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

Paulo Issler* Richard Stanton* Carles Vergara† Nancy Wallace*

*Haas School of Business, U.C. Berkeley
†IESE Business School

Bank of Canada
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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 of the effect of wildfire events on:
    - Residential house-price and size dynamics,
    - Mortgage default.
    - Gentrification.

- Our focus:

    1. Exploit a quasi-experimental design identified by fire “treatment” and “control” areas.
        - Burn-area boundaries arise from random confluence of physical and meteorological forces,
        - Empirical boundaries are identified ex-post by CalFire scientists.

    2. Carry out a property-level empirical analysis of the association of high-frequency geospatial and meteorological data and wildfire incidence in California:
        - To assess the expected value-at-risk of wildfires on the California housing stock.

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

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

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

- 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 H 1 invests, we have

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

- **Fire has overcome the coordination problem – the 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	H2: 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),

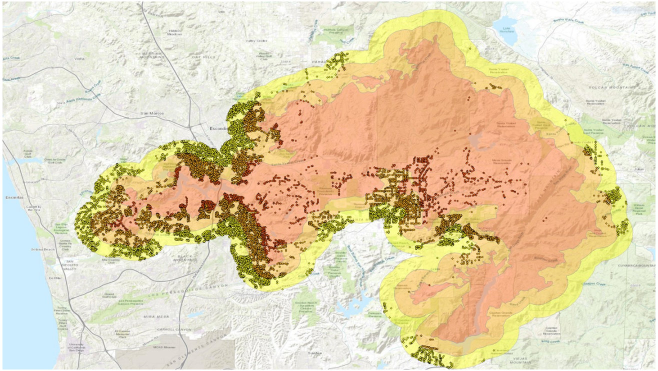
$$\hat{H}_1 = 83 + 0.15 \times 116.67 \approx 109,$$

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

- **Game has a unique symmetric equilibrium in which both homeowners play a mixed strategy**.

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 (2000–2018)

- **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).**
  - **Zillow – zip code house price indices.**

- **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?
2. What are the long-run effects of wildfires on house size?
3. What are the effects of wildfires on mortgage default?
4. Are there other wildfire gentrification effects?

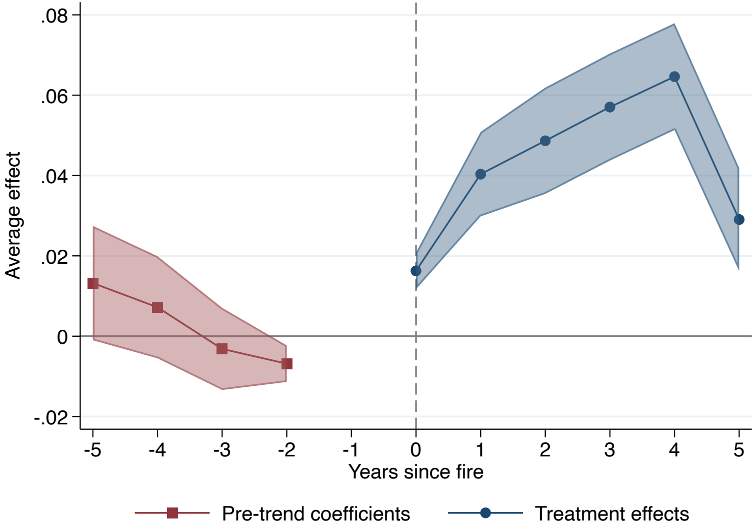
Empirical Specification

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

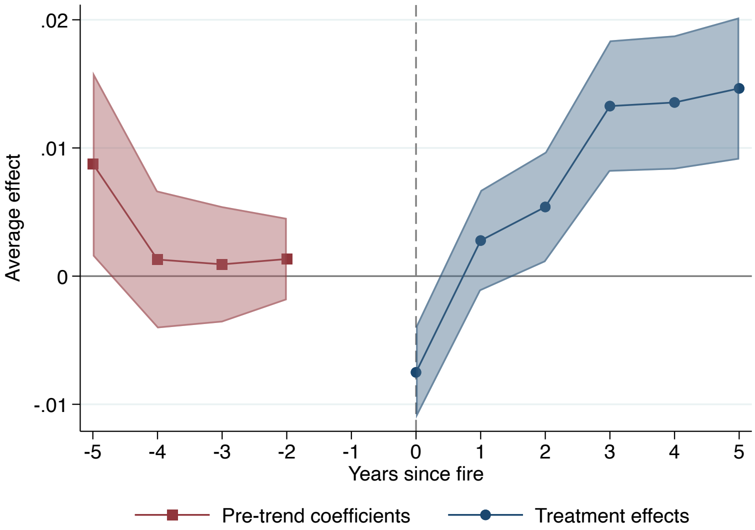
$$\log\left(\text{price}_{ijt}\right) = \alpha_i + \alpha_{jt} + \beta_0 + \beta_1 \mathit{fire}_i + \sum_{k \in \{-5,-4,\ldots,-2,0,1,\ldots,5\}}^{5} \gamma_k I(t = \text{fire year}_j + k) \times \mathit{fire}_i + \epsilon_{it}.$$

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

Fire Treatment versus Control 1: Log house prices



Fire Treatment versus Control 1: 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?**

Difference-in-Differences: Mortgage Delinquency/Foreclosures

Dependent variable:	ΔDelinquency	ΔDelinquency	ΔForeclosure	ΔForeclosure
Treatment group:	Fire	Fire	Fire	Fire
Control group:	Control1	Control1	Control1	Control1
	[1]	[2]	[3]	[4]
Fire	0.00418***	0.00398***	0.00303***	0.00298***
	(0.000490)	(0.000492)	(0.000380)	(0.000382)
Interest rate (original)	1.799***	1.798***	1.041***	1.041***
	(0.00864)	(0.00864)	(0.00677)	(0.00677)
Term (original)	0.000158***	0.000157***	0.000107***	0.000107***
	(2.12e-06)	(2.12e-06)	(1.53e-06)	(1.52e-06)
Loan amount (original)	8.47e-08***	8.48e-08***	5.23e-08***	5.23e-08***
	(2.45e-09)	(2.45e-09)	(1.49e-09)	(1.49e-09)
Property value (original)	-2.91e-08***	-2.91e-08***	-1.73e-08***	-1.73e-08***
	(1.64e-09)	(1.63e-09)	(9.75e-10)	(9.74e-10)
Credit score (original)	-0.000363***	-0.000363***	-0.000185***	-0.000185***
	(1.95e-06)	(1.95e-06)	(1.43e-06)	(1.43e-06)
LTV (original)	-0.000995***	-0.000994***	-0.000541***	-0.000539***
	(6.50e-05)	(6.49e-05)	(4.16e-05)	(4.16e-05)
GSE dummy	0.0827***	0.0826***	0.0625***	0.0625***
	(0.00125)	(0.00125)	(0.00108)	(0.00108)
Mortgage age	-0.00375***	-0.00379***	-0.00224***	-0.00225***
	(5.33e-05)	(5.42e-05)	(3.80e-05)	(3.87e-05)
Controls	No	Yes	No	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observations	3,911,416	3,911,416	3,911,416	3,911,416
R-squared	0.079	0.079	0.048	0.048

The Impact of Wildfire Size on Mortgage Defaults

Dependent variable: BigFire:	ΔDelinquency Num. acres [1]	ΔDelinquency Dummy acres [2]	ΔForeclosure Num. acres [3]	ΔForeclosure Dummy acres [4]
Fire x BigFire	-1.51e-05***	-0.0119***	-1.15e-05***	-0.0111***
	(8.97e-07)	(0.000978)	(6.97e-07)	(0.000755)
Fire	0.0111***	0.00890***	0.00859***	0.00795***
	(0.000737)	(0.000729)	(0.000580)	(0.000576)
BigFire	-1.20e-05***	-0.0110***	-6.70e-06***	-0.00575***
	(4.01e-07)	(0.000380)	(2.97e-07)	(0.000286)
Interest rate (original)	1.849***	1.849***	1.079***	1.079***
	(0.00883)	(0.00883)	(0.00685)	(0.00685)
Term (original)	0.000207***	0.000207***	0.000134***	0.000134***
	(2.18e-06)	(2.18e-06)	(1.56e-06)	(1.56e-06)
Loan amount (original)	1.02e-07***	1.02e-07***	6.17e-08***	6.19e-08***
	(2.52e-09)	(2.52e-09)	(1.52e-09)	(1.52e-09)
Property value (original)	-3.06e-08***	-3.06e-08***	-1.80e-08***	-1.80e-08***
	(1.68e-09)	(1.68e-09)	(9.93e-10)	(9.93e-10)
Credit score (original)	-0.000348***	-0.000349***	-0.000177***	-0.000177***
	(1.97e-06)	(1.97e-06)	(1.43e-06)	(1.43e-06)
LTV (original)	-0.000784***	-0.000783***	-0.000435***	-0.000434***
	(6.55e-05)	(6.55e-05)	(4.15e-05)	(4.14e-05)
GSE dummy	0.0866***	0.0862***	0.0649***	0.0647***
	(0.00131)	(0.00131)	(0.00111)	(0.00111)
Mortgage age	0.00208***	0.00208***	0.000574***	0.000576***
	(2.72e-05)	(2.72e-05)	(1.89e-05)	(1.90e-05)
Fixed effects	Yes	Yes	Yes	Yes
Observations	3,911,416	3,911,416	3,911,416	3,911,416
R-squared	0.043	0.043	0.025	0.025

Summary: Wildfires and Mortgage Performance

- Insured mortgages on houses that are burned in wildfires are more likely to become 90 day delinquent or to become foreclosed.

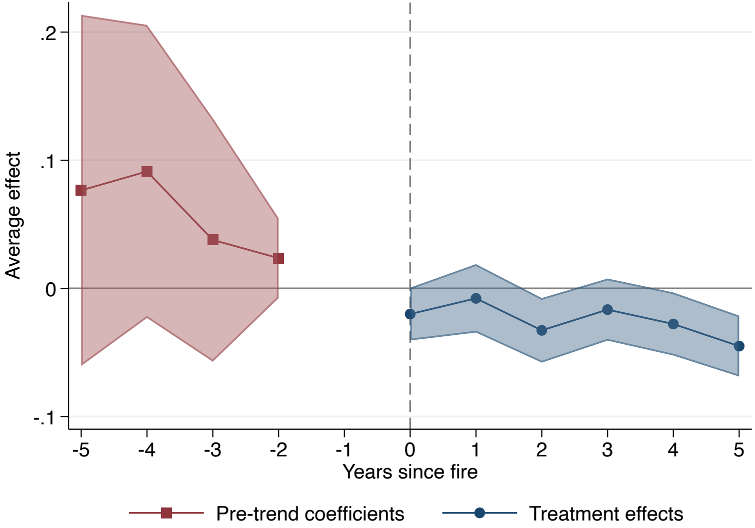
- However, insured mortgages in very large wildfires are less likely than in small fires to become 90 day delinquent or to become foreclosed.

- Possible positive externalities due to CA fire-insurance codes.
  - Replacing "old" for "new built-to-code."
  - Payout from personal property coverage is fungible.
  - Large scale "in-place gentrification" due to incentives to rebuild.

Lack of Evidence for “In-place Gentrification”

		Total properties with mortgages [1]	Properties with new purchase mortgages [2]	Properties with new refinanced mortgages [3]	Properties with unchanged mortgage positions [4]
Fire (treatment)	Num. Prop.	2,908	224	712	1,972
	% of total treat+control	3%			
	% of total loans		8%	24%	68%
Control1	Num. Prop.	43,656	3,982	8,821	30,853
	% of total treat+control	44%			
	% of total loans		9%	20%	71%
Control1to2	Num. Prop.	51,824	4,815	9,580	37,429
	% of total treat+control	53%			
	% of total loans		9%	18%	72%
Total treat+control	Num. Prop.	98,388	9,021	19,113	60,959
	%	100%	9%	19%	65%

Fire Treatment versus Control 1: Log household income



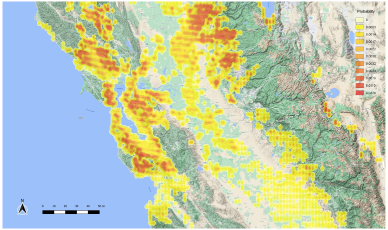
Empirical Analysis I: Estimate the Probability of California Wildfires

- **Geographic Area** — Geoprocess all of California into 1.5 by 1.5 kilometer grids (urban areas) and 4.5 by 4.5 kilometer grids (rural areas).

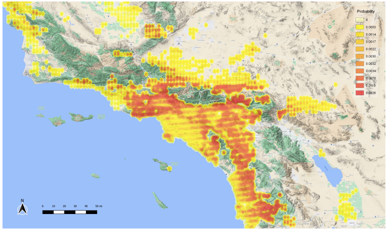
- **Data collection for each grid point (June through October)**:
  1. **USGS**: slope and elevation.
  2. **SILVIS Labs Data**: Wildland Urban Interface (vegetation and urban coverage).
  3. **Meterological NARR data are simulated with WRF/UCM models and verified with NOAA station measurements (Vahmani, Jones, and Patricola, 2019)**: daily averages for wind direction, wind speed, max. temperature, relative humidity.
  4. **ATTOM Data Solutions**: grid location of single-family residential homes (prices/characteristics) and mortgages (contract/performance).

- **Estimation strategy:** Logistic regression.

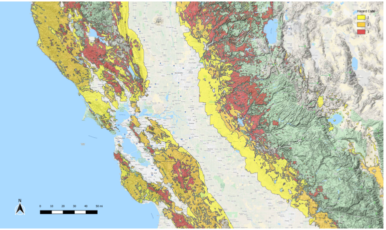
Estimates for Wildfire Probability Heatmaps (Oct.) versus California Department of Insurance (CDI) Hazard Maps



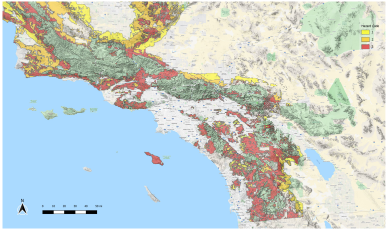
(a) Northern California logistic regression



(b) Southern California logistic regression



(c) Northern California CDI hazard zones



(d) Southern California CDI hazard zones

Regulatory Distortions in the California Casualty-Insurance Market

The California Department of Insurance (CDI):

1. Prohibits the use of probabilistic wildfire models for pricing.
2. Allows for adjustment factors to increase rates for high-risk locations.
   - However, insurers claim the deterministic factor structure is too flat.
3. Prohibits the inclusion of reinsurance margins as an expense in the rate-approval process.

Analysis II: Effect of Climate Shocks on CA Housing Assessed Values

	Wildfire Probability (% Change)	Incremental Property Effects (Number)	Change in Assessed Value from Wildfire Losses ($ Billion Losses)	Change in Assessed Value from Fire Coordination effects ($ Billion Gains)
One std. dev. shock to max. temperature	0.0013	10,377	-4.867	5.035
Two std. dev. shock to max. temperature	0.0022	16,848	-7.902	8.174
One std dev. shock to relative humidity	0.0011	8,243	-3.866	4.000
Two std dev. shock to relative humidity	0.0014	10,633	-4.987	5.159
One std dev. shock to wind speed	0.0012	9,508	-4.459	4.612
Two std dev. shock to wind speed	0.0018	14,138	-6,632	6.861
Total effect one std. dev.	0.0016	12,464	-5.846	6.048
Total effect two std. dev.	0.0032	24,293	-11.396	11.788

Realized costs in 2020 were $12.079 Billion including CA fire suppression costs

Conclusions

- First study of the effect of California wildfires on: long-run house price dynamics, long-run dynamics of the housing stock, and mortgage delinquencies and foreclosure.
    - Merging large geospatial datasets: fire incidence and magnitude; topographical, vegetative, and meteorological data; house price and characteristic dynamics; and mortgage characteristics and performance.

- Evidence of "fire coordination effects" in wildfire recovery areas:
    - 5-Year post-wildfire increase in house prices.
    - 5-Year post-wildfire increase in square footage.

- Insurance-related findings for mortgage performance
    1. 6-month delinquency/foreclosure rates about 60 bps higher in fire- than control areas.
    2. 6-month delinquency/foreclosure rates fall by 1.4% after large wildfires.

- Limited evidence of household income gentrification

Conclusions 2

- Important weather-related wildfire risks to California housing and mortgage markets
  - **From wildfire probability estimates** peak-season daily risk exposure of -$2.89 billion.
  - **A one std. dev. max temperature shock** increases the peak daily risk to -$8.74 billion.
  - **A one std dev. max temperature shock** increases in-place rebuild benefits +$8.94 billion.
  - **Overall wildfire costs to California** has exceeded these benefits every year since 2017.
  - **Private insurance policy non-renewal rates** have increased by 31% (2018-2019).
  - **California Fair Plan policies** have increased by 35%. (2018-2019).

- Implications for regulation of fire insurance/bank supervision.
  - Need for re-thinking casualty-insurance pricing – currently a one-year cancellation moratorium in burn areas.
  - Need for stress-test monitoring of wildfire risk – housing stock, mortgage market exposure.