**.
- **Positive spill-over externalities of post-fire redevelopment: "replace old with new".**

Analysis I: DID Identification Strategy

San Diego Witch Fire Example



- Treatment Group (orange):
  - 5,508 properties
  - 1,446 mortgages.
- Control Group 1 (pale orange): 0 to 1 mile:
  - 22,000 properties
  - 6,570 mortgages
- Control Group 2 (yellow): 1 to 2 miles
  - 22,000 properties
  - 7,289 mortgages

Data Sources

- **CalFire:** treatment areas, control 1 and control 2, and size of fires.

- Administrative data:
    - **ATTOM Data Solutions – Transaction data** house price transaction data, mortgage performance data.
    - **ATTOM Data Solutions – Annual house specific snapshot of characteristics (e.g. square footage, number of rooms etc).**

- **McDash Black Knight:** Mortgage characteristics and performance.

- **Data Axle:** Household demographics, income, wealth.

Roadmap

1. What are the long-run effects of wildfires on house prices?
   - Modeling framework: given coordination equilibrium house prices should increase.
2. What are the long-run effects of wildfires on house size?
   - Indirect evidence that house sizes should also increase.
3. What are the effects of wildfires on mortgage terminations?
   - Outside modeling framework: empirical question.
4. Are there other wildfire gentrification effects?
   - Outside modeling framework: alternative causal channel to price changes.

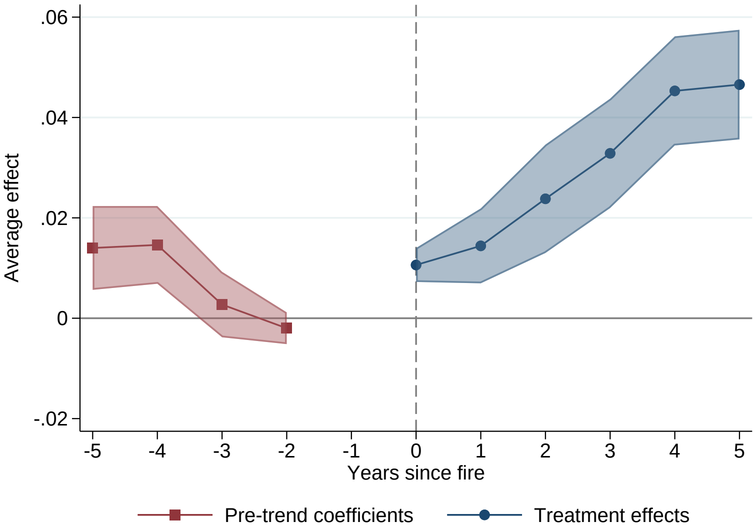
Empirical Specification

- For house i in fire area j in year t, we have

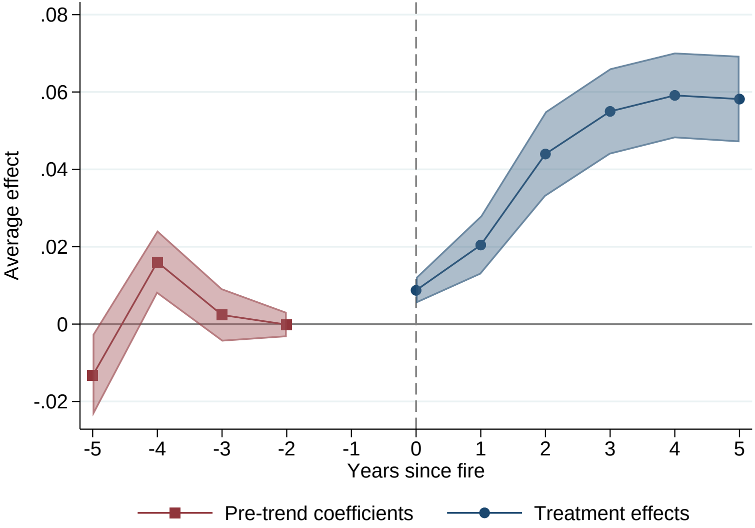
$$\begin{aligned}\log\left(\text{price}_{ijt}\right) &= \alpha_i + \alpha_{jt} + \beta_0 + \beta_1 fire_i \\ &+ \sum_{k\in\{-5,-4,\ldots,-2,0,1,\ldots,5\}}^{5} \gamma_k I(t = \text{fire year}_j + k) \times fire_i + \epsilon_{it},\end{aligned}$$

  where
  - α_i is house-specific fixed effect.
  - α_{jt} is year $\times$ fire fixed effect.
- We're interested in the γs.

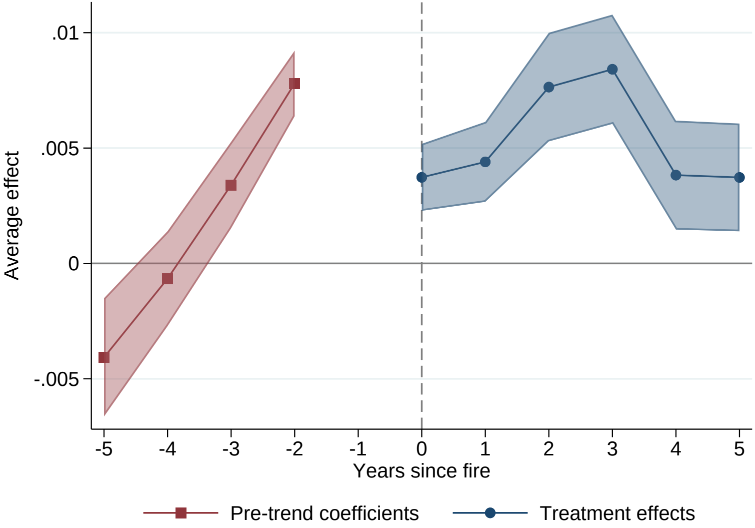
Fire Treatment versus Control 1: Log house prices



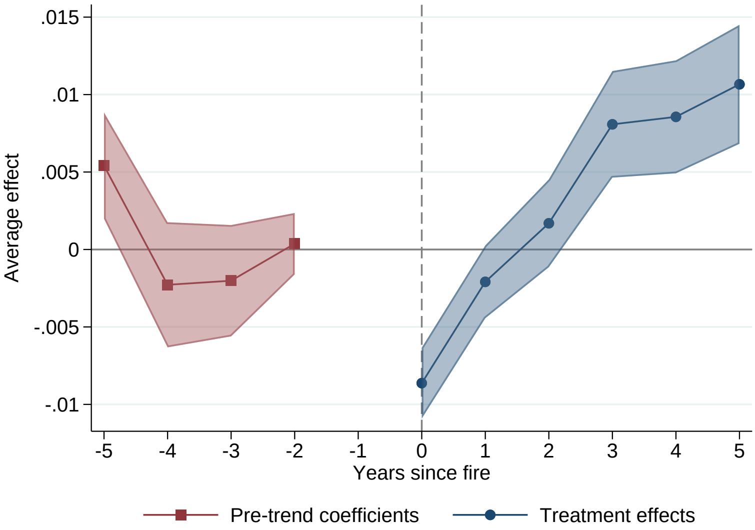
Fire Treatment versus Control 2: Log house prices



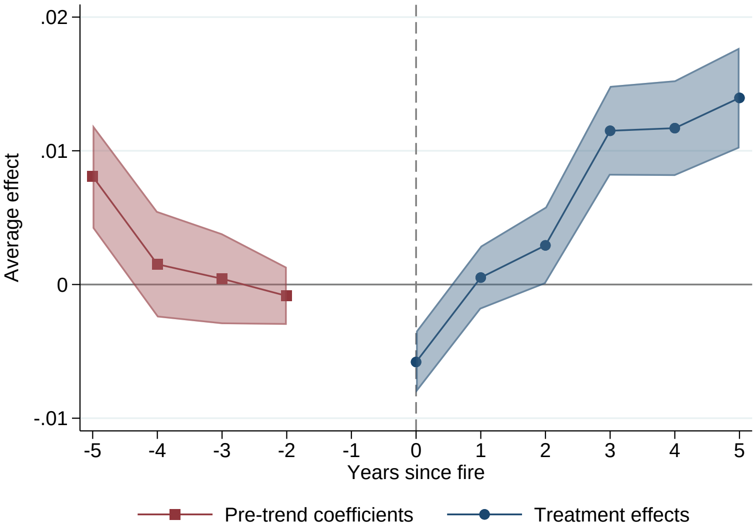
Fire Treatment Inner Control1 to Control2: Log house prices



Fire Treatment versus Control 1: Log square footage



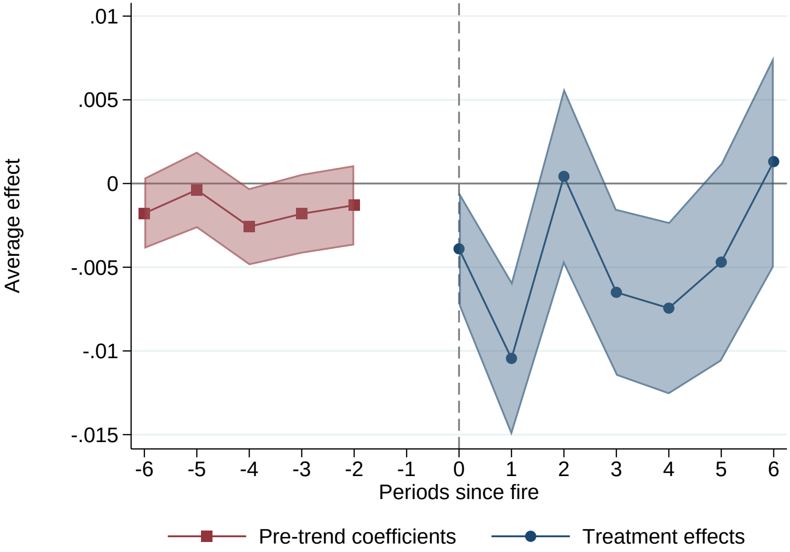
Fire Treatment versus Control 2: Log square footage



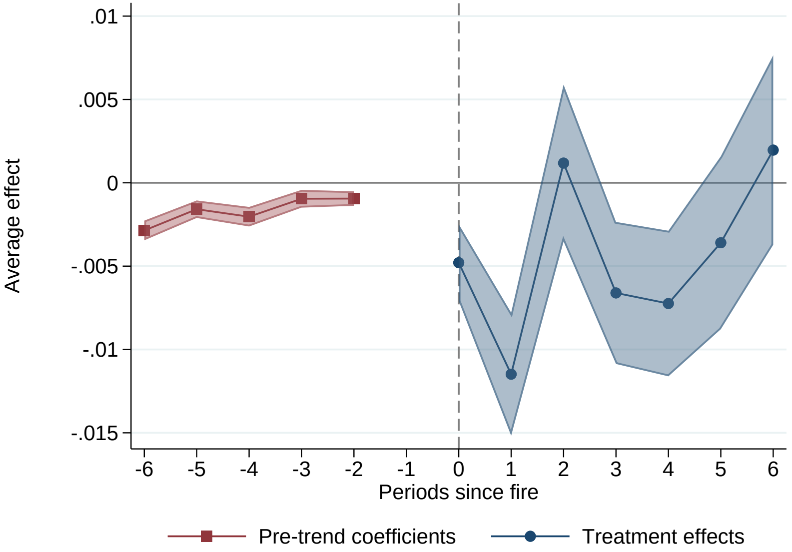
Summary of Evidence

1. **So far is there evidence of fire-related coordination effects?**
   - There are long-run positive effects of wildfires on…
     - Log house prices relative to control 1 and control 2 area.
     - Log square footage relative to control 1 and control 2 area.
2. **What are the effects on mortgage performance?**

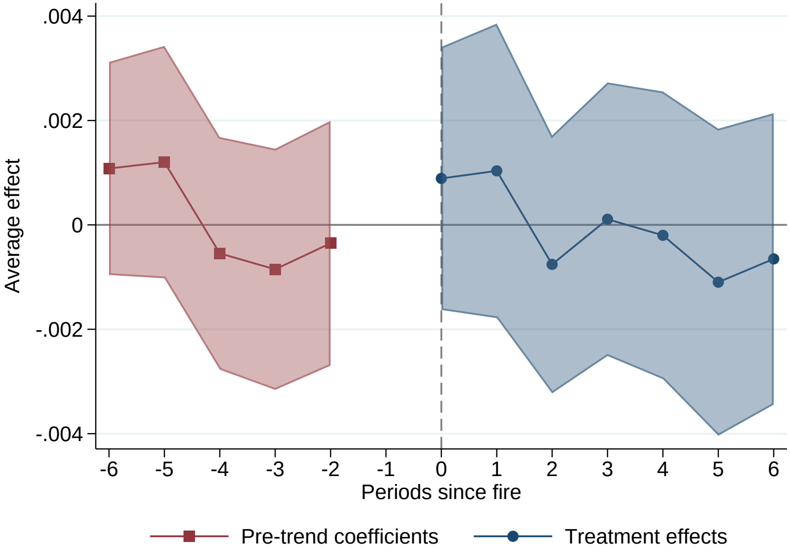
All terminations, quarterly



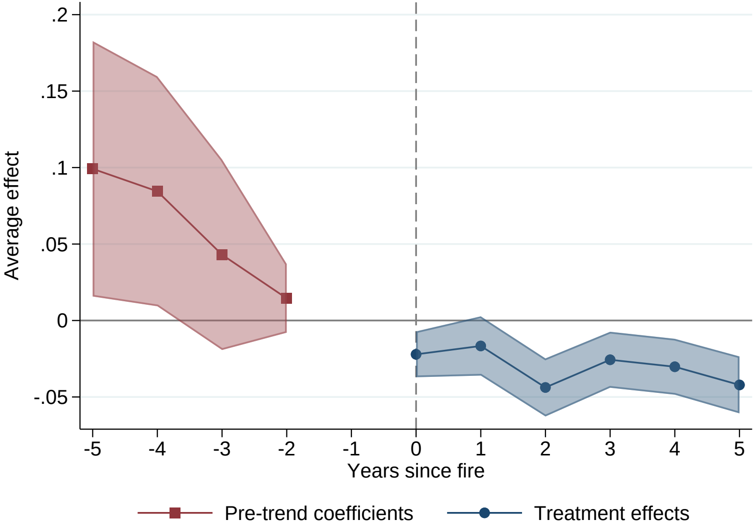
Prepayment, quarterly



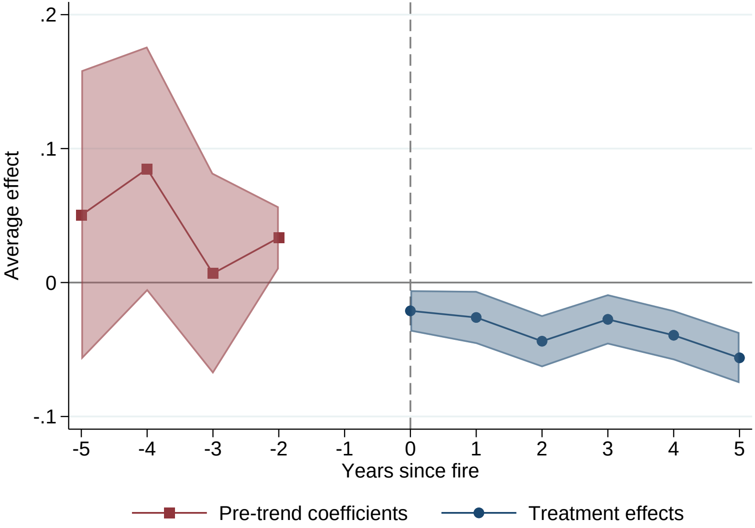
Default, quarterly



Fire Treatment versus Control 1: Log household income



Fire Treatment versus Control 2: Log household income



Summary of Evidence

1. **Evidence of fire-related coordination effects?**
   - There are long-run positive effects of wildfires on...
     - Log house prices relative to control 1 and control 2 area.
     - Log square footage relative to control 1 and control 2 area.
2. **Lack of evidence for wildfire incidence on mortgage default.**
3. **Lack of evidence for gentrification.**

Analysis II: What are wildfire expected losses to the California housing stock?

- **In sample exercise:** Compute property-specific measures of wildfire risk similar to measures of expected loss commonly used in the mortgage market.

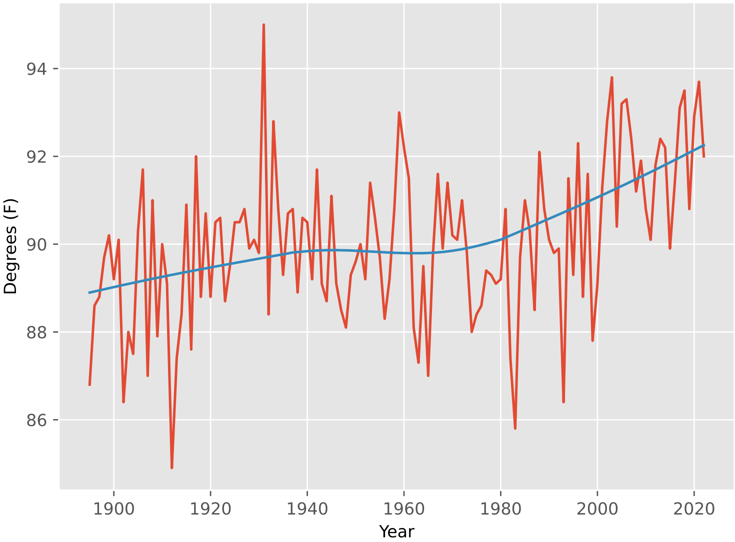
- **First, what is the probability of wildfire over fire season May–September:**

$$log \frac{p}{1-p} = \beta_0 + \beta_{weather} X_{weather} + \beta_{physical} X_{physical} + \beta_{season} X_{season} + \epsilon.$$

- Granular estimation by urban nodes (1.5 by 1.5 K) and rural nodes (4.5 by 4.5 K), 48,391 nodes.

- Data sources:
  1. **USGS**: slope and elevation.
  2. **SILVIS Labs Data**: Wildland Urban Interface (vegetation and urban coverage).
  3. **Meteorological NARR data are simulated with WRF/UCM models and verified with NOAA station measurements:** daily averages for wind direction, wind speed, max. temperature, relative humidity.

Maximum Annual Temperatures: West Climate Region



Probability of wildfires: Logistic regression

	Coefficient	Std. Error	[0.025	0.975]	p-value
Intercept	-11.8412	0.048	-11.934	-11.748	0.000
Weather Characteristics:					
Wind Speed	0.5218	0.005	0.513	0.531	0.000
Maximum Temperature	0.3832	0.020	0.345	0.421	0.000
Relative Humidity	-1.2906	0.023	-1.335	-1.246	0.000
NE Wind (Diablo)	1.1193	0.027	1.066	1.173	0.000
SE Wind (Santa Ana)	0.2143	0.033	0.149	0.280	0.000
Physical Characteristics:					
Slope	0.3909	0.010	0.371	0.411	0.000
Elevation	0.1943	0.016	0.163	0.226	0.000
Vegetative coverage without housing	0.3414	0.046	0.252	0.431	0.000
WUI: intermix	0.7367	0.054	0.631	0.842	0.000
WUI: interface	1.5773	0.061	1.458	1.697	0.000
Peak fire months:					
September	0.2373	0.032	0.175	0.300	0.000
October	0.9196	0.034	0.853	0.986	0.000
No. of observations	110M				
Log-Likelihood	−84921.354				
Log-Likelihood p-value	0.000				

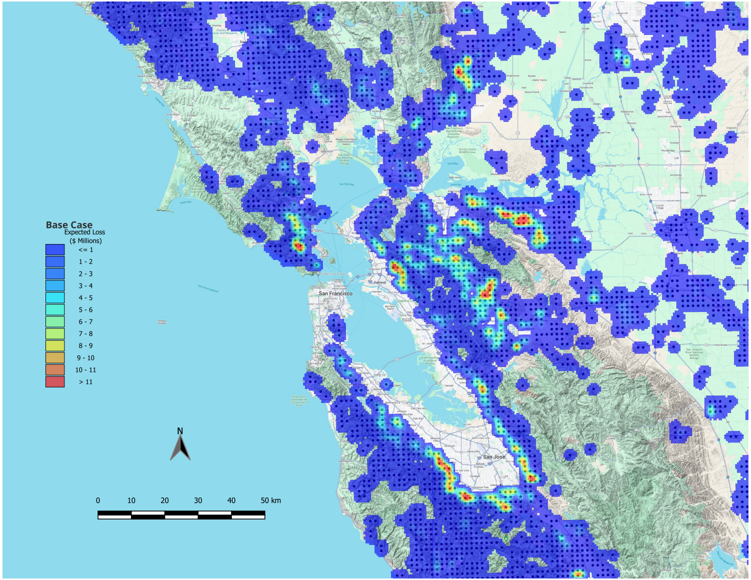
Analysis II: What are wildfire expected losses to the California housing stock?

- **Second, what are the expected losses to the California housing stock – baseline measured as the unit by unit assessed value (in 2020)**
    1. Value of the housing stock as the aggregate assessed value for houses in "neighborhoods" defined by nodes, 9.1 million housing units;
    2. Evaluate wildfire propensity daily by year accounting for the nodal average slope and elevation of "neighboring" house locations
    3. Assume that losses rates are equivalent to the estimated probability of wildfire.
    4. Evaluate a 2.00 degree Fahrenheit climate shock (0.1664 standard deviation shock to the maximum daily temperature for a day).
    5. **Expected loss:** Nodal probability times 2020 assessed values over season (152 days).

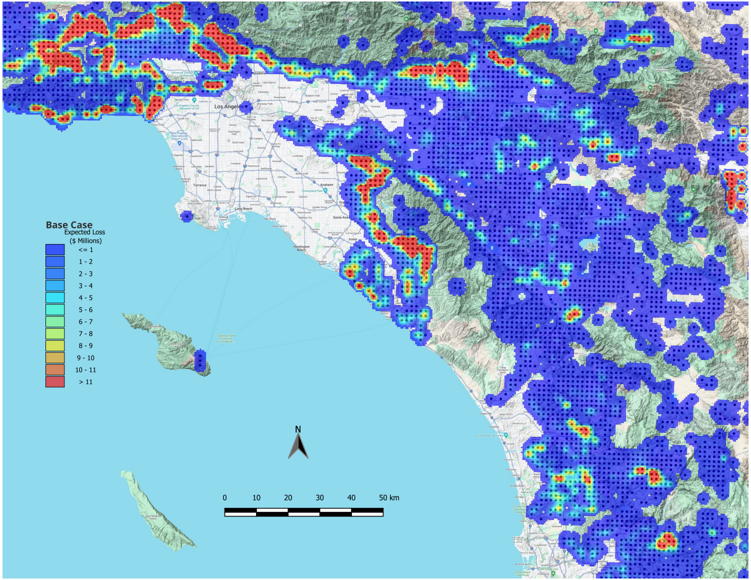
Expected wildfire Loss to California residential real estate

Year	Base Case Expected loss before shock ($ M)	Base Case Expected Loss before shock (%)	Climate Shock Expected Loss after shock ($ M)	Climate Shock Expected Loss after shock (%)	Shock - Base Case Expected Loss Difference ($ M)
2001	10.84	0.53	13.09	0.64	2.25
2002	11.11	0.55	13.39	0.66	2.28
2003	19.56	0.96	23.68	1.17	4.12
2004	10.84	0.53	13.08	0.64	2.24
2005	11.20	0.55	13.53	0.67	2.33
2006	14.93	0.73	18.07	0.89	3.14
2007	37.62	1.85	45.14	2.22	7.52
2008	24.58	1.21	29.80	1.47	5.22
2009	17.03	0.84	20.65	1.02	3.62
2010	10.26	0.51	12.39	0.61	2.13
2011	9.89	0.49	11.94	0.59	2.05
2012	15.80	0.78	19.16	0.94	3.35
2013	20.93	1.03	25.36	1.25	4.43
2014	15.04	0.74	18.23	0.90	3.19
2015	9.82	0.48	11.88	0.58	2.06
Mean	15.96	0.79	19.29	0.95	3.33

Expected annual losses to single-family housing: Bay Area



Expected annual losses to single-family housing: Los Angeles Basin



Regulatory Distortions in the California Casualty-Insurance Market

- **Role of Proposition 103**
  - All rate changes must be approved by the California Department of Insurance
  - All rate changes $\geq$ 7% must have public hearings.

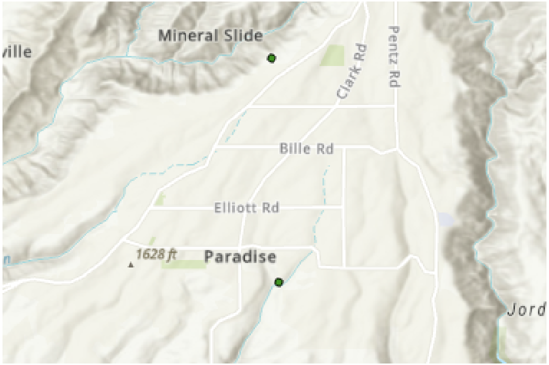
- California Department of Insurance (CDI) policies:
  1. Prohibit use of probabilistic wildfire models for pricing: must apply last 20 average loss rates. (September 28, 2023 CDI announced will move to allow).
  2. Prohibits the inclusion of reinsurance margins as an expense in the rate-approval process (September 28, 2023 announced will study inclusion with CA regional limits).

- State Farm and Allstate will no longer write new homeowners policies in California.

- AIG has left the state entirely.

- California has second lowest annual homeowner insurance rates.
  - Oh, Sen, and Tenekedjieva (2022).

Some intriguing out-of-sample results



1. **Paradise Camp Fire, 2018**
   - Overall losses $16.5 Billion.
2. **Wildfire effects on housing stock.**
   - 9,700 single-family houses lost.
   - 85 people perished.
3. **Predicted nodal wildfire probabilities:**
   - Paradise north node 5.6%
   - Paradise south node prob 2.5%
4. **Current rebuilding activity**
   - 80% destruction rate within burn area.
   - Building permits (2,926 applications, 2,702 permits issued, 2042 occupancy permits issued)
   - Rebuilt houses (86.94 sqft larger, $62,982 higher assessed value).

Conclusions

- First study of the effects of California wildfires on: post-wildfire house price and size dynamics (2000–2015, long-run dynamics of the housing stock, mortgage performance, and gentrification).
  - Merging large geospatial datasets: fire incidence and magnitude; topographical, vegetative, and meteorological data; house price and characteristic dynamics; and mortgage characteristics and performance.

- Our simple game-theoretic motivation highlights how neighborhood externalities can lead to a “prisoner’s dilemma” for homeowners considering remodelling or construction.
  - Wildfire events with rebuilding code requirements and historical fire casuality coverage appear to overcome the coordination problem.

- Empirically we find clear evidence that house prices and house sizes are positively affected by the incidence of wildfire due to the coordinating effects of neighborhood rebuilding activity and insurance coverage.
  - Little effect on mortgage terminations.
  - Little to no evidence of gentrification.

Conclusions (cont'd)

- Wildfire annual average risk exposure to maximum temperature climate shock (within sample):
    - **$19.29 B annually.**

- Implications for regulation of fire insurance/bank supervision.
    - Need for probabilistic wildfire forecasting models.
    - Need for re-thinking casualty-insurance pricing, especially tail risk insurance.
    - Need for stress-test monitoring of wildfire risk: housing stock, mortgage-market exposure.