Virtual Seminar on Climate Economics

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

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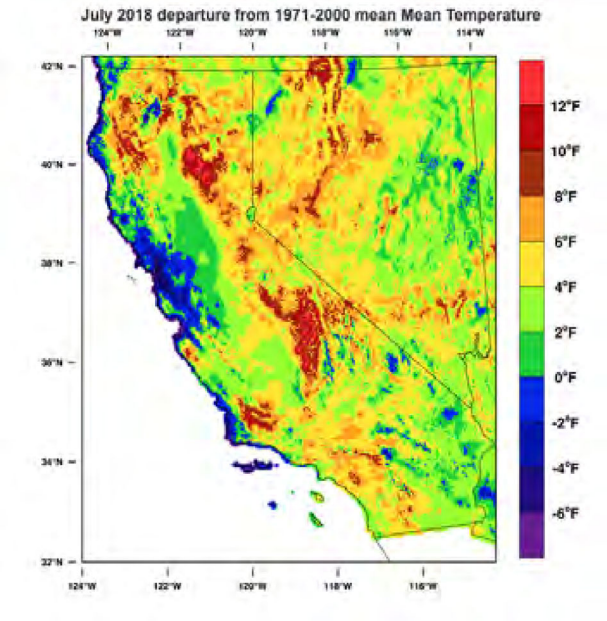
Wildfires in California

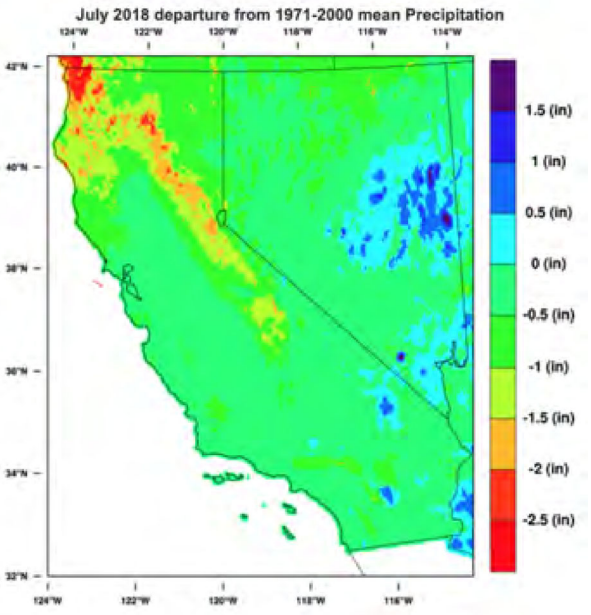
- Since 1972, the area burned each year in California has increased 5-fold.
- 2018: 1.8 M acres burned (over $16 B estimated losses and 85 deaths); more than any other U.S. state.
- 2019: 4 wildfires caused losses $>$ $25 B.
- 2020: 9,279 fire events, 4.2 M acres burned, 32 deaths. August Complex, largest ever wildfire in California, burned $>$ 1 million acres.
- 2021: Second largest wildfire in CA history, Dixie fire: 960,335 acres burned (as of Sept. 12).

California Temperature and Precipitation

July 2018 vs. 1971–2000 average



(a) Temperature



(b) Precipitation

Purpose of the Study

- To investigate of the effect of wildfire events on:
  - Residential house-price and size dynamics,
  - Household income and wealth,
  - Mortgage default,
  - Property-insurance risk.

- Our focus:

  1. Carry out an empirical analysis based on high-frequency geospatial data:
     - To estimate the wildfire exposure of residential single-family homes and mortgages.
     - To determine the long- and short-term effects of wildfires on insured properties.
  2. Exploit a quasi-experimental design identified by fire “treatment” and “control” areas.
     - Burn-area boundaries are determined by CalFire scientists.
  3. Inform policy debate concerning residential fire-insurance regulation in California.

California Wildfire Incidence and Questions of Interest

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

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).

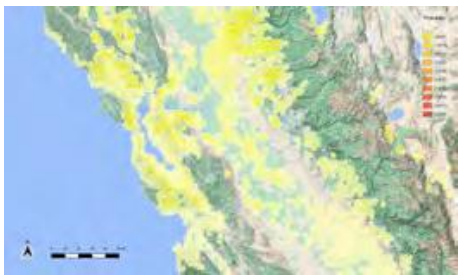
- **Data collection for each grid point (June through October)**:
  1. **USGS**: slope and elevation.
  2. **SILVIS Labs Data**: Wildland Urban Interface (vegetation and urban coverage).
  3. **Meterological NARR data are simulated with WRF/UCM models and verified with NOAA station measurements (Vahmani, 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.

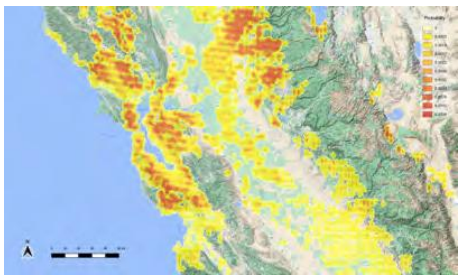
Probability of wildfires: Logistic regression

	coefficient	std. err.
Constant	-10.7559***	0.039
Wind Speed	0.3976***	0.005
Maximum Temperature	0.4854***	0.018
Relative Humidity	-0.2549***	0.016
Slope	0.4003***	0.011
Elevation	0.2821***	0.011
Percentage of Urban Site Coverage	-0.0429*	0.021
Percentage of Vegetative Site Coverage	0.0677***	0.018
Northeasterly Wind	0.3743***	0.031
Southeasterly Wind	0.3921***	0.032
September	1.9573***	0.042
October	3.2897***	0.043
Observations	28,978,800	
Pseudo R-squared	0.16	

Logistic Regression: Wildfire Probability Heat Maps



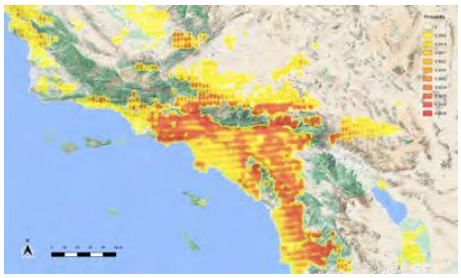
i. June



ii. October

(a) Northern California

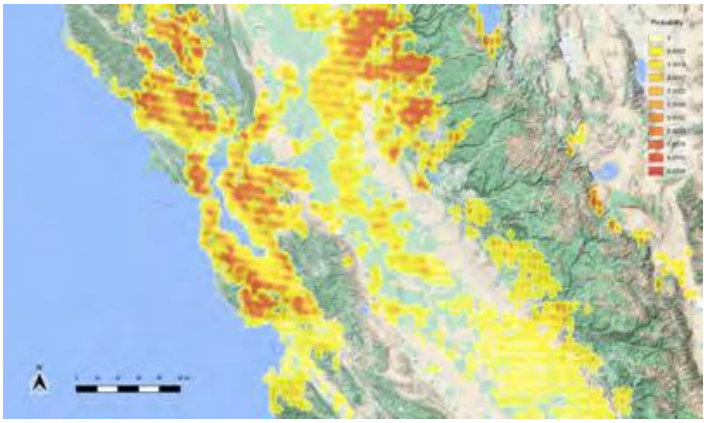
i. June



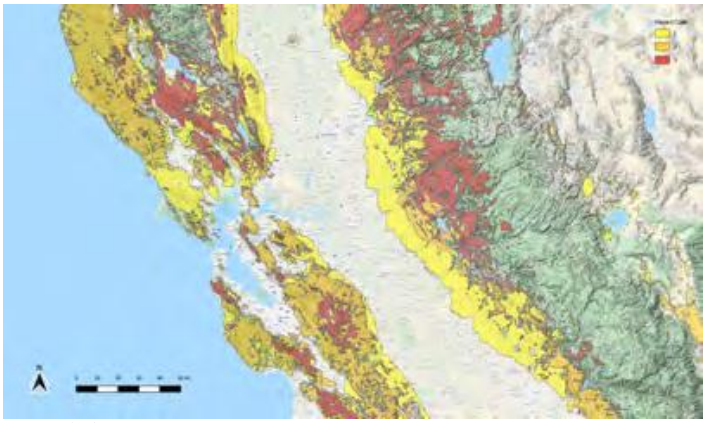
ii. October

(b) Southern California

Estimates for Northern California (Oct.) versus California Department of Insurance (CDI) Hazard Maps

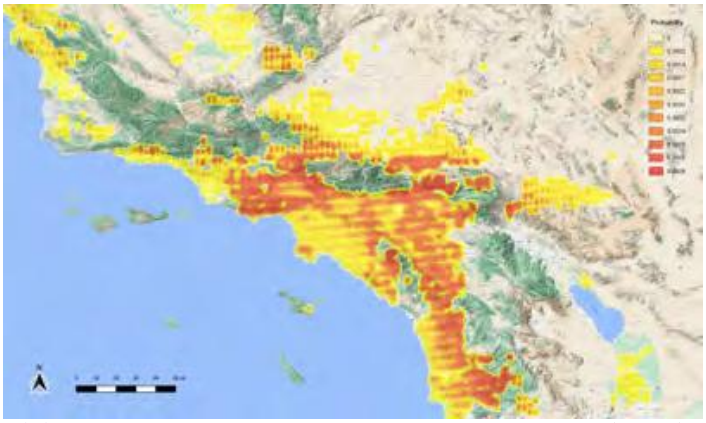


(a) Northern California Wildfire Estimates (Oct.)

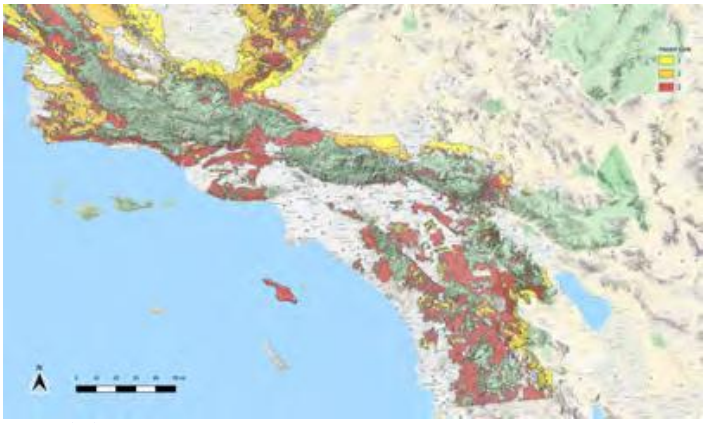


(b) CDI Northern California Hazard Maps

Estimates for Southern California (Oct.) versus California Department of Insurance (CDI) Hazard Maps



(a) Southern California Wildfire Estimates (Oct.)



(b) CDI Southern California Hazard Maps

Comparison of the California Department of Insurance Hazard codes and Logistic Regression Average Daily Probability of Wildfire

			Estimated Daily Probabilities	
Month	CDI Hazard code	Grid Count	Mean Mean	Std. Dev.
June	0	8,613	0.000034	0.000044
June	1	1,304	0.000055	0.000044
June	2	1,134	0.000069	0.000061
June	3	1,659	0.000070	0.000067
October	0	8,613	0.000712	0.000875
October	1	1,304	0.001045	0.000695
October	2	1,134	0.001259	0.000814
October	3	1,659	0.002021	0.001518

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.

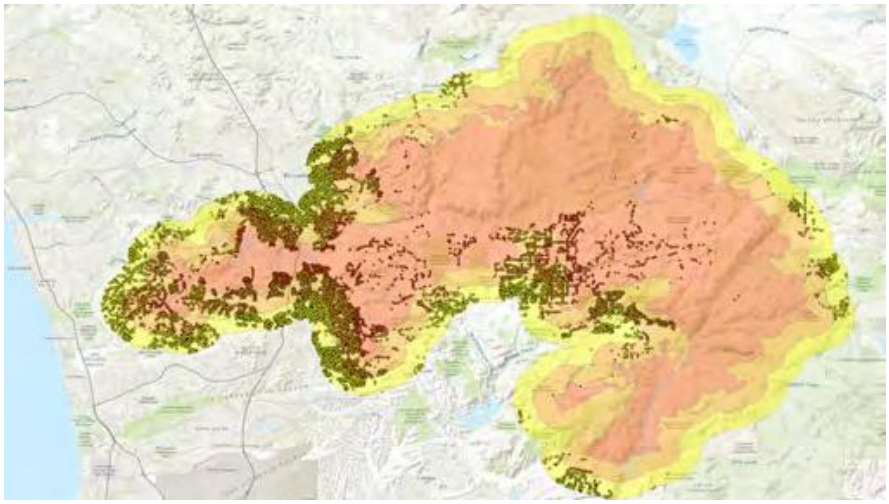
Analysis II: Difference-in-Differences Estimation

- Burn-area boundaries define a quasi-experimental design:

  1. **Random treatment effect:** Weather, ignition event, and fire boundary.
  2. Test for long-run post-fire differentials between treatment and control areas:
     - Quality of the housing stock,
     - House price dynamics,
     - Gentrification,
     - Mortgage default.
  3. Also use panel spatial autoregressive (SA) model to allow for spatial autocorrelation.

Analysis II: 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

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.
  - If rebuild or purchase elsewhere:
    - *Replacement cost value* (RCV) – **must rebuild or repurchase at new site**.
    - Coverage for additional living expenses – **repayment of expenditures**.
    - Build-to-code upgrades – **must rebuild or purchase at new site**.
    - Personal property coverage – **fungible, no itemized replacement required**.
- **Positive spill-over externalities of redevelopment "replace old with new".**

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. Is there evidence of gentrification?
   - What are the long-run effects of wildfires on house size?
   - What are the long-run effects of wildfires on house prices?
   - What are the long-run effects of wildfires on household wealth?
   - What are the long-run effects of wildfires on household income?
2. What are the effects of wildfires on mortgage default?

Gentrification: Effect on House Size after 5 Years

Approach:	DID	DID	Panel SA	Panel SA
Treatment group:	Fire	Fire	Fire	Fire
Control group:	Control1	Control1	Control1	Control1
Dep. variable:	$\log(size)$	$\log(size)$	$\Delta \log(size)$	$\Delta \log(size)$
	[1]	[2]	[3]	[4]
Fire $\times$ Afterfire	0.0103**	0.0114***		
	(0.00516)	(0.00353)		
Fire	0.0552***	0.0536***	0.0138***	0.0146***
	(0.00398)	(0.00354)	(0.00367)	(0.00481)
Afterfire	-0.0098***	0.0117		
	(0.00125)	(0.00860)		
$\log(size_{t_0})$			-0.0647***	-0.0763***
			(0.00251)	(0.00375)
Controls	Yes	Yes	Yes	Yes
Fixed effects	No	Yes	No	Yes
Observations	152,765	152,765	20,483	20,483

Gentrification: Effect on House Prices after 5 Years

Approach:	DID	DID	Panel SA	Panel SA	Panel SA	Panel SA	Panel SA
Treatment group:	Fire	Fire	Fire	Fire	Fire	Fire	Fire
Control group:	Control1	Control1	Control1	Control1	Control1	Control1to2	Control1to2
Dep. variable:	$\log(price)$	$\log(price)$	$\Delta \log(price)$	$\Delta \log(price)$	$\Delta \log(price)$	$\Delta \log(price)$	$\Delta \log(price)$
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Fire$\times$ Afterfire	0.0536***	0.0580**					
	(0.01253)	(0.02562)					
Fire	-0.0085	-0.0038	0.0498***	0.0418***	0.0344***	0.0567***	0.0492***
	(0.00973)	(0.02172)	(0.00970)	(0.00982)	(0.00961)	(0.00960)	(0.00927)
Afterfire	0.0413***	-0.0263					
	(0.00307)	(0.07985)					
$\log(price_{t_0})$			-0.1883***	-0.1910***	-0.1820***	-0.1699***	-0.1565***
			(0.00478)	(0.00477)	(0.00552)	(0.00276)	(0.00313)
$\Delta \log(size_{t_0,t_0+5})$			0.2620***	0.2632***	0.2580***	0.2644***	0.2663***
			(0.0173)	(0.0172)	(0.0166)	(0.0102)	(0.0098)
Control1						0.0228***	0.0179***
						(0.00381)	(0.00370)
Controls	Yes	Yes	No	Yes	Yes	Yes	Yes
Fixed effects	No	Yes	No	No	Yes	No	Yes
Observations	118,582	118,582	13,359	13,359	13,359	41,802	41,802

Gentrification: Effect on Household Income after 5 Years

Approach:	DID	DID	Panel SA	Panel SA	Panel SA	Panel SA	Panel SA
Treatment group:	Fire	Fire	Fire	Fire	Fire	Fire	Fire
Control group:	Control1	Control1	Control1	Control1	Control1	Control1to2	Control1to2
Dep. variable:	$\log(i)$	$\log(i)$	$\Delta \log(i)$	$\Delta \log(i)$	$\Delta \log(i)$	$\Delta \log(i)$	$\Delta \log(i)$
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Fire$\times$ Afterfire	0.0404*	0.0550**					
	(0.02289)	(0.02335)					
Fire	-0.0468**	-0.0682***	0.1311***	0.1272***	0.0525**	0.2101***	0.1240***
	(0.01953)	(0.01988)	(0.02110)	(0.02091)	(0.02131)	(0.02082)	(0.02080)
Afterfire	0.3783***	0.4012***					
	(0.00651)	(0.00621)					
Control1						0.0749***	0.0696***
						(0.00779)	(0.00741)
Controls	Yes	Yes	No	Yes	Yes	Yes	Yes
Fixed effects	No	Yes	No	No	Yes	No	Yes
Observations	36,610	36,610	10,818	10,818	10,818	24,108	24,108

Gentrification: Effect on Household Wealth after 5 Years

Approach:	DID	DID	Panel SA	Panel SA	Panel SA	Panel SA	Panel SA
Treatment group:	Fire	Fire	Fire	Fire	Fire	Fire	Fire
Control group:	Control1	Control1	Control1	Control1	Control1	Control1to2	Control1to2
Dep. variable:	$\log(w)$	$\log(w)$	$\Delta \log(w)$	$\Delta \log(w)$	$\Delta \log(w)$	$\Delta \log(w)$	$\Delta \log(w)$
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Fire× Afterfire	0.0754***	0.0565**					
	(0.01501)	(0.02721)					
Fire	-0.0111	-0.0155	0.0506***	0.0519***	0.0214*	0.0740***	0.0433***
	(0.01268)	(0.01999)	(0.01061)	(0.01071)	(0.01120)	(0.01072)	(0.01081)
Afterfire	-0.3176***	0.0182					
	(0.00331)	(0.01670)					
Control1						0.0216***	0.02370***
						(0.00395)	(0.00387)
Controls	Yes	Yes	No	Yes	Yes	Yes	Yes
Fixed effects	No	Yes	No	No	Yes	No	Yes
Observations	51,129	51,129	10,818	10,818	10,818	24,108	24,108

Summary for Evidence of Gentrification

So far is there evidence of fire-related gentrification?

There are long-run positive effects of wildfires on...

- house size in CA.
- house prices in CA.
- household wealth in CA.
- household income in CA.

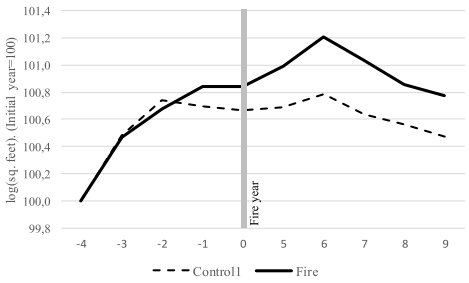
Difference-in-Differences: Mortgage Delinquency/Foreclosures

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

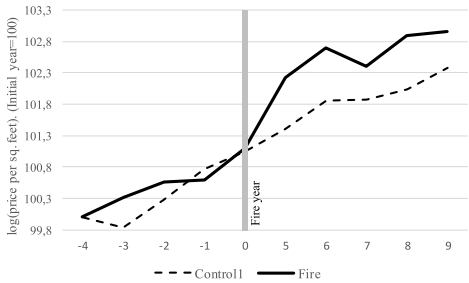
The Impact of Wildfire Size on Mortgage Defaults

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

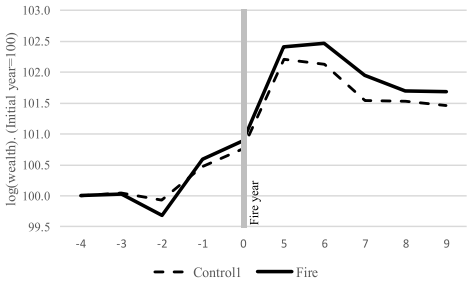
Parallel Trends



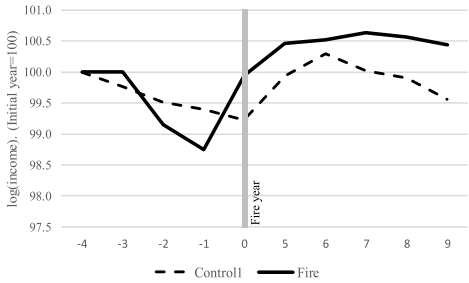
(a) **House size**



(b) **Price per sq. feet**



(c) **Wealth**



(d) **Income**

Wildfires and Mortgage

- 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 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 gentrification due to incentives to rebuild in place.
  - Mis-pricing of fire casualty insurance coverage

What are the wildfire expected losses to house values and mortgage balances?

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

- Our expected loss estimate is computed by:
  1. Estimating the probability of wildfire for each geographic grid;
  2. Computing the October 2015 value for each mortgaged house within the grid using a local house price index;
  3. Computing the current balance of the mortgage.
  4. **Expected loss:** Property market value (loan balance) times the probability of wildfire for the grid in the month of October (calculation prior to any reimbursements from insurance coverage).

Estimated Average Monthly Losses for Homes and Mortgages (In Sample for October)

CDI	Properties	Total Property Value $ Billion	Total Loan Value $ Billion	Mean Property Value $ Thousand	Mean Loan Value $ Thousand	Total October Property Loss $ Billion	Total October Loan Loss $ Billion
0	716,051	421	290	594	405	7.94	5.42
1	14,408	9	6	615	430	0.28	0.20
2	14,231	9	7	672	459	0.36	0.25
3	22,811	16	11	709	471	1.05	0.72
Total	767,501	455	314	593	409	9.63	6.59

Expected Wildfire Loss on California Housing Assessed Values

- Back-of-the-envelope risk-assessment for the effect of climate shocks on California's residential housing stock:
  - Calculate the estimated probabilities of wildfire from the logistic regression results.
  - Calculate the estimated long-run effects of wildfire on rebuilt homes from DID of five year ahead price effects.
  - Calculate one and two standard deviation shocks to the weather variables.

- Focus is the total single family CA housing stock of 7,687,975 units (single family, duplexes, triplexes, quadruplexes) for CDI zones 0 – 3.
  - The assessed value of these properties is $3.6 trillion (a lower bound).

- Starting point: the expected peak-season daily risk exposure for the assessed value $2.89 billion.

Effect of Climate Shocks on CA Housing Assessed Values

	Wildfire Probability (% Change)	Incremental Property Counts (Number)	Increment of Assessed Value to Wildfire Losses ($ Billion)	Increment of Assessed Value to Gentrification Gains ($ Billion)
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

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.

- Establishes the actuarial risk of wildfire to the residential single family mortgage market.

- Evidence of gentrification in wildfire recovery areas:
  - Long-run elevated returns.
  - Long-run housing size growth.
  - long-run increases in household income and wealth.

Conclusions 2

- 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.
     - Positive externalities from coordinated re-building.

- Implications for losses from insured mortgages in California
  - **Back-of-the-envelope** expected peak-season daily risk exposure for the assessed value of California housing is $2.89 billion.
  - **A one standard deviation max temperature shock** increases the daily risk to $8.74 billion.

- Implications for regulation of fire insurance/bank supervision.
  - Need for probabilistic wildfire forecasting models.
  - Need for actuarial casualty-insurance pricing.
  - Need for bank stress-test monitoring of wildfire risk.