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Understanding Homeowner Proactive Actions for Managing Wildfire Risks

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Abstract

Wildfires have become increasing threats to residents, built environments, and ecosystems in the United States. Individual responsibility plays a significant role in reducing structure-level ignitability, and in turn, overall community vulnerability. Moreover, homeowners insurance can serve as the second line of defense by allowing homeowners to avoid substantial financial burden from repair/reconstruction costs induced by wildfire. To understand homeowner decisions on wildfire-related proactive actions and the effects of such decisions on the housing recovery, this study conducted an online survey of homeowners living in high to extreme risk of wildfire in the Western United States and collected data related to two types of proactive actions, i.e., individual-level risk reduction actions and homeowners insurance. First, a regression model for each proactive action was estimated to identify key characteristics of homeowners and house/property that had the greatest impact on these actions. The results indicated that homeowner age and household income were the two common factors affecting their decisions about home hardening and insurance policies, while the only statistically significant factor in homeowner decisions about defensible space was satisfaction with the surrounding environment. Moreover, the effects of each proactive action on the housing recovery process were evaluated. The results showed that home hardening was a more effective action in reducing wildfire damage to a house than defensible space was, which was consistent with homeowner perception. The survey results also indicated that homeowners with insurance were less likely to experience post-wildfire financial hardship, and subsequently were more likely to repair their damaged houses.

Keywords

Wildfire, Homeowner decisions, Proactive actions, Risk mitigation actions, Homeowners insurance

1. Introduction

Wildfire risk has increased significantly in recent years and is expected to grow across many parts of the United States (U.S.). Eight out of the top ten costliest wildfires in the U.S. occurred between 2017 and 2020 ([Insurance Information Institute, 2020](#)), with notable examples in California (e.g., the Carr Fire, the Woolsey Fire, and the Camp Fire, all of which occurred in 2018 and destroyed over 20,000 structures in California). Climate change may play a role in increasing the frequency and severity (in terms of fire size and duration) of wildfire. More importantly, growing population and human activities in the wildland-urban interface (WUI) have altered the environment and increased the exposure of human and high-value assets to wildfire, making the problem even more complicated and severe ([Westerling et al., 2011](#); [Moritz et al., 2014](#); [Smith et al., 2016](#)). One third of residential buildings in the U.S. are located in the WUI ([Wisch & Yin, 2019](#)), and 4.5 million U.S. homes are at high to extreme risk of wildfire ([Verisk, 2019](#)). Such population growth in the WUI, where flammable vegetation is dominant, has increased the likelihood of wildfire ignition (considering that 90% of wildfires are human-caused). Moreover, due to increased exposure in wildfire-prone areas, the small historical fires (e.g., Awbrey Hall Fire, Oregon, 1990) that did not cause significant economic losses could pose much greater risks if they were to occur today, as demonstrated by [Wisch and Yin \(2019\)](#). With the increasing occurrence of large wildfires and their higher

consequences, in recent years, the federal/local governments, insurance companies, and the general public have paid greater attention to risk mitigation actions to protect communities from potential wildfires.

As part of wildfire risk reduction efforts, since the early 1900s, the U.S. federal and local governments have developed and implemented a variety of community-level wildfire protection plans. In the early stages, these policies were intended to reduce the consequences of wildfire by suppressing fires in an efficient and timely manner (Yin, 2018), which included fire department support, fire crew allocation, adequate water supply and flow for firefighting, and road improvement for facilitated access. Wildfire policies have since evolved, and community-level efforts have placed more emphasis on reducing the likelihood of wildfire by removing fuel accumulation in high-risk areas (Yin, 2018). For example, the Butte County Fire Prevention Program recently added multiple risk management activities such as pre-fire strategies and tactics, vegetation management (i.e., clearing fuels around communities and along roadways and evacuation routes), and fire break zones (Butte County, 2021). The federal and local governments also enforce compliance with defensible space laws and regulations and home hardening to reduce property-level risk. To increase wildfire awareness and educate homeowners about wildfire risk reduction actions and evacuation preparedness, educational workshops and brochures are also provided as part of community-level efforts (Haines et al. 2004). Such additional components have been added because there has been an increasing awareness that, unlike other types of natural hazards, the probability of ignition, the rate of fire propagation, and the consequences of wildfire (all of which constitute wildfire risk) can be reduced by human efforts. Community Wildfire Protection Plans (CWPPs) are tailored to specifically address a community's unique conditions and risks related to wildfire (USFA, 2020) and have helped nearly 4,800 communities in the U.S. WUI in identifying their priorities for the protection of life, property, and critical infrastructure (Communities Committee, 2004).

In addition to the community-level wildfire risk management actions, individual homeowner proactive actions are also vitally important for enhancing community resilience. As described in Fig.1, there are two types of proactive actions that homeowners can take prior to a wildfire event: individual-level risk reduction actions and homeowners insurance.

Proactive Action 1: Individual-Level Risk Reduction Actions

Individual responsibility plays an important role in reducing structure-level wildfire risk. It has been demonstrated that wildfire risk to an individual structure can be significantly decreased by reducing its ignition vulnerability to firebrands and flames (i.e., home hardening) and creating defensible spaces surrounding a house (Communities Committee, 2004; Syphard et al., 2014). Evans et al. (2015) found that such individual-level efforts can reduce the average home hazard by 20%. Home hardening involves the use of non-combustible or ignition-resistant siding and trim, installing Class A fire-resistant roof assembly, and installing dual pane windows and/or fire sprinklers, all of which decrease the likelihood of ignition and combustion of an individual house. Designing and maintaining defensible space is also important given that the presence of flame and firebrand ignitions within 40 meters from a structure would highly increase the chance of home ignition (Alexandre et al., 2016). Defensible space creates the buffer between a house and surrounding vegetation to slow the spread of wildfire and protect the house from fire. For example, the U.S. National Fire Protection Association (NFPA) defines three home ignition zones based on the distance from the exterior point of a house (NFPA, 2021): immediate zone, intermediate zone, and extended zone, which are the areas of 0 – 5', 5 – 30', and 30' – 100' from the furthest attached exterior of the house, respectively. The NFPA suggests various risk reduction actions that should be taken for each zone ranging from removing flammable material to vegetation treatment (e.g., thinning tree canopies, spacing trees). The abovementioned individual-level risk reduction actions not only protect a house from wildfire but also affect the vulnerability of neighboring houses.

Extensive studies have been conducted to examine factors that influence homeowner decisions about wildfire mitigation actions (e.g., McGee and Russell, 2003; Schulte and Miller, 2010; McFarlane et al., 2011; Ghasemi et al., 2020). Common factors identified as the key variables affecting homeowner

mitigation decisions include property type and value, financial availability, mortgage situation, risk perception and attitude, previous experience with wildfire and other natural hazards, etc. For example, there is considerable evidence that people who have experienced natural disasters are more inclined toward taking risk mitigation actions (Peacock, 2003; Ge et al., 2011; Lindell & Perry, 2012). McGee and Russell (2003) suggested that several attributes of homeowners, including previous experiences with wildfires, involvement in agriculture and with the local fire brigade, and their social network, contributed to mitigation behavior, while wildfire preparedness within the community was affected by “a culture of self-reliance, experience with fires as part of farming, and social cohesion.” The attributes of mitigation measures (such as costs and perceived efficacy) also play a key role in homeowner decisions (Winter and Fried, 2000; McCaffrey, 2008; Collins, 2009). In addition to the characteristics of homeowners, communities, and mitigation measures, spillover effect (normally termed as neighbor decisions) is also identified as one of the main factors affecting mitigation decisions given that wildfire risk is interdependent (Shafran, 2008; Shafran, 2010; Taylor, 2019; Dickinson et al., 2020). If a structure ignites and burns due to flame or firebrand, the burning structure could become a new source of firebrand generation and threaten adjacent structures (Suzuki et al. 2014). Thus, one’s mitigation behavior affects the risk levels of the neighboring environment and vice versa. For example, unmitigated properties or public lands adjacent to the property would reduce the willingness of owners to take mitigation actions, as they believe the efficacy of their own mitigation actions would be low (Brenkert-Smith et al., 2006). Inversely, mitigation actions taken by neighbors can cause the free-rider problem. NFPA (2020) also highlighted the importance of collaborative actions between neighbors to reduce their shared risk. As such, homeowner mitigation decisions have been well studied in the past two decades. However, many of them have focused on a single type of mitigation action and have not related these actions to housing damage and recovery, which is necessary for assessing their roles in community resilience.

The extent of structural damage induced by wildfire depends on various factors that include property-level parameters and landscape factors such as vegetation management, fuel characteristics, and topography. To gain knowledge about the relationship between wildfire risk mitigation actions and the associated structural damages, several studies (Moore, 1981; Radtke, 1983; Syphard et al., 2012; Penman et al. 2014; Alexandre et al. 2016; Syphard et al., 2017) have recently investigated the effects of individual-level risk reduction actions on building damage and its survival rate. As most of them have utilized computer-based simulation or laboratory experiments, until recently, existing wildfire risk mitigation actions have been driven from limited empirical studies that are based on significant assumptions on fire behavior, thus resulting in highly theoretical “best practices” (Syphard & Keeley, 2019). Without having the actual damage and response dataset, it is nearly impossible to predict the best proactive plan. Hence, post-wildfire surveys and field studies are necessary to collect observations and validate simulation and/or laboratory results. While a number of researchers have attempted to conduct post-wildfire field surveys on schools and hospitals (Schulze et al., 2020), channel environment (Benda et al., 2003), etc., few studies have collected post-wildfire structural damage sustained by houses.

Proactive Action 2: Homeowners Insurance

Homeowners insurance, which covers damages to structures and personal belongings induced by wildfire and smoke, is another important proactive action that homeowners can take in case their properties are damaged by residual wildfire risks (Zhao et al., 2020). It helps policyholders in alleviating excessive financial burdens from repair/reconstruction costs following a high-consequence wildfire event by transferring risks to a third party and over time (Pelling, 2003). With sufficient insurance coverage, homeowners may receive reliable and timely claim payments that enable the expedited recovery processes of houses, and in turn, the community as a whole. The role of catastrophe risk insurance (e.g., earthquake insurance or flood insurance which is not covered by homeowners insurance and requires a separate endorsement) has been well investigated in several studies (Hazell, 2001; Kunreuther & Pauly, 2006; Paudel, 2012; Charpentier, 2014), but most of these studies have taken a qualitative approach to assessing its effect on community resilience. Due in part to the lack of quantitative assessment of catastrophe

insurance, the effect of insurance has often been underestimated or neglected in many community resilience planning studies. While a limited number of studies have developed either theoretical or statistical models for the insurance purchase behavior of forest owners and/or homeowners through experimental economics and survey (McKee et al., 2004; Gan et al., 2014), most of these studies have considered only binary variables in their models (i.e., purchase insurance or not). However, given that homeowners with a mortgage (i.e., over 70% of the U.S. population) are required to purchase homeowners insurance, insurance coverage limits play a more significant role in housing recovery than insured status does. In many cases, uninsured and underinsured homeowners are low- (and middle-) income residents who are identified as economical and socially vulnerable groups in society (Eriksen & de Vet, 2021; Priest et al., 2005; Mockrin et al., 2015), and therefore their post-disaster financial availabilities may greatly affect community resilience. Moreover, few studies have attempted to relate homeowner purchasing behavior to their financial availability following a hazard event.

Fig.1 Role of homeowner proactive actions in the post-wildfire housing recovery process

To address the significant research gaps identified above, this paper examines potential factors that may affect homeowner proactive actions for managing wildfire risks and the role of such actions in housing recovery. To achieve the goal, a post-wildfire online survey of homeowners was conducted in multiple counties at high to extreme risk of wildfire in California and Washington. Based on the online survey results, we identified the key factors that contributed most to homeowner decisions about each proactive action and estimated a set of logistic regression models in order to relate the characteristics of houses and homeowners to their willingness to invest in the proactive action. Then, the effect of proactive actions on the housing recovery process was explicitly modeled by assessing (a) the effect of homeowners insurance policy on delay time (T_{delay}), and (b) the effect of individual-level risk reduction actions on house damage. The rest of this paper is organized as follows. Section 2 describes the investigation methods including the main research questions, online survey data collection, and statistical analyses. In Section 3, the results obtained from the data analyses are presented and discussed. Finally, Section 4 presents summary, limitations, and conclusions.

2. Investigation Methods

2.1. Research Questions

This study is motivated by the following research questions:

- 1) What factors affect homeowner proactive actions for managing wildfire risks?
- 2) How do the proactive actions taken prior to a wildfire event affect the housing recovery process following the event?

To answer the research questions, this study used a quantitative approach to identifying independent variables that are likely to influence homeowner proactive actions for managing wildfire risks and assessing their impacts on the housing recovery processes through an online survey. The quantitative models developed based on the survey results will provide federal/local government with preliminary insights into how to motivate homeowners to take proactive actions and which proactive action could be more effective in expediting the housing recovery process.

2.2. Data Collection

To collect data used to support quantitative models, we conducted an online survey of homeowners in California and Washington where at least one wildfire event occurred in the past five years. The affected areas were identified by being overlaid with the layer containing wildfire perimeters in the past five years in ArcMap. Participants were recruited in January 2021 by Qualtrics research service, a professional organization that uses prequalified respondents to achieve significant response rates for the purpose of validity. While online convenience sampling was used to recruit participants, these samples collected by Qualtrics panels could be demographically and politically representative, as demonstrated in [Boas et al. \(2020\)](#). The inclusion criteria for participating in this survey were to be homeowners in the study area (Fig.2) who were at least 18 years of age and whose houses were damaged by at least one wildfire event (i.e., house experienced at least a minor damage state due to wildfire) in the past five years. Since the survey was designed to assess the effect of pre-wildfire proactive actions on post-wildfire house damage and delay time, homeowners whose houses were not damaged by wildfires were excluded. Fig.2 shows the study areas and the number of valid survey responses received from each area.

Fig.2 Study areas and the number of survey responses received from each area

In the study area, about 30,000 structures (i.e., the estimated total population size) were damaged or destroyed by major wildfires in the past five years. Based on the approach to determining sample size presented in [Krejcie and Morgan \(1970\)](#), 64 responses were a sufficient sample size to generate 90% confidence interval and 10% margin of error (MoE), while 95 sample size was required for 95% confidence interval and 10% MoE. After excluding all invalid responses, we collected 80 valid responses, which could generate 93% confidence interval and 10% MoE. Although 10% MoE may be considered large, there was a barrier to increasing the sample size because (a) only homeowners who experienced at least minor wildfire damage to their houses in the past five years could participate in this survey, and (b) convenience sampling was used.

To enable participants to clearly understand the four possible damage states (i.e., none, minor damage, major damage, and destroyed) sustained by a house due to wildfire, a detailed information page describing

the damage states was provided at the beginning of the survey. The page presented the images of a house experiencing each damage state along with a detailed description as illustrated in Table 1. The online survey consisted of a set of closed-ended quantitative and qualitative questionnaires, including demographic information; property type and value; risk perception/attitude; previous experience with wildfire and other types of natural hazards; homeowners insurance policy; homeowner financial availability prior to and following a wildfire event, mortgage situation, and proactive actions taken at the time of the most recent wildfire event; and time to initiate and complete the recovery of their houses. Moreover, participants were encouraged to have their homeowners insurance policy document (the policies they held at the time when their properties were damaged by the most recent wildfire) at hand so that they could answer the questions related to their insurance policies, such as dwelling/content coverage limits and deductibles, additional living expenses (ALE) coverage limit, and annual insurance premium.

Table 1. Damage state description (Butte County GIS, 2021)

None	Minor	Major	Destroyed

Surrounding vegetation burnt; no-damage to structure	Nonstructural damage; minor structural damage	Extensive damage to structure; partially collapsed	Complete destruction

2.3. Statistical Analyses

The data were analyzed in two steps. First, to investigate the first research question, we assessed the effects of independent variables on homeowner decisions about two different types of proactive actions and identified the key variables that should be included in the logistic regression models. Then, to address the second research question, we constructed the quantitative relationship between homeowner proactive actions and variables related to the housing recovery process.

2.3.1. Regression Models for Proactive Actions

To identify key variables affecting homeowner decisions about each type of proactive action (i.e., individual-level risk reduction actions and homeowners insurance), we performed logistic regression analysis for each action based on the survey data. The independent variables considered at the initial step of estimating the regression models were the variables describing the characteristics of house/property and homeowners and are summarized in Table 2 and Appendix A. We first coded all these independent variables as dummy variables to analyze qualitative data such as categorical representation (e.g., house damage state, demographic information). As a homeowner had decided whether or not to take a certain type of proactive action before their properties were damaged by the most recent wildfire, a decision variable can take only two values, 1 (take action) or 0 (do not take action), which are mutually exclusive and collectively exhaustive. Thus, the probability (p) that an individual homeowner had taken a certain type of proactive action is expressed by the following logistic regression equation:

$$p = \frac{e^{\beta x}}{1 + e^{\beta x}} \quad (1)$$

in which β = the vector of coefficients for independent variables; and X = the vector of independent variables. Higher p indicates a higher probability that a homeowner had taken proactive action. The regression model for each proactive action was estimated using a backward stepwise regression approach. It began with all the independent variables and at each step gradually eliminated the least significant variables from the regression model until only statistically significant variables are left in the model. At each step, the Wald Chi-Square Test was used to select the variable that should be eliminated: the variable with a p -value greater than a 5% level of significance was eliminated. This process was repeated until all the remaining variables did not meet the specified level for elimination. The final model obtained from this approach was compared with the models with more independent variables (obtained from the previous steps) and was found to be the optimal one based on the Akaike Information Criterion (AIC) and/or Bayesian Information Criterion (BIC).

Table 2. Demographic characteristics and census data

Characteristics	Classes	Sample percentage	Census percentage
Gender	Male	60%	49.5%
	Female	40%	50.5%
Age (years)	18 – 29	22.50%	19.3%
	30 – 39	41.25%	17.4%
	40 – 49	21.25%	19.8%
	50 – older	15.00%	43.4%
Education	Less than high school degree	5%	17.7%
	High school degree or equivalent	35%	48.2%
	Associate degree	11.25%	8.3%
	Bachelor's degree	33.75%	16.6%
	Master's degree	13.75%	6.1%
	Professional degree	0%	1.9%
	PhD degree	1.25%	1%
Employment	Employed, working 1 – 39 hours per week	31.25%	26.7%
	Employed, working 40 or more hours per week	41.25%	36.2%
	Not employed or retired	27.5%	37.1%
Ethnicity	Caucasian	68.75%	72.3%
	Asian	6.25%	6.28%
	African American	6.75%	2.95%
	Native American/Hawaiian/Pacific Islander	8.75%	1.68%
	Others	9.5%	16.8%
Annual household income before taxes	Less than \$24,999	17.5%	20.5%
	\$25,000 to \$99,999	43.75%	52.5%
	\$100,000 to \$149,999	22.5%	15.0%
	\$150,000 to \$199,999	7.5%	6.3%
	Over \$200,000	8.75%	5.7%

First, logistic regression models were estimated for two types of individual-level risk reduction actions. The survey asked participants to indicate the types of individual-level risk reduction actions they took at the time when their properties were damaged by the most recent wildfire and then classified them into two categories: homeowners adopting home hardening (e.g., use of non-combustible or ignition-resistant siding and trim, installation of Class A fire-resistant roof assembly, installation of multi-pane windows or ideally tempered glass, installation of fire sprinklers) and homeowners designing and maintaining defensible space.

Hence, the dependent variables for the regression models were whether or not home hardening or defensible space was adopted at the time of the most recent wildfire.

A logistic regression model for homeowners insurance was also estimated, where the dependent variable was binary: a homeowner had purchased or had not purchased homeowners insurance prior to the most recent wildfire. However, as explained in Section 1, a binary logistic regression model for insurance purchase could be meaningful only if homeowners can fully decide whether to buy insurance based on their preferences. However, about 70% of U.S. households have a mortgage, and lenders require homeowners with a mortgage to insure houses to protect their investment. Consequently, these homeowners do not have much room to decide whether or not to purchase homeowners insurance. However, they may have more freedom to choose insurance coverage limits (although some lenders still have minimum requirements for dwelling coverage limits). Moreover, insurance coverage limit plays a critical role in estimating the financial availability of homeowners following a wildfire event. If a house is not fully insured, homeowners still experience financial hardship and tend to delay house repair until they obtain financing. In light of this, in addition to the binary logistic regression model for insurance purchase, homeowner decisions about insurance policy were also investigated. Homeowners insurance policy includes four types of coverage: dwelling, personal property, additional living expenses (ALE), and liability protection. The survey did not include any questions pertinent to liability protection because the study focused on structural damage to the house, attached structure, and personal property, and the associated economic losses. Dwelling coverage is the main component of homeowners insurance policy, and the other two coverages are often determined by the percentages of the selected dwelling coverage, such as 50% to 70% of dwelling coverage for personal property and 20% of dwelling coverage for ALE. Thus, only a linear regression model for dwelling coverage limit was estimated. The ordinary least squares approach was used to estimate unknown coefficients, and then a stepwise backward approach with t-tests was used to eliminate insignificant independent variables.

2.3.2. Quantitative Relationship between Proactive Actions and Housing Recovery

To quantitatively assess the impacts of individual-level wildfire risk reduction actions and homeowners insurance on the housing recovery processes, we examined the relationship between proactive actions and variables related to house damage and repair. First, we investigated how homeowner risk reduction actions taken prior to a wildfire event affected post-wildfire damage states. Four different groups of homeowners were considered as independent variables: homeowners without any risk reduction actions, with home hardening only, with defensible space only, and with both actions. The frequency distributions of house damage state (minor damage, major damage, and destroyed) for each group were constructed. In this study, the houses that had been already hardened before homeowners bought them were not considered because many homeowners were not likely to be aware of structural hardening adopted before they moved in.

We also assessed the effect of insurance on housing recovery by considering homeowner repairing decision, post-wildfire financial availability, and delay time as dependent variables. The participants were divided into three groups, including Group A (homeowners with full dwelling coverage limits), Group B (underinsured homeowners), and Group C (uninsured homeowners). Then, for these three groups, homeowner repairing decisions were compared. Moreover, several questions about homeowner post-wildfire financial situation were asked during the survey, including homeowner out-of-pocket expenses, financial hardship they experienced due to a wildfire event, and the most helpful financial source for them to recover from wildfire-induced damage. The relationships between independent variables (three groups of homeowners) and dependent variables were constructed. Lastly, in this study, delay time was defined as the time between wildfire containment and the initiation of the house repair/reconstruction process. It can be induced by many different impeding factors, such as post-disaster inspection; engineering mobilization and review/redesign; financing; contractor mobilization and bid process; and permitting (Zhao et al., 2020). Specifically, financing delay was calculated as the sum of the time required for homeowners to secure funding sources and the time due to delayed payments associated with insurance, loan, or government assistance. To estimate the total delay time, the survey question also asked participants about the time taken

to initiate their structural (house) repair/reconstruction process since the wildfire in the community had been contained. Then, we examined how delay time was impacted by insurance coverage limit.

3. Results and Discussions

The demographic characteristics of the sample are presented in Table 2. Sixty percent of the participants were male, and 40% of them were female. The age group between 30 and 39 years old comprised the highest proportion in the sample, and 68.75% of the respondents were Caucasian. The majority of the respondents (60%) attended college. At the time when their properties were damaged by the most recent wildfire, 72.5% of the respondents were employed, and 43.75% of the respondents reported an annual household income before taxes of \$25,000 to \$99,999, followed by \$100,000 to \$149,999 (22.5%) and less than \$24,999 (17.5%). Census demographic data (in percentage) are also summarized in Table 2. Although some deviations between sample data and census data are observed in several classes, they show similar distributions especially in employment, ethnicity, and annual household income classes, which implies the representativeness of the collected sample.

3.1. Key Factors Affecting Homeowner Proactive Actions

This subsection identifies independent variables that are likely to influence homeowner proactive actions for managing wildfire risks to answer the first question specified in Section 2.1.

3.1.1. Individual-Level Risk Reduction Actions

Based on the survey results, 65% of the respondents adopted home hardening, while 58.75% of the respondents adopted defensible space. As shown in Table 3, the key independent variables that affected decisions to adopt home hardening were homeowner age, household income, total wealth, and willingness to invest in individual-level wildfire risk mitigation actions. It should be noted that some of these actions (e.g., siding, asphalt roof shingles, dual pane windows) could have been taken for aesthetic purposes or simply to replace worn items. However, given that homeowner willingness to invest in wildfire risk mitigation actions was identified as one of the most statistically significant factors, the results implied that many homeowners took such actions to harden homes. Interestingly, homeowner age has a negative effect on home hardening decisions possibly because of the small sample size of older people (50 years or older). There was no significant evidence to claim that age was correlated with other key independent variables. Homeowner decisions about home hardening obtained from the survey were plotted against the simulated ones from the regression model in Fig.3. It showed 80% accuracy in estimating decision variables. The logistic regression results for defensible space are summarized in Table 4. Satisfaction with the surrounding environment (e.g., scenic beauty, proximity to recreation) was identified as the only variable that significantly affected homeowner decisions to design and maintain defensible space surrounding their homes. Seventy percent of the simulated results from the regression model for defensible space matched the survey results. As presented in Table 4, the variables describing the characteristics of homeowners and houses did not have any statistically significant impacts on homeowner decisions about defensible space. It can be interpreted that homeowners perceived defensible space as a proactive action to mitigate wildfire risks to the surrounding environment rather than a house itself, whereas home hardening was adopted to protect their houses from wildfires.

Table 3. Logistic regression results of homeowner decisions about home hardening (95% confidence interval)

Variable	Estimated coefficient	Wald chi-square	p-value
Intercept	0.5270	0.6111	0.5412
Age	-0.7946	-2.8978	0.0038
Homeowner willingness to invest in individual-level wildfire risk mitigation actions	0.7825	3.0941	0.0020

Household income	0.4100	-2.1754	0.0296
Homeowner total wealth	0.4382	2.5510	0.0107

Table 4. Logistic regression results of homeowner decisions about defensible space (95% confidence interval)

Variable	Estimated coefficient	Wald chi-square	p-value
Intercept	-1.2465	-1.9622	0.0497
Satisfaction with surrounding environment	0.5221	2.6573	0.0079

Fig.3 Comparison of homeowner decisions about home hardening between simulated and survey results

3.1.2. Homeowners Insurance

The survey data indicated that 80% of respondents had homeowners insurance in place at the time of wildfire. As presented in Table 5, the homeowner mortgage balance and neighbor proactive actions were identified to have statistically significant impacts on homeowner decisions about insurance purchase. Considering that homeowners with a mortgage were required to purchase homeowners insurance, the finding that positive mortgage balance was the most significant factor in this regression model was well-supported. While several studies revealed that risk reduction decisions and insurance decisions could be jointly determined (Meldrum et al., 2019), which is often referred to as moral hazard, the survey results did not support the claim that both actions were statistically dependent.

Table 5. Logistic regression results of homeowner decisions to purchase homeowners insurance

Variable	Estimated coefficient	Wald chi-square	p-value
Intercept	-1.0227	-1.5580	0.1192
Homeowner mortgage balance	0.8715	2.5757	0.0100
Neighbor proactive actions	1.4021	2.1651	0.0304

In addition, we also examined the independent variables that might affect homeowner decisions about insurance policy (more specifically dwelling coverage limits) through linear regression analyses. The results are summarized in Table 6. As expected, property value had the greatest impact on homeowner decisions about dwelling coverage limits because dwelling coverage limit is often proportional to property value. Interestingly, the other two independent variables (i.e., age and household income) in the regression model were also the key variables that were likely to affect homeowner decisions about home hardening (see Table 3). Given that the binary regression model for insurance purchase does not reflect homeowner

preference appropriately, homeowner age and household income can be considered the two most statistically significant factors affecting homeowner decisions to take proactive actions.

Table 6. Linear regression results of homeowner decisions about dwelling coverage limit (95% confidence interval)

Variable	Estimated coefficient	t	p-value
Intercept	-0.8940	-1.543	0.128
Age	0.4260	2.519	0.014
Property Value	0.5231	5.558	<0.001
Household income	0.2421	2.626	0.011

3.2. Effect of Proactive Actions on Post-Wildfire Housing Recovery

This subsection quantitatively assesses the impacts of pre-wildfire proactive actions on the post-wildfire housing recovery processes to answer the second question specified in Section 2.1.

3.2.1. Individual-Level Risk Reduction Actions

We assessed the effect of individual-level wildfire risk reduction actions on house damage state. Only 12.5% of the respondents did not take any pre-wildfire risk reduction actions (i.e., neither home hardening nor defensible space) at the time when their houses were affected by the most recent wildfire. As shown in Table 7, 60% of homeowners without any risk reduction actions experienced minor structural damage to their houses, while 40% of their houses were destroyed by a fire. The vast majority (87.5%) of respondents adopted at least one individual-level wildfire risk reduction action. More specifically, homeowners who adopted only fuel treatment in defensible space had similar house damage state distribution as those who did not adopt any mitigation actions. Minor structural damage comprised the highest proportion (56%), followed by destroyed (33%) and major damage (11%). Based on the results, it was not clear if designing and maintaining defensible space was effective in reducing wildfire damage to a house. It might be because defensible space reduces the chance of firebrand ignitions in the surrounding environment rather than mitigating wildfire consequences if a home has already ignited. Since homeowners who did not experience home ignition were screened out at the beginning of the survey, the reduced chance of ignition (i.e., the efficacy of defensible space) was not captured in the survey results. The result was also consistent with our interpretation that defensible space was perceived as a proactive action to mitigate wildfire risks to the surrounding environment rather than reducing house damage (see Section 3.1.1). On the other hand, homeowners who adopted only home hardening or both types of mitigation actions were less likely to experience destroyed damage state (i.e., 13% and 21%) compared to those who adopted only defensible space or none of these actions. Hence, it can be inferred from the results that home hardening could be a more effective action to reduce wildfire damage to a house.

Table 7. Frequency distributions of house damage states: with and without individual-level wildfire risk reduction actions

Mitigation actions	Minor damage	Major damage	Destroyed
Without mitigation (12.5%)	60%	0%	40%
Defensible space only (22.5%)	56%	11%	33%
House hardening only (28.75%)	65%	22%	13%
With both mitigation (36.25%)	67%	10%	21%

3.2.2. Homeowners Insurance

First, we examined the effect of insurance on homeowner repairing decisions. Among the three groups, Group B (underinsured homeowners) comprised the highest proportion of the participants, followed by Group A (homeowners with full dwelling coverage) and Group C (uninsured homeowners). Table 8 summarizes the repairing decisions of these three groups. While the damage state distributions of the three

groups were similar, Group C homeowners were much less likely to repair their houses especially when the houses were completely destroyed. It should be noted that it could be because Group C homeowners were more likely to be seasonal or second homeowners and were not willing to rebuild their homes that were not their primary residence. However, the result generally suggested that insurance could ensure homeowners to be financially secure following a wildfire event and helped them repair their houses. Hence, it can be expected that a community with a higher insurance take-up rate (and more homeowners having full coverage) would have a higher rate of housing repair after a wildfire event.

Table 8. Comparison of repairing decisions between three groups

Group	Damage state	Repair	No repair
Group A (28.75%)	Minor damage (65.2%)	80%	20%
	Major damage (26%)	100%	0%
	Destroyed (8.7%)	100%	0%
Group B (51.25%)	Minor damage (68.2%)	86%	14%
	Major damage (9.8%)	100%	0%
	Destroyed (22%)	56%	44%
Group C (20%)	Minor damage (60%)	63%	38%
	Destroyed (40%)	0%	100%

We also assessed the effect of homeowners insurance on the financial availability of homeowners following a wildfire event because their post-wildfire financial situation determines the financing delay time of the housing recovery process as well as repairing decisions. First, we estimated homeowner out-of-pocket expenses by measuring the difference between their estimated total wealth (including housing equity, vehicles, retirement, life insurance, fixed income investment, managed assets, common stock and mutual fund shares, liquid assets, farms, business equity in other real estates, and net worth) prior to and following a wildfire event. The out-of-pocket expenses of the three groups were compared in Fig.4(a). As expected, Group A experienced the least out-of-pocket expenses (\$23,913), which indicated that full dwelling coverage reduced the financial burden of Group A homeowners following a wildfire event. However, contrary to our expectation, the mean value of the out-of-pocket expenses of Group B (\$125,000) was much higher than the mean value of Group C (\$35,938). It may be because most of the homeowners in Group C decided not to repair their damaged houses due to lack of financial availability as shown in Table 8, and thus their out-of-pocket expenses could not necessarily reflect repair/reconstruction costs. On the other hand, a higher portion of the homeowners in Group B decided to repair their houses because they received payment from insurance companies. They still had to pay deductibles and the remaining repair/reconstruction costs that were not covered by homeowners insurance, which induced higher out-of-pocket expenses. Therefore, it would not be wise to conclude that homeowners insurance was not effective in reducing the financial burden of underinsured homeowners.

Fig.4 Comparison of financial situations between three groups

The effectiveness of homeowners insurance in post-wildfire financial situation was further supported by the survey results. Fifty percent of Groups A and B homeowners (who had either full or partial insurance coverage) indicated that insurance was the most helpful financial source for them to recover from the wildfire event, followed by loans (23.43%), government assistance (18.75%), and other sources (7.82%), while 62.5% of Group C homeowners reported government assistance as the most helpful financial source. Participants were also asked to answer a question about the type of financial hardship they experienced due to wildfire damage (e.g., mortgage default, mortgage forbearance, selling their properties, and huge loan or debt). As shown in Fig.4(b), only 25% of Group C homeowners responded that they did not experience any financial hardship after experiencing wildfire, while homeowners who did not report any financial hardship in Groups A and B were 43.5% and 31.7%, respectively. Moreover, Groups A and B homeowners answered that, on average, 75.38% of repair/reconstruction costs were covered by insurance. All these results supported the effectiveness of homeowners insurance in reducing post-wildfire homeowner financial burden.

Moreover, the effect of homeowners insurance on delay time (T_{delay}) was examined. The mean values of the delay time of Group A (8.1 months) and Group B (8.9 months) were longer than the mean value of Group C (6.8 months), which was contrary to our common belief. Since delay time was not only induced by lack of financing but also induced by other impending factors and only limited number of Group C homeowners repaired their damaged properties, this result might not be able to capture the effect of homeowners insurance on the delay time. In this regard, we further quantified the effect of different types of financial sources on financing delay time (which was defined as the time between claim application and payment). However, government financial aid showed a shorter delay time (3.05 months), followed by homeowners insurance (3.21 months) and loans (3.23 months). In conclusion, the findings of this study indicated that homeowners insurance did not reduce financing delay, while it encouraged homeowners to repair their damaged houses by relieving financial burden from repair/reconstruction costs.

4. Summary, Limitations, and Conclusions

This study conducted a post-wildfire online survey and statistical analysis of homeowners in multiple counties at high to extreme risk of wildfire in California and Washington to understand homeowner decisions on wildfire-related proactive actions and the effect of such actions on the housing recovery. The online survey was targeted at homeowners in these counties whose properties were damaged by wildfires in the past five years. The survey results revealed that homeowner age and household income were the common key independent variables affecting homeowner decisions about both home hardening and homeowners insurance, while the only key independent variable in the regression model for defensible space was satisfaction with the surrounding environment. Although the survey results indicated that home hardening was found to be more effective in reducing wildfire damage to a house than defensible space did, it would not be wise to generalize this conclusion due to the limited sample size. Moreover, the results clearly implied that the effect of homeowner insurance on post-wildfire financial availability was significant, and homeowners with higher coverage limits were more likely to repair their damaged properties. However, as contrary to our initial expectation that homeowners with full coverage might receive expedited claim payments that could speed up the housing recovery processes, its effect on reduced financing delay was not supported by the findings. The results from this study can provide guidance to federal/local government on (a) how to motivate homeowners to adopt proactive actions by identifying the key factors affecting homeowner decisions (i.e., the answer to the first research question in Section 2.1), and (b) how to effectively enhance community resilience by understanding the effect of proactive actions on housing recovery process (i.e., the answer to the second research question).

There are some limitations and room for improvement in this study that could be addressed in future research. First, to generalize the results, the sample size needs to be increased, and the collected sample should be able to reflect the general population. Post-wildfire reconnaissance surveys can also be conducted to quantify the effects of individual-level risk reduction actions on structural damage to houses, and in turn, the repair time of houses. These results will greatly complement the results obtained from the online survey

because the impact of defensible space on wildfire risks to house was not clearly quantified in this study. Moreover, based on our content validity, some respondents seemed to have difficulty quantifying their total wealth, property values, expenditures, economic losses, among others. Therefore, in-depth individual interviews with homeowners will also be helpful to provide sufficient information and guidance on such quantification processes to interviewees.

Appendix A. Independent variables that are likely to affect a homeowner decision to take proactive actions

Independent variable	Coded Representation	Frequency
Property type	Single family house = 1	66.25%
	Others = 0	33.75%
Property construction material	Wood frame = 1	62.50%
	Others = 0	37.50%
Property value	<\$49,999 = 1	13.75%
	\$50,000-\$99,999 = 2	8.75%
	\$100,000-\$199,999 = 3	15.00%
	\$200,000-\$299,999 = 4	11.25%
	\$300,000-\$399,999 = 5	12.50%
	\$400,000-\$499,999 = 6	7.50%
	\$500,000-\$749,999 = 7	17.50%
	\$750,000-\$999,999 = 8	8.75%
	\$1,000,000-\$1,499,999 = 9	3.75%
	>\$1,500,000 = 10	1.25%
Remaining mortgage balance	<\$49,999 = 1	38.75%
	\$50,000-\$99,999 = 2	18.75%
	\$100,000-\$199,999 = 3	16.25%
	\$200,000-\$299,999 = 4	7.50%
	\$300,000-\$399,999 = 5	11.25%
	\$400,000-\$499,999 = 6	5.00%
	\$500,000-\$749,999 = 7	2.50%
Personal belonging value	<\$24,999 = 1	17.50%
	\$25,000 - \$49,999 = 2	13.75%
	\$50,000 - \$74,999 = 3	16.25%
	\$75,000 - \$99,999 = 4	10.00%
	\$100,000 - \$149,999 = 5	18.75%
	\$150,000 - \$199,999 = 6	6.25%
	\$200,000 - \$249,999 = 7	6.25%
	\$250,000 - \$349,999 = 8	3.75%
	\$350,000 - \$499,999 = 9	2.50%
	\$500,000 - \$749,999 = 10	1.25%
	>\$750,000 = 11	3.75%
Surrounding satisfaction	Very dissatisfied = 1	11.25%
	Somewhat dissatisfied = 2	22.50%
	Neither satisfied nor dissatisfied = 3	27.50%
	Somewhat satisfied = 4	18.75%
	Very satisfied = 5	20.00%
Willingness to pay for individual-level risk reduction actions (\$/year)	<\$249 = 1	27.50%
	\$250-\$499 = 2	30.00%
	\$500-\$749 = 3	17.50%
	\$750-\$999 = 4	5.00%

	\$1,000-\$1,499 = 5	12.50%
	\$1,500-\$1,999 = 6	3.75%
	>\$2,000 = 7	3.75%
Willingness to pay for community-level risk reduction actions (\$/year)	<\$249 = 1	25.00%
	\$250-\$499 = 2	30.00%
	\$500-\$749 = 3	11.25%
	\$750-\$999 = 4	18.75%
	\$1,000-\$1,499 = 5	8.75%
	\$1,500-\$1,999 = 6	3.75%
	>\$2,000 = 7	2.50%
Whether neighbors adopted mitigation actions	Yes = 1	60.00%
	No = 0	40.00%
Willingness to invest in individual- and/or community-level risk reduction actions	None = 1	17.50%
	Only one type of the actions = 2	40.00%
	Both types of the actions = 3	42.50%
Total wealth before a wildfire event	<\$ 49,999 = 1	22.50%
	\$50,000 - \$99,999 = 2	10.00%
	\$100,000 - \$199,999 = 3	18.75%
	\$200,000 - \$299,999 = 4	12.50%
	\$300,000 - \$399,999 = 5	2.50%
	\$400,000 - \$499,999 = 6	7.50%
	\$500,000 - \$749,999 = 7	10.00%
	\$750,000 - \$999,999 = 8	5.00%
	\$1,000,000 - \$1,499,999 = 9	6.25%
	\$1,500,000 - \$1,999,999 = 10	3.75%
	\$2,000,000 - \$2,999,999 = 11	0.00%
	>\$ 3,000,000 = 12	1.25%
Homeowner perceived probability that wildfire will occur in his/her community in the next 5 years	0% = 1	2.50%
	0%-1% = 2	1.25%
	1% - 4% = 3	2.50%
	5% - 9% = 4	2.50%
	10% - 19% = 5	12.50%
	20% - 39% = 6	13.75%
	40% - 59% = 7	22.50%
	60% - 79% = 8	17.50%
	80% - 100% = 9	22.50%
Homeowner perceived probability that his/her property will be damaged by a wildfire event	Highly unlikely = 1	3.75%
	Unlikely = 2	6.25%
	Neither likely nor unlikely = 3	35.00%
	Likely = 4	43.75%
	Highly likely = 5	11.25%
Homeowner self-assessment of preparedness for wildfire	1 (poorly prepared to take risk)	15.00%
	2	15.00%
	3	32.50%
	4	23.75%
	5 (well prepared to take risk)	13.75%
Entity who is responsible for paying for wildfire damage to house	Primarily government = 1	8.75%
	Government > Homeowner = 2	12.50%
	Government = Homeowner = 3	18.75%
	Government < Homeowner = 4	23.75%

	Primarily homeowner = 5	36.25%
Past experience with natural hazards	Yes = 1	78.75%
	No = 0	21.25%

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Statements and Declarations

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