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Yanjun (Penny) Liao, Simon Sølvsten, Zachary Whitlock

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About the Authors

Yanjun (Penny) Liao is an applied microeconomist and Fellow at Resources for the Future (RFF). Her current research focuses on issues of natural disaster risk management and climate adaptation.

Simon Sølvsten is established the European Center for Risk & Resilience Studies at the University of Southern Denmark in 2023. Simon's primary research focus revolves around risk financing, and organizational resilience.

Zachary Whitlock is a Senior Research Analyst at Resources for the Future. His research interests lie at the intersection of materials engineering and environmental stewardship.

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From Catastrophe to Caution: The Effect of Wildfires on Community Hazard Mitigation Investments*

Yanjun (Penny) Liao† Simon Sølvsten‡ Zachary Whitlock§

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Abstract

This paper examines the impact of wildfires on community-level hazard mitigation efforts, specifically focusing on participation in the Firewise USA program. Using a panel dataset of ZIP Code Tabulation Areas in the western United States from 2002 to 2019, we find that wildfires significantly increase participation. However, the response is notably weaker in areas with higher shares of minority populations, suggesting that these communities face greater barriers to engaging in risk reduction efforts. The paper also explores the role of homeowners' insurance, finding that Firewise participation can mitigate increases in insurance premiums after a wildfire, although it does not significantly affect the availability of coverage. The findings highlight the need for targeted support and coordination to enhance resilience in vulnerable communities.

Keywords: wildfires, risk mitigation, Firewise communities, homeowners' insurance.

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†Resources for the Future. Corresponding author: yliao@rff.org.

‡European Center for Risk & Resilience Studies.

§Resources for the Future.

1 Introduction

Over the past several decades, historic population growth and development in wildfire-prone areas, overgrowth of forests and rangelands, and climate change have led to millions of buildings exposed to the risk of wildfires in the United States (IBHS (Insurance Institute for Business Home Safety), 2023; Radeloff et al., 2023). The last 10 years in particular have seen unprecedented levels of property losses from wildfire events, with an average of more than 3,500 structures destroyed every year nationwide.[1] Catastrophic wildfire losses have significantly threatened the profitability of the property and casualty insurance industry.[2] US wildfire coverage of a residential property is typically bundled in the standard homeowners' insurance held by the vast majority of homeowners. As insured losses spiked, the availability and affordability of such insurance has deteriorated, particularly in high-hazard areas in the western United States.[3]

Policy discussions often point to risk mitigation as a fundamental solution to enhancing community resilience against wildfires and addressing insurability challenges. However, despite the urgency and importance of these actions, engagement in them remains remarkably low. For example, clearing vegetation and combustible materials surrounding the structure to create a "defensible space" is an effective and low-cost measure (Hedayati et al., 2023). Yet, according to a series of USDA Forest Service reports focusing on different wildfire-prone communities across the western United States, the majority of households have overgrown vegetation and other combustibles within 30 feet of their homes.[4]

It is critical to understand how risk mitigation investment co-evolve with wildfire occurrences that are becoming more frequent and destructive than ever before. We study whether wildfire experiences motivate communities to engage in risk mitigation actions and whether concerns about insurance factor into these behaviors. Our focus on community actions is informed by the characteristics of wildfire damage. Because embers from burning buildings nearby are the most important contributor to wildfire spread, fire mitigation at one property substantially reduces the risk of neighboring properties (Baylis and Boomhower, 2022; Dale and Barrett, 2023). Households might lack incentive to take actions if their neighbors do not (Shafran, 2008; Warziniack et al., 2019). As a result, wildfire mitigation activities conducted or coordinated by the community can be more beneficial than individual actions.

We measure community mitigation activities using participation in the Firewise USA

[1] See https://www.fs.usda.gov/managing-land/fire/fac.

[2] For the case of California, see https://www.milliman.com/en/insight/wildfire-catastrophe-models-could-spark-the-changes-california-needs.

[3] See, for example, Liao et al. (2022) on the California insurance market.

[4] See https://wildfireresearchcenter.org/document-library/?dfg_active_filter=55 for the collection.

Program (Firewise), which is designed to provide a framework for communities to implement mitigation measures. The program recognizes communities with 8–2,500 dwelling units that have met a set of voluntary criteria annually as Firewise USA sites. That recognition is used as the basis for premium discounts by several major insurers, including California's Fair Access to Insurance Requirement (FAIR) plan, which is the state insurer of last resort covering many high-risk properties.[5] In addition, recent California regulation mandated insurers to offer premium discounts to policyholders that meet the Safer from Wildfires framework, which includes community participation in Firewise.[6]

We assemble a panel of ZIP Code Tabulation Areas (ZCTAs) in the western states during 2002–2019. For each ZCTA, we calculate the share of population in Firewise communities and total annual investment to maintain good standing in the program. We also define wildfire events for each ZCTA and year based on the population exposed to wildfires. We then use a fixed effects model to estimate the effect of a wildfire event on Firewise participation.

We find that wildfire occurrences strongly affect Firewise activities. A wildfire that affects at least 1 percent of the ZCTA's population, for example, increases the share of Firewise residents among the population by 1.4 percentage points, which is 171 percent of the sample average and associated with a 34.3 percent increase in annual investment amount. Furthermore, more severe wildfires (those with greater population exposure) lead to a stronger response. However, we also find that the adaptive response does not exist in ZCTAs with a higher share of minority populations. No significant differences appear in the response of ZCTAs that are vulnerable in other dimensions, including socioeconomics, household composition, or housing and transportation.

Research shows that wildfire incidence disproportionately affects high-income, White, and older populations (Wibbenmeyer and Robertson, 2022). Our finding suggests that, faced with evolving risks and new levels of destructiveness, more communities in high-hazard areas are adapting by engaging in community-wide mitigation activities. However, we find no response in areas with a higher share of racial and ethnic minorities, potentially because they face greater barriers to making such investments. This highlights the importance of targeting these communities for resources and assistance for adaptation.

As the vast majority of homes are covered by homeowners' insurance for wildfire damage, Firewise participation might be partially driven by concerns about the affordability or availability of insurance coverage. We show that a wildfire event substantially increases both annual premiums and the market share of the FAIR Plan, indicating that wildfires indeed

[5]See https://altahoefirewise.com/insurers-currently-offering-discounts/.

[6]For more details, see https://www.nfpa.org/news-blogs-and-articles/blogs/2022/12/15/new-rules-benefit-california-property-owners-in-firewise-sites.

affect homeowners' insurance access. Inn ZCTAs with Firewise communities, we find that the premium increase is only one third the magnitude of the average increase and shrinks with a higher share of Firewise residents or investment amount. In contrast, we do not find any systematic difference in the increase in FAIR Plan market share across ZCTAs with different levels of Firewise participation. The FAIR Plan accounts for only 0.3 percent of the market in an average ZCTA. It is possible that most communities are primarily concerned about the affordability of premiums rather than the availability of coverage, at least during our sample period. We interpret these findings as suggestive evidence that the motivation to keep premiums affordable drives some communities to participate in the program.

This paper contributes to several lines of research. A large literature stream has studied factors driving wildfire mitigation decisions. Most of these studies rely on qualitative analysis and household surveys in specific communities to understand the connection between self-reported mitigation activities and a range of factors, including risk perception, disaster experience, households, and neighborhood characteristics (e.g. Brenkert-Smith et al. 2006; Martin et al. 2009; McGee et al. 2009; Brenkert-Smith et al. 2012; Champ et al. 2013; Larsen et al. 2021). The evidence has been mixed on both risk perception and disaster experience and highly dependent on the study context. Of particular relevance to this paper is research investigating factors driving Firewise participation. Survey-based research has identified potential barriers to participation, including cost, concerns over aesthetics, and treatment of part-time residents (Auerbach, 2015; Paveglio and Kelly, 2018). In a quantitative descriptive analysis based on California, Kampfschulte and Miller (2023) find that Firewise communities in the Sierras and the Bay Area appear to be more strongly motivated by underlying fire hazard than other geographic regions are, and participation tends to concentrate in Whiter, older, and more well-educated areas compared to the median population. Our study adds to this literature by providing direct causal evidence of the dynamic process of communities responding to wildfire events by engaging risk mitigation activities. Our finding on the differential responses of minority populations reinforces the cross-sectional pattern in Firewise participation by revealing unequal capacities for adaptation as an underlying mechanism.

Several studies have considered the role of incentives from the insurance market for reducing wildfire risk or exposure. Boomhower et al. (2023) show, theoretically, the potential role of insurer discounts in motivating self-protection investment and overcoming the information barriers households face. However, a common observation is that households often underestimate wildfire risk and might not be adequately incentivized to avoid it (Donovan et al., 2007; McCoy and Walsh, 2018). This might be because insurance premiums were not set to fully reflect the expected cost of living in a high-hazard area, which is further complicated by widespread underinsurance (United Policyholders, 2021; Hazra and Gallagher, 2022;

Boomhower et al., 2024). Compared to migration, our findings suggest that community-level mitigation actions are likely more responsive to financial incentives, perhaps because these actions entail much lower costs, and thus might be fruitful avenues for further adaptation.

The rest of the paper is organized as follows. Section 2 provides background on Firewise and homeowners' insurance markets. Section 3 introduces the data and Section 4 the econometric models. Section 5 presents and discusses the findings, and Section 6 concludes.

2 Background: The Firewise Program

Firewise was created by the National Fire Protection Association in 2002 as an initiative to help communities reduce the risk of wildfires through education and collaborative efforts.[7] It offers a framework with a series of practical steps that homeowners and communities can undertake related to landscaping, home construction, community planning and more to reduce the amount of flammable materials surrounding homes. Communities that have met certain planning and implementation criteria are recognized as Firewise sites. The program is cosponsored by the US Department of Agriculture Forest Service, US Department of the Interior, and National Association of State Foresters and also recommended by other federal and state agencies as a key tool for community wildfire mitigation actions, including FEMA and CAL FIRE. As of 2022, more than 1,800 Firewise sites were active nationwide (Miller, 2022).

Firewise participation is a grassroots effort that begins with creating a board or committee of volunteers and delineating the boundaries of the Firewise site. These communities may include 8–2,500 dwelling units and are typically homeowners' associations. Next, the board must complete a community wildfire risk assessment, which identifies priority areas for risk reduction and must be updated every five years. Based on the findings, the board creates a three-year action plan that breaks down planned community-wide investments and homeowner actions to be completed annually. At a minimum, one volunteer hour or its equivalent dollar amount ($25.43 in 2019 dollars) per unit is required annually to be in good standing with the program.[8] Each year, the leader of the board discloses the program's activities through the online Firewise Portal. Qualifying activities include collaboration with fire experts, coordination of outreach events, improvements and maintenance to homes and outbuildings or ignition zones, and completion of neighborhood-focused projects, such as debris removal and the establishment of evacuation routes. Therefore, a community has flexibility

[7]The Program's website is https://www.nfpa.org/education-and-research/wildfire/firewise-usa.

[8]For more details on renewal, see https://www.nfpa.org/education-and-research/wildfire/firewise-usa/annual-renewal-information.

in choosing activities suitable for its circumstances, but being recognized by Firewise does not imply that it is now safe from wildfires or done with its risk mitigation process.

Taking part in Firewise can yield several benefits for communities in wildfire-prone areas. Most directly, the activities promoted by the program are shown to be effective in lowering ignition risk (Baylis and Boomhower, 2022; Hedayati et al., 2023). This is supported by case studies in New Mexico and San Diego that show that Firewise sites provide protection benefits to nearby properties, at least in these specific contexts (Maranghides et al., 2013; Kramer et al., 2018).

Communities and individuals that participate in Firewise may also benefit in terms of insurance cost and availability. A National Association of Insurance Commissioners report in 2020 shows that structural and vegetation modifications combined can reduce wildfire risk up to 75 percent, as projected by a catastrophe model (Czajkowski et al., 2020). Depending on the jurisdiction and insurance provider, insurance discounts may be offered based on a Firewise site recognition or mitigation due to participation. USAA, for example, offers discounts to policyholders living in Firewise communities in California, Colorado, Texas, Arizona, Oregon, New Mexico, Utah, Wyoming, Montana, and Idaho.[9] The California Department of Insurance recently enacted the Safer from Wildfires regulation, which requires insurers to provide premium discounts for a range of risk mitigation activities, including forming a Firewise community.[10]

However, questions remain about whether the discounts are commensurate with the reduction in risk. Outside of California, many insurers do not offer such a discount at all. A substantial portion of them do not have access to a catastrophe model, limiting their abilities to accurately price the mitigating effect (Boomhower et al., 2023). Moreover, mitigation of one property can benefit neighboring properties, but such spillover benefits often accrue to other insurers and are unlikely to be priced in (Baylis and Boomhower, 2022).

3 Data

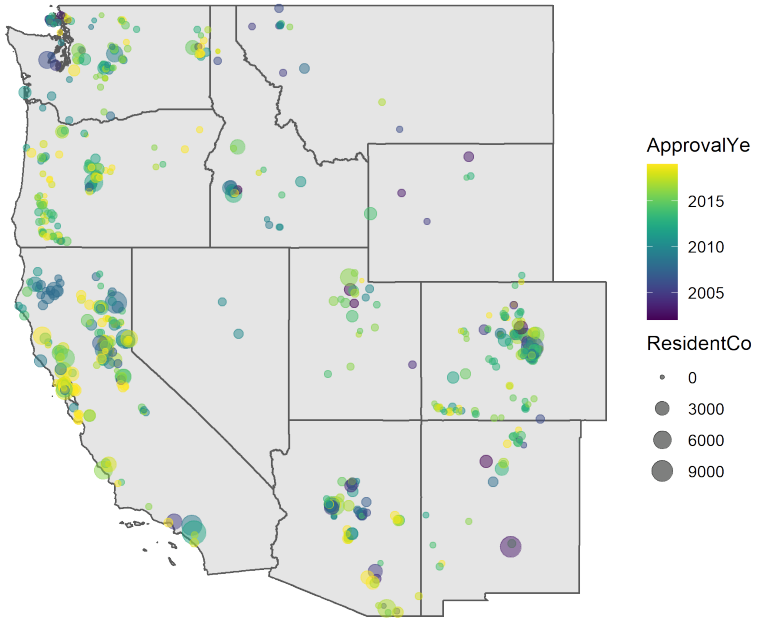
Our estimation sample for Firewise participation is a balanced panel of all ZCTAs in the Western United States from 2002 to 2019.[11] Table A2 presents the summary statistics. Next, we describe the data sources and procedures we use to assemble this dataset.

[9] See https://www.nfpa.org/Education-and-Research/Wildfire/Firewise-USA/Become-a-Firewise-USA-site/Program-benefits/Insurance-discounts-for-USAA-members-in-seven-states.

[10] See https://www.insurance.ca.gov/01-consumers/105-type/95-guides/03-res/upload/FAQ-Safer-from-Wildfire-Regulation.pdf.

[11] The US Census Bureau created ZCTAs as generalized areal representations of ZIP codes, which represent postal routes and have no defined spatial boundaries. ZCTAs cover only populated areas and were designed to represent ZIP codes that are assigned to census blocks.

Figure 1: Firewise communities in good standing in 2019

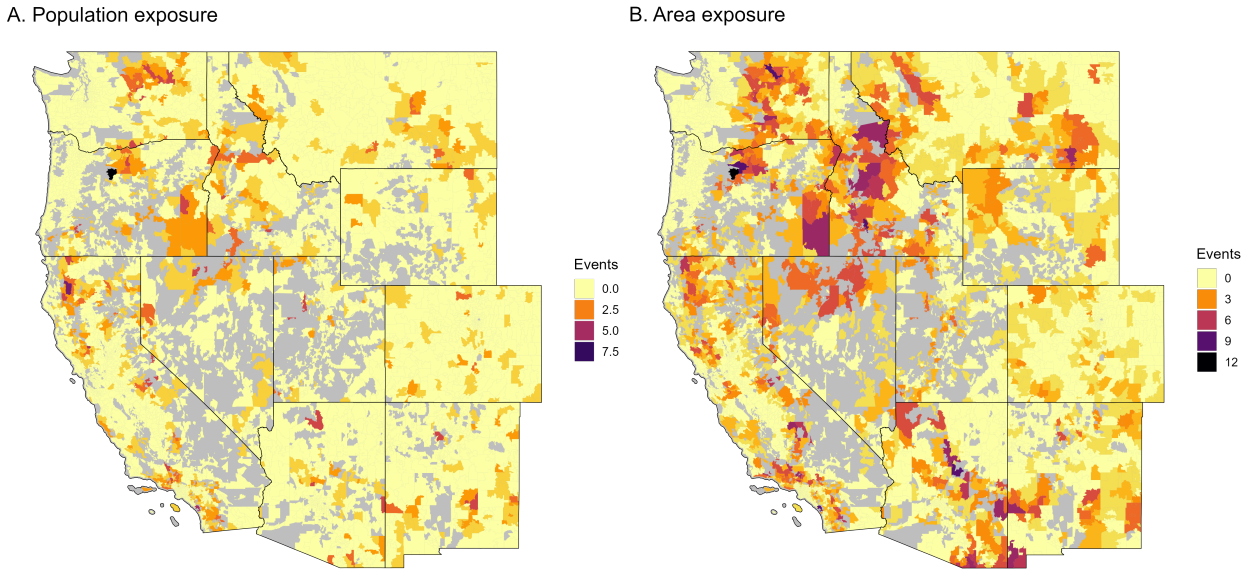


3.1 Firewise Recognition

We obtain geospatial data on communities in good standing in the program. For each site, the data identify its geographic coordinates (latitude and longitude), year it was first certified, number of residents, and annual investment in risk mitigation. We aggregate the data to the ZCTA level and calculate several measures of program participation for each year: the number of Firewise communities in the ZCTA, the share of ZCTA population that is Firewise community residents, and total annual investments in the ZCTA.

Figure A1 shows Firewise participation over time among communities in the western United States. Since the program started in 2002, both the number of communities and residents in it have been growing steadily, with faster growth in recent years. In 2019, 833 communities with 522,510 residents were in good standing in the program, making up about $372 million in annual investment in risk mitigation. Figure 1 shows the location of these communities, with the color indicating their certification year and the size of the circle showing the resident counts. Overall, participation is quite low despite the relatively relaxed requirements: ZCTAs average around 0.8 percent population living in Firewise communities. However, participation also varies widely across ZCTAs: some have 100 percent participation rate, but the majority are zero or close to it. Participation varies with the underlying risk, as shown in Table A1: in 2019, the 20 percent ZCTAs that are most at risk have on average 4.9 percent population participation and spend $66 per capita annually, and participation is

Figure 2: Number of wildfire events based on population vs. area exposure



Notes: Each panel displays the total number of wildfire events in each ZCTA during 2002–2019, defined as having more than 1 percent of population in burned areas in Panel A and more than 1 percent of land area burned in Panel B. The gray areas are unpopulated areas with no ZCTA.

0.5 percent and investment \$4 per capita for the 20 percent that are least at risk.[12]

3.2 Wildfire Events

To measure wildfire events, we obtain data from the USGS Monitoring Trends in Burn Severity (MTBS) project. It maps the extent of large fires since 1984 based on Landsat satellite data.[13] For each ZCTA, we measure its wildfire exposure in two ways: percentage of area burned each year and percentage of population exposed. For the former, we overlay the fire extents with ZCTA shapefiles and assign the area based on the fire's ignition date. To calculate population exposure, we further combine the shapefiles with gridded population counts at 30 arc-second grid cells (about 1 km at the equator) in 2010.[14] This allows us to calculate the percent of population in the ZCTA that is in the burned area each year.

Figure 2 shows the number of wildfire events defined based on population exposure in Panel A and area exposure in Panel B, using a 1 percent threshold in both. Overall, the

[12]Risk is measured using the Risk To Potential Structure score created by the US Forest Service. See https://www.fs.usda.gov/rds/archive/catalog/RDS-2020-0016 for more detail.

[13]In the western United States, MTBS includes fires 1,000 acres or greater. In 2004, the project captures over 95 percent of land burned nationwide (Eidenshink et al., 2007).

[14]The population raster comes from Gridded Population of the World v4. https://sedac.ciesin.columbia.edu/data/collection/gpw-v4.

two measures show similar patterns, with the area-based measure identifying more events because wildfires tend to burn wild lands that have no residents. In the analysis, we use the population-based measure as the main measure because wildfires that affect a larger population are more likely to be salient and affect risk mitigation behaviors. Nevertheless, we also report alternative results using the area-based measure in the appendix and show that they are qualitatively similar. To check robustness, we also vary the percentage threshold used to define a wildfire event and report estimates from multiple thresholds.

3.3 Socioeconomic Conditions

We are also interested in studying heterogeneous responses by communities with different socioeconomic conditions. To represent these conditions at the ZCTA level, we use the Social Vulnerability Index (SVI) constructed based on methodology from the Centers for Disease Control and Prevention and Agency for Toxic Substances and Disease Registry with data from the 2012 American Community Survey (ACS). Their SVI ranges from 0 (least vulnerable) to 1 (most vulnerable), representing percentile ranks of ZCTAs within the region. These rankings are based on 16 US census variables grouped into four themes: socioeconomic, household characteristics, racial and ethnic minority status, and housing and transportation.[15] To supplement the analysis based on SVIs with aggregate themes, we also obtain separate demographic variables from the 2012 ACS.

3.4 California Insurance Market

To understand how Firewise interacts with the homeowners' insurance market, we obtain data from the California Department of Insurance on homeowners' multiple peril policies. For each ZIP code and year during 2003–2018, the data contain the total dollar amount of premiums earned and the number of unit-months insured, collected from all insurers who wrote $1 million or more in total premiums in the voluntary market and the FAIR Plan. Using the HUD-USPS crosswalk between ZIP codes and ZCTAs[16], we construct an annual panel of California ZCTAs and calculate the average annual premium and FAIR Plan market share of it. Our analysis sample consists of only 1,721 ZCTAs for which we can continuously observe a nonzero average premium; Table A3 presents the summary statistics. The average annual premium is about $993. The FAIR Plan accounts for a very small share in most ZCTAs, with an average of 0.03 percent, but also has been the sole insurer in some ZCTAs.

[15] We do so using the R library "findSVI." For the official SVI publication and methodology, see https://www.atsdr.cdc.gov/placeandhealth/svi/index.html.

[16] Available at https://www.huduser.gov/portal/datasets/usps_crosswalk.html.

4 Empirical Framework

4.1 Baseline Model

We estimate the effect of a wildfire on Firewise participation using a regression equation:

$$Y_{zt} = \beta CumFires_{zt} + \delta_z + \lambda_t + \epsilon_{zt} \tag{1}$$

Y_{zt} is an outcome measuring the extent of Firewise participation at ZCTA z and year t. We examine two main outcomes: share of Firewise residents among ZCTA population and annual Firewise investment.[17] We model these outcomes as a function of the cumulative number of wildfire events the ZCTA has been exposed to since the beginning of the sample period ($CumFires_{zt}$). The specification also includes a ZCTA fixed effect (δ_z) to control for time-invariant drivers of hazard mitigation activities in each ZCTA, such as baseline hazard level and local government capacity, and a year fixed effect (λ_t) to control for general trends in hazard mitigation investment. We cluster the standard errors by ZCTA throughout.

The coefficient of interest is β, which measures the effect of having an additional wildfire event in the ZCTA on the level of Firewise participation. Although wildfires in any location are determined by baseline hazard level in the long run, the fixed effects ensure that this coefficient is derived from short-term variation in occurrences across ZCTAs and over time, which is plausibly exogenous. In essence, this is a difference-in-differences framework, comparing the Firewise participation outcomes in "treatment" ZCTAs that have wildfires to "control" ZCTAs that do not before and after the event. The key identifying assumption is parallel trends: treatment and control ZCTAs would follow parallel trajectories had the wildfires not taken place.

We also extend the baseline model to examine the dynamic patterns of hazard mitigation investments over time after a wildfire event. This allows us to investigate how fast the investments ramp up and whether they are persistent. We estimate these dynamic effects using an event study framework, where we define the event to be the first wildfire in the ZCTA (if applicable) during the sample period and focus on a time frame of five years prior to eight years after it. We employ the estimator proposed by Sun and Abraham (2021), which is robust to heterogeneous effects in a staggered treatment setting.[18] Notably, the estimated pre-event trends will allow us to partially test the parallel trends assumption. If

[17] We apply inverse hyperbolic sine transformation to the investment outcome to accommodate the right-skewed distribution. It allows us to interpret the estimates in percent terms similar to a log transformation but also keeps the valid zeros in the data.

[18] Specifically, the estimator proposed by Sun and Abraham (2021) generates cohort-based estimates and aggregates them to calculate the average treatment effect. This addresses the issue in a two-way fixed effects setting where effects from other periods might contaminate the estimated lead and lag coefficients.

significant differences are observed between treatment and control ZCTAs in their Firewise program participation *before* the event, this assumption is unlikely to hold. Conversely, the absence of a significant relative pretrend will support the assumption.

4.2 Differential Responses

Communities might have different abilities to recover from a wildfire and engage in follow-up hazard mitigation activities. In particular, the literature has highlighted that marginalized communities are more vulnerable to disaster impacts. To investigate if this effect manifest in this setting, we estimate the differential response by more compared to less socially vulnerable communities:

$$Y_{zt} = \beta_1 CumFires_{zt} + \beta_2 CumFires_{zt} \cdot \mathbf{1}(HighSVI)_z + \delta_z + \lambda_t + \varepsilon_{zt}. \tag{2}$$

This model augments the baseline one with an interaction term between the cumulative wildfire events and an indicator for high-vulnerability ZCTA, defined based on whether it has above-median SVI. The coefficient β_1 represents the response of low-capacity communities to a wildfire event, and β_2 captures the differential responses of high-SVI communities relative to the low-SVI ones. The other controls in the model are the same as before.

We also run two variants of this model. First, to understand which aspect of social vulnerability is most associated with the differential responses, we replace the interaction term with four interaction terms representing high vulnerability in each of the SVI themes. Second, we also run a similar specification where we interact cumulative events with indicators of above-median values in key demographics, including median income, share of non-Hispanic White population, and share of college graduates.

4.3 Interactions with the Insurance Market

One motivation to participate in Firewise is that it might allow households to obtain discounts on their homeowners' insurance; they often face an increase in premiums and might seek to curb this by supporting and participating in risk mitigation measures that insurers offer discounts for, including Firewise community recognition. Risk mitigation activities might also help households avoid being dropped by their insurers after a fire.

To explore the significance of insurance consideration for participating in the program, we estimate the following model using insurance data from California:

$$P_{zt} = \gamma_1 CumFires_{zt} + \gamma_2 Firewise_{zt} + \gamma_3 CumFires_{zt} \cdot Firewise_{zt} + \delta_z + \lambda_t + \varepsilon_{zt} \tag{3}$$

Table 1: The effect of wildfire events on Firewise USA participation

	Dependent variable:					
	Firewise residents percent			inhs(Firewise investment)		
	(1)	(2)	(3)	(4)	(5)	(6)
Cum. fires	0.568***	1.397***	1.522**	0.162***	0.295***	0.356**
	(0.132)	(0.421)	(0.625)	(0.032)	(0.083)	(0.139)
Exposure threshold	0%	1%	5%	0%	1%	5%
Number of fires	0.47	0.11	0.04	0.47	0.11	0.04
Outcome mean	0.815	0.815	0.815	-	-	-
Observations	97,002	97,002	97,002	97,002	97,002	97,002
Adjusted R^2	0.567	0.567	0.566	0.557	0.557	0.557

Notes: This table reports estimates following Equation (1). The outcome in Columns (1)–(3) is the share of Firewise residents in the ZCTA population, and the inverse-hyperbolic-sine-transformed annual investment amount is in Columns (4)–(6). The wildfire events are defined based on population exposure greater than 0%, 1%, and 5% alternatively for each outcome. *p<0.1; **p<0.05; ***p<0.01

The outcome of interest is the average annual premium or FAIR Plan market share[19] in ZCTA z and year t. To estimate the response of premiums to short-term variation in wildfire occurrences, we model the average annual premium as a function of the cumulative number of fires while controlling for ZCTA and year fixed effects. The coefficient γ_1 represents the magnitude of this response. To gauge the potential impact of Firewise participation on this response, we also add a measure of that and its interaction with cumulative wildfires. The coefficient on the interaction, γ_3, captures the differential changes in premiums after a wildfire where Firewise participation is higher relative to lower. We measure participation in multiple ways: an indicator of any participation, the share of population that resides in a Firewise community, and annual investment amount. Because participation is not random, we do not interpret γ_3 as a causal parameter. Nevertheless, this estimation will shed light on any systematic differences in premium behaviors in places with different participation levels.

5 Results

5.1 The Effect of Wildfires on Firewise Participation

Table 1 reports estimates from the baseline model as specified in Equation (1). We examine the effect of wildfire events on the share of Firewise residents in the ZCTA in Columns (1)–(3) and that on log annual investment in Columns (4)–(6). As described in Section 3.2, we vary the threshold of population exposure that defines the events for robustness: 0, 1, and 5 percent. As the threshold increases, the number of events decreases: the average ZCTAs experience 0.47 events with at least minimal exposure and 0.11 and 0.04 events where population exposure exceeds 1 and 5 percent, respectively. The estimates across all columns are positive and statistically significant at the 1 percent level. Columns (1) and (4) show that, for each event with at least minimal exposure, the percent of Firewise community residents increases by about 0.6 percentage points (p.p.), and annual investment amount increases by 17.6 percent.[20] The rest of the columns show that events with greater population exposure lead to a stronger response, as expected: the percent of Firewise residents in the ZCTA increases by 1.4 and 1.5 p.p. for events with 1 and 5 percent population exposure, respectively, and annual investments increase by 34.3 and 42.8 percent .[21]

We also estimate an alternative model: instead of alternating between wildfire events defined by different thresholds, we simultaneously include counts of events with population exposure below 1 percent , 1–5 percent , and above 5 percent. Figure 3 plots the coefficients for the Firewise residents share on the left and those for log annual investments on the right. This specification allows us to examine how the hazard mitigation response varies more straightforwardly with the intensity of the exposure. As expected, the larger the population exposure, the stronger the response in participation. Wildfires with minimal exposure lead to a 0.4 p.p. increase in the share of Firewise residents, and more severe exposure leads to responses in Firewise resident share that are more than three times as large. The effect on annual investment also increases progressively with the severity of the exposure.

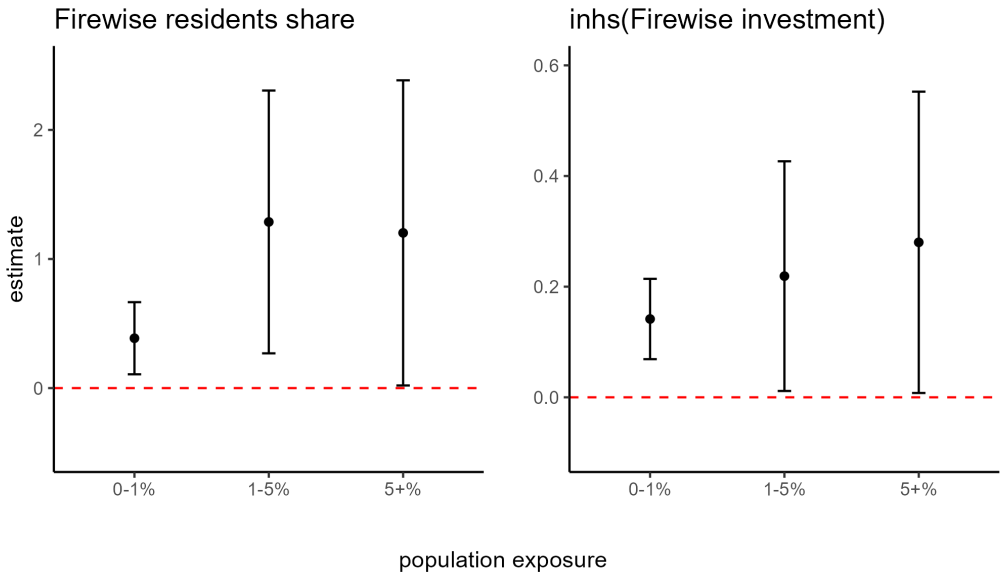
Table A4 reports estimates using alternative event measures defined based on area exposure. In general, a larger share of areas is exposed than population, which results in more events for each of the three thresholds. Again, all estimates are positive and statistically significant, demonstrating the robustness of our main findings. These estimates, however, are all smaller in magnitude compared to their counterparts defined by the same threshold

[19] We use the market share of FAIR Plan as a proxy for availability of insurance in the voluntary market. It offers expensive and limited coverage for households that cannot acquire coverage in the voluntary market.

[20] $e^{0.162} - 1 \approx 0.176$.

[21] $e^{0.295} - 1 \approx 0.343$, $e^{0.356} - 1 \approx 0.428$.

Figure 3: Firewise USA participation by exposure intensity



Notes: This figure plots the point estimates and their 95 percent confidence intervals following an augmented version of Equation (1), where we include separate counts of wildfire events with population exposure below 1 percent, 1–5 percent, and above 5 percent. The outcome variables are displayed at the top of each panel.

but for population exposure. This suggests that population exposure captures variation in wildfire occurrences that are possibly more relevant for hazard mitigation decisions.

Figure A2 shows the event study estimates, tracing the dynamics of the share of Firewise residents from five years before to eight years after a ZCTA's first wildfire with at least 1 percent population exposure, relative to those without an event. Before the event, there is no differential change in participation, which provides support for the parallel trends assumption. After the event, we see a continual increase in the share of Firewise residents in the first 5 years that stabilizes at about 1 p.p. in later years.

Overall, these results show that wildfire occurrences have a large effect on subsequent participation, suggesting that the experience of wildfire is a major motivator for community investment in hazard mitigation. Furthermore, the effect increases with the intensity of the wildfire. This could be because larger events make the risk more salient in people's minds.

5.2 Differential Responses

In this section, we analyze whether the responses to wildfires differ across ZCTAs and how they correspond with a ZCTA's social vulnerability and other demographic characteristics. We define wildfire events as those with more than 1 percent population exposure.

Table 2: Differential responses by social vulnerability

	Dependent variable:			
	Firewise residents percent		inhs(Firewise investment)	
	(1)	(2)	(3)	(4)
Cum. fires	1.685***	1.250***	0.313***	0.284**
	(0.591)	(0.466)	(0.111)	(0.117)
Cum. fires ×				
1(High SVI overall)	−0.589		−0.024	
	(0.843)		(0.171)	
1(High SVI socioeconomic)		1.898		0.133
		(1.201)		(0.212)
1(High SVI household)		0.120		0.065
		(1.226)		(0.220)
1(High SVI minority)		−2.427***		−0.413**
		(0.839)		(0.182)
1(High SVI housing)		0.471		0.284
		(0.964)		(0.214)
Outcome mean	0.815	0.815	-	-
Observations	94,968	94,950	94,968	94,950
Adjusted R^2	0.567	0.569	0.557	0.558

Notes: This table reports estimates following Equation (2). The outcome in Columns (1)–(2) is the share of Firewise residents in the ZCTA population, and the inverse-hyperbolic-sine-transformed annual investment amount in Columns (3)–(4). The wildfire events are defined based on population exposure greater than 1% for each outcome. The cumulative fires variable is interacted with an indicator of above-median overall SVI in Columns (1) and (3) and a set of indicators of above-median SVIs by theme in Columns (2) and (4). *p<0.1; **p<0.05; ***p<0.01

Table 2 presents results following Equation (2), which differentiates the responses of ZCTAs with above-median SVI and those below median. Column (1) shows a statistically significant increase of 1.7 p.p. in the share of Firewise residents in response to an additional wildfire among the less vulnerable ZCTAs. The coefficient on the interaction term is negative, indicating a smaller response from more vulnerable ZCTAs at 1.1 p.p., but statistically insignificant. We find the same pattern for annual Firewise investment in Column (3). Columns (2) and (4) break down the differential responses by the four SVI themes. The result highlight the main driver of differential responses is racial and ethnic minority status: ZCTAs that are vulnerable along this dimension see a decrease in the share of Firewise residents and annual investment after a wildfire, *conditional on* other dimensions of vulnerability, including socioeconomic conditions, household composition, and housing and transportation. Communities that are vulnerable in those three dimensions appear to have more Firewise participation and investment, although the coefficients are not statistically significant.

In Table A5, we use the same specification to examine key demographic variables directly, by differentiating the responses from ZCTAs with above-median levels of per capita income, total population, and share of college graduates and non-Hispanic White and Black population. The results again highlight racial and ethnic minority status as the main source of heterogeneity. The increase in participation is mainly driven by ZCTAs with above-median non-Hispanic White share; none of the other characteristics are associated with systematic differences in their response to wildfires. The specification includes indicators for different demographic characteristics simultaneously, so these findings are not driven by correlations between racial composition and income or education levels.

In summary, both sets of results indicate that areas with a greater share of racial and ethnic minorities have been less able to ramp up their Firewise participation after a wildfire compared to those with a larger share of non-Hispanic White population. A variety of factors might contribute to this pattern. For example, minority groups might be more vulnerable to wildfire impacts, have a harder time recovering, and thus lack resources and capacity to invest in risk reduction. They might also face greater language and information barriers in accessing the program. Regardless of the reason, these results show that self-directed community actions, in addition to agency actions, are a further source of inequality in wildfire defense along racial and ethnic dimensions (Anderson et al., 2023).

5.3 Interaction with the Insurance Market

To understand whether communities are partly motivated by insurance premiums or continuing coverage to participate in Firewise, we examine whether participation helped

Table 3: Firewise activities and insurance premiums

	Dependent variable:			
	Average premium			
	(1)	(2)	(3)	(4)
Cum. fires	112.792***	122.099***	119.585***	117.361***
	(36.463)	(41.855)	(40.445)	(39.021)
Cum. fires × 1(Firewise)		−86.911**		
		(37.419)		
Firewise residents share			−1.101**	
			(0.440)	
Firewise investment ($1,000s)				−0.048*
				(0.027)
Outcome mean	992.574	992.574	992.574	992.574
Observations	27,536	27,536	27,536	27,536
Adjusted R^2	0.750	0.750	0.750	0.750

Notes: This table reports estimates following Equation (3). The outcome is the average premium in each ZCTA. The wildfire events are defined based on population exposure greater than 1% for each outcome. *p<0.1; **p<0.05; ***p<0.01

curb the increase in insurance premiums or FAIR Plan participation after a wildfire event by estimating Equation (3). Due to insurance data availability constraints, we focus on the California market for this analysis; we observe a stronger increase in participation after wildfire events than in western US ZCTAs on average, as shown in Table A6. A wildfire with more than 1 percent population exposure leads to 2.7 p.p. increase in the share of Firewise residents in California and a 72.5 percent increase in annual investments.[22]

We next turn to average homeowners' insurance premium in Table 3 as a proxy for insurance affordability. Column (1) focuses on the baseline relationship between average annual premium and the number of wildfires. It shows that the premium responds strongly to wildfire occurrences: an additional wildfire increases the average premium by $113, which is about 11.4 percent of the mean. To further examine the dynamic effects, Figure A3 presents the event study based on this relationship. No differential pretrend appears before the wildfire, which supports the parallel trend assumption in this setting. The premium does not increase until year 3 after the event, when it spikes and continues to increase slightly

[22] $e^{0.545} - 1 \approx 0.725$.

in later years. This dynamic response is consistent with regulations faced by Californian insurers. During this period, the California rate regulations require overall rate increase on filings to be justified based on historical claims, which can drive the large retroactive rate increases.[23] Additionally, the delay in rate increases could result from the rate review process, which has a five-year average filing delay of 236 days.[24]

In the next three columns, we examine whether Firewise participation helps alleviate the rate hikes by interacting the cumulative fires with three measures of participation in turn. All three interaction terms are associated with negative and statistically significant coefficients, suggesting that premium growth is indeed lower where participation is higher. Column (2) shows that premium increases in ZCTAs with any Firewise activity average $87 lower, cutting the increase by two thirds relative to ZCTAs withoutFirewise activities. Column (3) shows that an additional p.p. of Firewise community residents is associated with a premium increase lower by $1.1, and Column (4) shows that an additional $1,000 in annual investment is associated with a smaller premium increase being lower by $0.05.[25] Together, these results suggest that participation substantially curbs premium increases after wildfires.

Next, we use the same specification to examine the percent of total premiums going to the FAIR Plan to proxy for insurance availability. Because the FAIR Plan is a last-resort option that is both limited in coverage and expensive, this outcome proxies the availability of regular options from private market. These results are reported in Table 4. As expected, wildfire occurrences have a positive and significant relationship with the FAIR Plan's market share. An additional wildfire is associated with a higher FAIR Plan market share by 0.6 p.p., which is twice the outcome mean. Unlike premiums, however, having more Firewise activities does not appear to alleviate this increase. If anything, the estimates on the interaction terms with Firewise participation measures are positive, though not statistically significant. Therefore, participation appears to be less helpful for maintaining regular insurance access.

As discussed, we note the caveat that Firewise participation might be endogenous in these specifications. However, to the extent that it positively correlates with the underlying risk, we would expect the omitted variable bias to go in the opposite direction for premiums: they would increase *more* after wildfires given more Firewise activities. Therefore, we interpret the findings on premiums as supportive evidence that premium discounts associated with

[23] According to California Code of Regulations Title 10, § 2644.5 - Catastrophe Adjustment, "In those insurance lines and coverages where catastrophes occur, the catastrophic losses of any one accident year in the recorded period are replaced by a loading based on a multiyear, long-term average of catastrophe claims. The number of years over which the average shall be calculated shall be at least 20 years for homeowners multiple peril fire, and at least 10 years for private passenger auto physical damage."

[24] See https://laweconcenter.org/resources/rethinking-prop-103s-approach-to-insurance-regulation/.

[25] The average California ZCTA with Firewise communities has 44.5 percent Firewise residents and $1.5 million in annual investment.

Table 4: Firewise activities and Fair Plan market share

	Dependent variable:			
	Percent of premiums from FAIR Plan			
	(1)	(2)	(3)	(4)
Cum. fires	0.065**	0.060**	0.059**	0.063**
	(0.025)	(0.027)	(0.026)	(0.026)
Cum. fires × 1(Firewise)		0.025		
		(0.044)		
Firewise residents share			0.0004	
			(0.001)	
Firewise investment ($1,000s)				0.00002
				(0.00002)
Outcome mean	0.030	0.030	0.030	0.030
Observations	27,536	27,536	27,536	27,536
Adjusted R^2	0.244	0.244	0.244	0.244

Notes: This table reports estimates following Equation (3). The outcome is the market share of the FAIR Plan in each ZCTA measured as the percentage of total premiums. The wildfire events are defined based on population exposure greater than 1% for each outcome. *p<0.1; **p<0.05; ***p<0.01

Firewise recognition might be a motivation for participation. Following the same logic, we would expect an upward bias for the relationship between FAIR Plan market share and Firewise activities. Our findings on this outcome thus have a less definite interpretation.

6 Conclusion

In recent years, wildfire losses have significantly escalated in the western United States. In this paper, we investigate how community's wildfire mitigation actions co-evolve with wildfire occurrences and the forces that shape these responses. We measure mitigation efforts using communities' Firewise participation and show that community efforts are highly responsive to wildfire occurrences. However, these effects are entirely driven by areas that have a high share of non-Hispanic White population; areas with a higher share of minority populations see no effect after a similar event. Further explorations using California insurance data suggest that Firewise recognition helps alleviate insurance premium hikes after a wildfire, which might be a motivating factor for participation. Although, in theory, risk mitigation

could also help make insurance more available, we find no supporting evidence by examining the takeup of FAIR Plan policies.

Overall, our results suggest that communities are taking steps to address the increasing threat of wildfires. However, the overall level of effort is still dwarfed by the magnitude of the problem: only 13.5 percent of the ZCTAs that are most at risk have any Firewise site in 2019, with 5 percent of their populations being Firewise residents. Our findings suggest that one approach to motivate more mitigation activities might be to simulate or recreate the experience of a wildfire. Concerns about insurance also appear to be an important driver of mitigation actions, which can be further strengthened through coordination between the insurance industry and communities, along the lines of California's recent regulatory changes under the Safer from Wildfires framework. Last but not least, policymakers should also consider targeting further incentives or assistance to minority communities to address the uneven investments in resilience measures.

One limitation of our analysis is that it does not capture the full extent of communities' mitigation activities if they do not engage in these under the Firewise program. Our results might underestimate the adaptive responses of communities that are less informed about the program and not capture the differences among Firewise communities. Nevertheless, as the program is considered a major tool for community mitigation efforts and has relatively low entry barrier, our findings are likely to be representative of the general adaptation responses to wildfires. Similarly, the results on interactions with the insurance market might not apply readily to states other than California, as insurers there face different market conditions and regulations and might behave differently.

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A Additional Figures and Tables

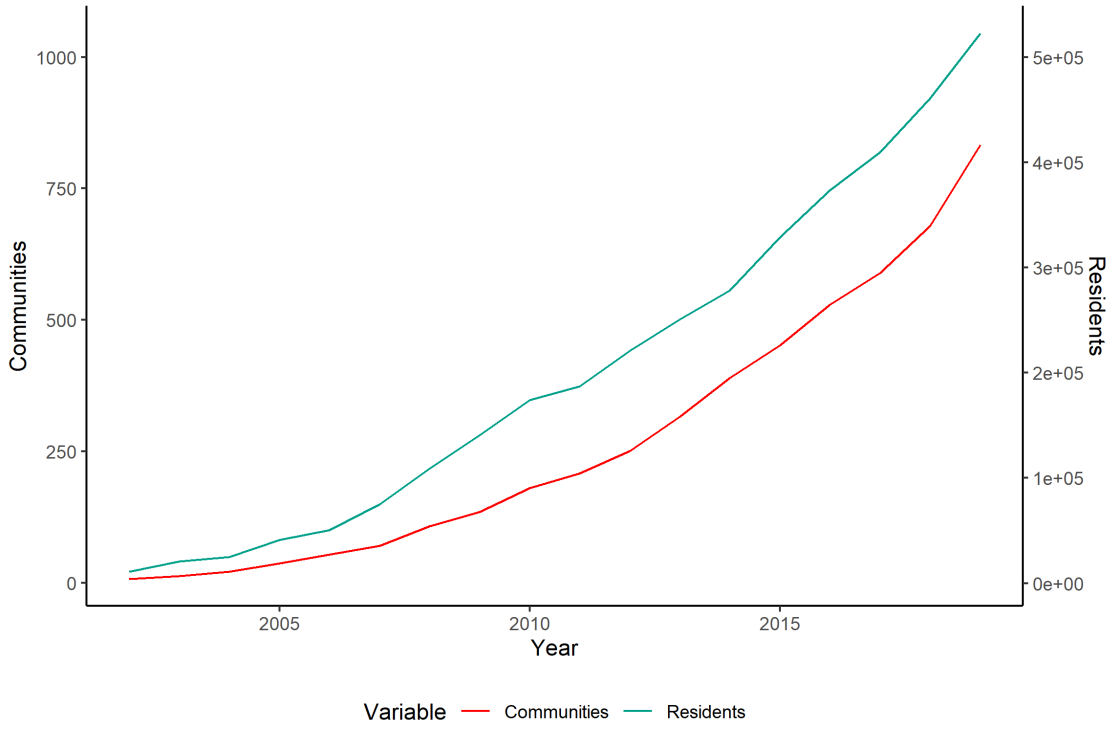


Figure A1: Firewise participation in the western United States, 2002–2019

Figure A2: Event study estimates for Firewise participation

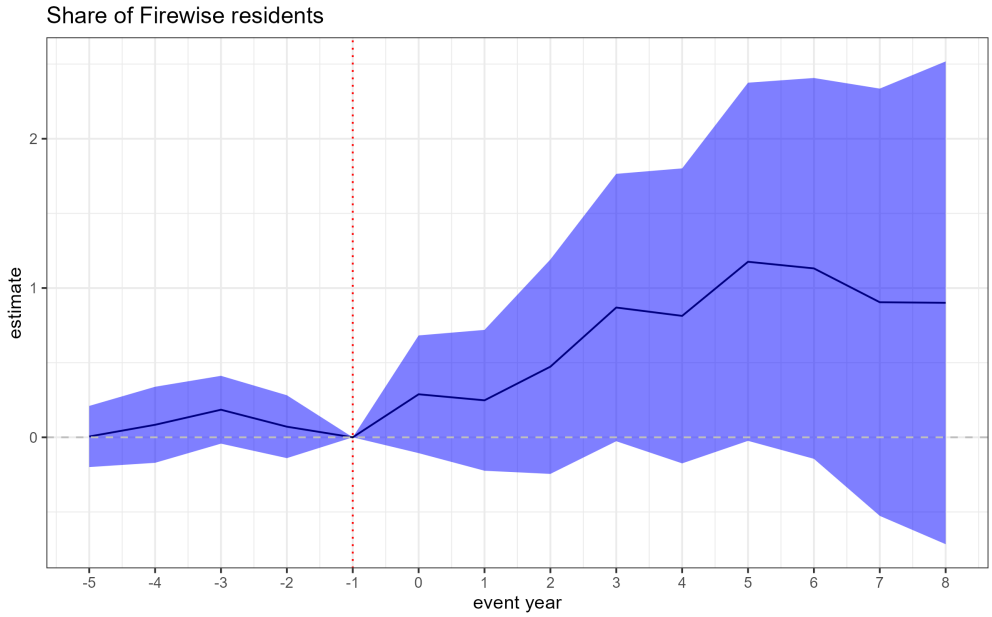


Figure A3: Event study estimates for average homeowners' insurance premium

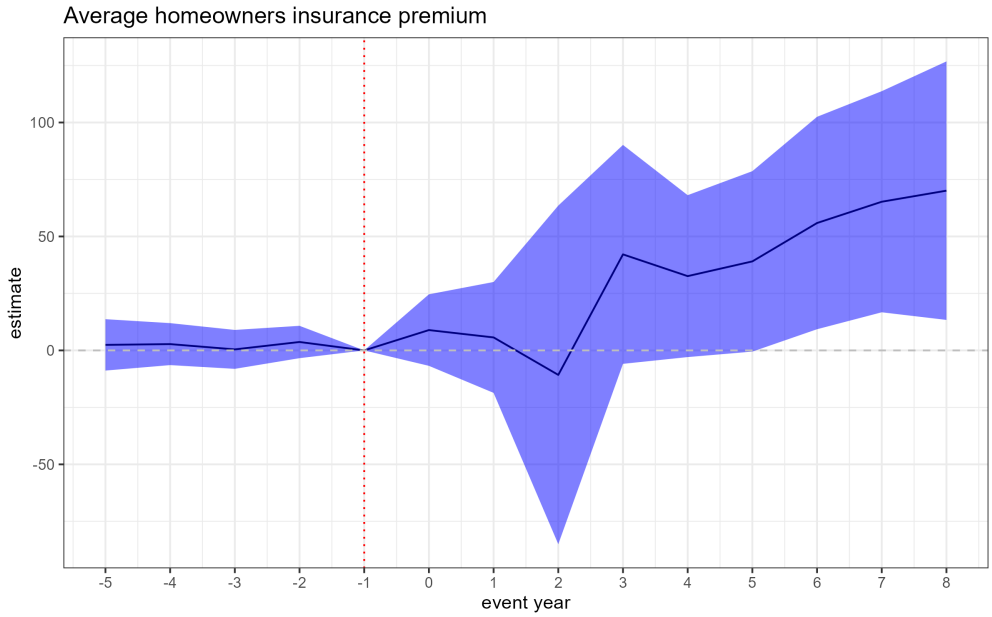


Table A1: Firewise participation in 2019 by risk category

RPS quintile	% any Firewise	% Firewise pop.	Investment per cap.
0-20%	2.4	0.5	3.98
20-40%	3.6	0.5	6.50
40-60%	6.0	1.3	14.18
60-80%	9.8	2.6	27.39
80-100%	13.5	4.9	66.30

Note: This table presents summary statistics of Firewise participation in 2019, grouping the ZCTAs in the western United States by the quintile of their Risk to Potential Structure score.

Table A2: Summary statistics: Western US ZCTA panel

Statistic	N	Mean	St. Dev.	Min	Max
Year	97,002	2,010.500	5.188	2,002	2,019
Any Firewise	97,002	0.028	0.166	0	1
# Firewise communities	97,002	0.050	0.457	0	25
# Firewise residents	97,002	37.907	417.714	0	14,761
Firewise residents percent	97,002	0.815	7.554	0	100
Total annual investment	97,002	30,123	385,461	0	19,278,238
% Pop exposed	97,002	0.109	1.792	0	100
% Area exposed	97,002	0.312	2.963	0	100
ZCTA population	97,002	12,994	17,461	0	105,549
Median income	94,446	26,979	11,229	2,499	130,673
Non-Hispanic White share	94,968	68.485	28.298	0	100
College share	94,860	25.315	17.454	0	100
SVI overall	94,968	0.500	0.289	0	1
SVI socioeconomic	94,950	0.500	0.289	0	1
SVI household	94,968	0.500	0.289	0	1
SVI minority	94,968	0.497	0.293	0	1
SVI housing & transport	94,968	0.499	0.290	0	1

Table A3: Summary statistics: California ZCTA panel

Statistic	N	Mean	St. Dev.	Min	Max
Year	27,536	2,010.500	4.610	2,003	2,018
Any Firewise	27,536	0.022	0.147	0	1
# Firewise communities	27,536	0.031	0.258	0	11
# Firewise residents	27,536	42.212	475.216	0	13,849
Firewise residents percent	27,536	0.989	8.661	0	100
Total annual investment	27,536	34,313	369,112	0	10,952,110
%Pop exposed	27,536	0.186	2.545	0	100
%Area exposed	27,536	0.479	4.269	0	100
ZCTA population	27,536	21,554.110	21,196.250	0.041	101,605.100
Insured units	27,536	3,684.998	3,715.958	0.167	20,450.420
Average premium	27,536	992.574	635.258	24.000	36,978.620
FAIR Plan market share (%)	27,536	0.030	0.762	0	100

Table A4: The effect of wildfire events on Firewise (area exposure)

	Dependent variable:					
	Firewise residents percent			inhs(Firewise investment)		
	(1)	(2)	(3)	(4)	(5)	(6)
Cum. fires	0.513***	0.877***	1.168***	0.150***	0.203***	0.291***
	(0.121)	(0.221)	(0.342)	(0.029)	(0.045)	(0.078)
Exposure threhold	0%	1%	5%	0%	1%	5%
Avg. no. of fires	0.52	0.3	0.13	0.52	0.3	0.13
Outcome mean	0.815	0.815	0.815	-	-	-
Observations	97,002	97,002	97,002	97,002	97,002	97,002
Adjusted R^2	0.567	0.567	0.566	0.557	0.557	0.557

Note: This table reports estimates similar to Table 1 but with events defined based on area exposure as a robustness check. *p<0.1; **p<0.05; ***p<0.01

Table A5: Differential responses by ZCTA demographics

	Dependent variable:	
	Firewise residents percent	inhs(Firewise investment)
	(1)	(2)
Cum. fires	0.021	−0.275
	(0.669)	(0.183)
Cum. fires ×		
1(High income)	−0.712	0.016
	(1.382)	(0.267)
1(High college share)	−0.137	0.156
	(1.238)	(0.229)
1(High White share)	2.397***	0.557***
	(0.807)	(0.198)
1(High Black share)	1.275	0.326
	(1.031)	(0.234)
1(High population)	−0.524	0.278
	(0.957)	(0.247)
Outcome mean	0.815	-
Observations	93,726	93,726
Adjusted R^2	0.560	0.556

Notes: This table reports estimates following Equation (2). The outcome in Column (1) is the share of Firewise residents in the ZCTA population, and the inverse-hyperbolic-sine-transformed annual investment amount in Column (2). The wildfire events are defined based on population exposure greater than 1% for each outcome. The cumulative fires variable is interacted with indicators of the ZCTA having above-median levels of median household income, share of college graduates, and non-Hispanic White population. *p<0.1; **p<0.05; ***p<0.01

Table A6: The effect of wildfire events on Firewise USA in California

	Dependent variable:					
	Firewise residents percent			inhs(Firewise investment)		
	(1)	(2)	(3)	(4)	(5)	(6)
Cum. fires	1.535***	2.690***	1.960*	0.360***	0.545***	0.467**
	(0.414)	(0.921)	(1.042)	(0.085)	(0.166)	(0.218)
Exposure threhold	0	1	5	0	1	5
Avg. no. of fires	0.39	0.14	0.07	0.39	0.14	0.07
Outcome mean	0.995	0.995	0.995	-	-	-
Observations	31,842	31,842	31,842	31,842	31,842	31,842
Adjusted R^2	0.534	0.533	0.529	0.507	0.504	0.502

Notes: This table reports estimates similar to Table 1 but with only ZCTAs in California. *p<0.1; **p<0.05; ***p<0.01

