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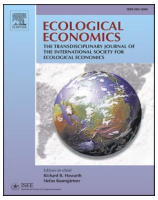

Rethinking cost-share programs in consideration of economic equity: A case study of wildfire risk mitigation assistance for private landowners

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ABSTRACT

Public agencies and organizations often deliver financial assistance through cost sharing, in which recipients contribute some portion toward total costs. However, cost sharing might raise equity concerns if it reduces participation among populations with lower incomes. Here, we revisit a past study using a richer dataset (n=1,689) to assess whether stated income levels affect survey respondents' willingness to participate in a cost share program for vegetation reduction to mitigate wildfire risk in western Colorado. Results show that residents with lower incomes are less likely to participate even though they can choose to contribute 0% toward a cost share. Residents reporting incomes less than $50,000 are 11 percentage points less likely to participate than those reporting incomes of $200,000 or more. They also are willing to pay a lower share (26 percentage points less) if they do participate. Results indicate potential economic equity concerns from the use of such programs.

1. Introduction

Populations with lower socioeconomic status may be particularly exposed and vulnerable to wildfire hazards (e.g., Cutter et al., 2003; Fothergill and Peek, 2004; Wigtil et al., 2016; Davies et al., 2018; Paleologou et al., 2019; Masri et al., 2021). Mitigation of wildfire risk on private property is a socially desirable behavior that provides an opportunity to reduce the direct (e.g., losing a home) and indirect (e.g., wildfire smoke exposure) effects of a wildfire on vulnerable populations. In the United States (U.S.), financial incentives are often used to encourage environmental and socially desirable behaviors. Examples include direct payments, e.g., Conservation Reserve Program, government-backed insurance, e.g., National Flood Insurance Program's voluntary Community Rating System for incentivizing community floodplain management, and tax deductions for easements that preserve undeveloped land. When individual behaviors have both private and public benefits, financial incentives often require cost sharing, in which funding is contingent on some level of financial match from the recipient.

However, many government entities are sensitive to equity considerations. For example, the U.S. Department of Agriculture (USDA) Forest Service recently reduced requirements for cash contributions (i.e., cost sharing) in partnership agreements, referencing U.S. Executive Order 13985 (Advancing Racial Equity and Support for Underserved Communities Through the Federal Government Biden, 2021) as motivation. The Forest Service prioritizes low-income communities for its Community Wildfire Defense Grant Program (https://www.fs.usda.gov/managing-land/fire/grants; accessed Jul. 14, 2023), and the National Oceanic and Atmospheric Administration recently incorporated census tract information into their Billion-Dollar Disaster mapping tool to foster decision-making that attends to socio-economic vulnerability (National Centers for Environmental Information, 2022). More generally, environmental justice concerns arise when public programs might lead to disproportionate adverse human health or environmental effects for low-income populations (Mohai et al., 2009; Department of the Interior, 2021).

Here, we investigate potential equity implications of using a cost-share incentive for funding wildfire hazard mitigation on private

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property. Such programs play an important role in the U.S.' National Cohesive Wildland Fire Strategy, which notes the importance of defensible space, vegetation reduction on private lands, and assistance to communities in becoming more fire adapted (The National Strategy, 2014). We analyze the potential effect of income on stated willingness to participate in a cost-share program for wildfire risk mitigation on private property, revisiting a previous study (Meldrum et al., 2014) with a larger dataset assembled from six projects following a similar approach. The cost-share program described is similar to those offered by many organizations around the western U.S. Our larger sample allows replication, to test the generalizability of the original study's results, while also providing greater resolution on heterogeneity of responses. Beyond general arguments for replication in economics and social science (e.g., Maniadis et al., 2014; Camerer et al., 2018), investigation of generalizability is important here given widespread demonstration of variation in the human dimensions of wildfire risk across study sites (e.g., Canadas et al., 2016; Meldrum et al., 2018; Paveglio, 2021). Further, richer investigation of heterogeneity enables us to ask new questions about variation in participation that could have implications for the equitable design of publicly funded risk mitigation programs.

2. Background

In this section, we review relevant literature to provide a broad context for the consideration of equity in natural hazards, particularly wildland fire. Our focus on economic equity in wildfire risk mitigation programs is motivated in part by recognition of how social vulnerability often correlates to differential risks from natural hazards. Socioeconomic status can differentiate experiences through all stages of a disaster (Fothergill and Peek, 2004). Social vulnerability describes how social inequalities, in terms of characteristics such as income, age, race, and employment, are often associated with increased exposure and vulnerability, and decreased adaptative capacity, to natural hazards (Cutter et al., 2003).

Exposure to hazards, i.e., the intersection of a natural hazard with people or valued assets, sometimes correlates with differences in socioeconomic status. In the context of wildfire, high exposure tends to be related to lower social vulnerability *on average* (Davies et al., 2018; Paveglio et al., 2018; Wigtil et al., 2016; Wibbenmeyer and Robertson, 2022), but averages do not tell the full story. Out of 131 million homes in the contiguous U.S., Wigtil et al. (2016) categorized about 372,000 as having both high social vulnerability and high wildfire potential. Davies et al. (2018) found that 12 million out of the 29 million people living in areas of the U.S. with modeled potential for extreme wildfires were socially vulnerable. Palaiologou et al. (2019) likewise found that areas with high social vulnerability faced disproportionately higher exposure to wildfire, based on fire behavior simulations. Census tracts in California with higher fire frequencies or more cumulative burned area between 2000 and 2020 had lower median incomes and lower median home values compared to other Census tracts (Masri et al., 2021). The most socially vulnerable counties in the U.S., as measured by poverty, income, and other community health factors, experienced higher smoke exposures than other counties between 2008 and 2012 (Rappold et al., 2017). Similarly, Liu et al. (2017) used Medicare enrollments in the western U.S to find that areas with higher poverty rates faced higher exposure to wildfire smoke between 2004 and 2009.

Populations with lower socioeconomic status may also be more vulnerable to wildfire hazards. Paveglio et al. (2018) found that sensitivity to wildfire increased with higher incomes, with sensitivity defined as a function of the value of structures at risk. However, one reason environmental phenomena become disasters is that less affluent people have less access to resources to help deal with natural hazards (Poudyal et al., 2012; Wisner et al., 2004). Those with fewer financial resources might be more vulnerable because of inadequate housing, constraints on evacuation, and less property insurance (Fothergill and Peek, 2004). Collins (2008) noted the difference between affluent populations and others as leading to "cascading patterns of hazard vulnerability within communities," (p. 26) in which the latter tend to have more to lose from wildfire, on a relative basis, while the affluent can externalize losses incurred from wildfire with property insurance. Chase and Hansen (2021) found low-income and uninsured property owners and renters more likely to be neglected by recovery efforts and at higher risk of facing homelessness following the 2021 Camp Fire. Mendez et al. (2020) similarly noted that, from the 2017 Thomas Fire, low-income, undocumented immigrants faced increased exposure to smoke due to farmworker occupations, being overlooked in the provision of emergency response information, and being excluded from certain recovery and relief efforts. Further, some studies have found higher vulnerability to wildfire smoke, in terms of negative health outcomes, among people with lower incomes (Reid et al., 2016; Rappold et al., 2012). However, while some studies have also found that communities with lower incomes and higher social vulnerability are exposed to more prescribed burns – and the associated smoke – than other communities, evidence is mixed regarding whether that translates into disparate health effects (Afrin and Garcia-Menendez, 2021; Kondo et al., 2022).

Populations with lower incomes tend to have lower adaptive capacity to hazards, in terms of less ability to absorb and recover from losses through the help of social safety nets, insurance, and entitlement programs compared to populations with higher incomes (Cutter et al., 2003). Areas with high social vulnerability or lower incomes tend to receive relatively low levels of short-term post-disaster assistance (Kamel, 2012; Emrich et al., 2019; Drakes et al., 2021). At the county level, Mercer and Prestemon (2005) found that Florida counties with higher poverty rates had fewer wildfire ignitions yet faced higher wildfire acreage and intensity, compared to more affluent counties, suggesting a negative impact from having fewer local resources available to respond to wildfires.

Adaptive capacity also pertains to the ability to mitigate risks before a hazard event occurs. Community Wildfire Protection Plans (CWPPs) and Firewise USA® programs are two mechanisms for communities to plan for and encourage reducing wildfire risk that often require internal resources and self-organization. Gaither et al. (2011) found that communities in the southeastern U.S. with high risk and high social vulnerability were less involved with developing CWPPs and Firewise USA® programs compared to more affluent high-risk communities, despite similar levels of awareness of risk. Ojerio et al. (2011) similarly found that communities with higher social vulnerability in Arizona were less likely to participate in wildfire risk mitigation activities such as CWPPs, Firewise USA® programs, and State Fire Assistance grants, holding biophysical wildfire hazard constant. However, not all studies agree about the relationship between social vulnerability and participation. For example, Palsa et al. (2022) did not find evidence that social vulnerability predicted either participation or participant diversity in an analysis of more than 1000 CWPPs from across the western U.S.

Evidence is also mixed regarding whether the location of federal mitigation programs varies with the socioeconomics of nearby communities. One recent working paper found that wealthier, whiter, and more educated communities were more likely to receive fuel treatments on nearby federally managed lands than other communities (Anderson et al., 2022). In contrast, another study found no disproportionate benefits from hazardous fuels reduction in the western U.S. across differences in social vulnerability, although a lack of consideration of environmental justice in planning was found to create unintended, localized hotspots of vulnerable populations not receiving equal benefits (Adams and Charnley, 2020). As noted above, some studies have found higher social vulnerability to correlate with more nearby prescribed burning (Afrin and Garcia-Menendez, 2021; Kondo et al., 2022); although these results indicate potential disparate exposure to smoke, they also might indicate that areas with lower incomes receive higher benefits from prescribed burns to the extent that proximity mitigates the overall risk of wildfire.

At the individual level, lower levels of preparedness for natural

hazards, including risk mitigation actions, are generally associated with a lack of resources among other factors (Fothergill and Peek, 2004). While financial assistance programs are often intended to overcome this barrier, some evidence indicates that financial assistance delivered through cost-share programs may be less effective for reaching lower income residents. Collins and Bolin (2009) interviewed 33 residents of Arizona's White Mountains and found that lower income residents did not participate in cost-share programs to reduce wildfire risk because the partial matches offered were insufficient for making mitigation financially attainable. A few stated preference studies have investigated the role of income and other demographic characteristics on willingness to pay for various approaches to wildfire risk reduction, and with the exception of one earlier study (Loomis et al., 2009), these consistently have found that willingness to pay for mitigation increases with income levels (Fried et al., 2000; Winter and Fried, 2001; Walker et al., 2007; Meldrum et al., 2014; González-Cabán and Sánchez, 2017; Sánchez et al., 2022).

The interpretation of these studies for consideration of economic equity is limited by an inability to separate the decision to participate in a program from the amount one is willing (or able) to pay toward that program. This distinction is critical for understanding whether any observed limits to participation relate to perceived insufficiency of the amount of cost-share funding offered versus other, not necessarily financial, barriers. Although economic theory predicts increasing willingness to pay with higher incomes, one might expect that interest in participation – if isolated from the amount paid toward a program – would be highest among those with lowest incomes and therefore the likely highest need for financial support. Only two studies (Winter and Fried, 2001; Meldrum et al., 2014) in the wildfire risk context simultaneously yet separately considered the two decisions: how much to contribute to a cost-share program and whether to participate in the cost-share program at all. Winter and Fried (2001) surveyed Michigan residents in 1994 and 1996 and estimated the participation decision based on responses to an open-ended willingness to pay question of "$0," with results showing positive income effects on both participation and willingness to pay. Meldrum et al. (2014) is unique in that respondents were asked two separate questions, thus allowing respondents to state they would participate in the program but are unwilling to pay the minimum proposed amount in an incentive-compatible dichotomous choice response format. The present study contributes to this understudied issue and builds on Meldrum et al. (2014) in leveraging a relatively large sample size from across multiple study sites, allowing for deeper and more generalizable investigation of influences on participation in cost share programs for wildfire risk mitigation.

3. Materials and methods

3.1. Study context and data collection

This study revisits an investigation of willingness to participate and willingness to pay for cost-shared wildfire risk mitigation on private property conducted by the Wildfire Research (WiRē) Team in partnership with West Region Wildfire Council (WRWC) in Ouray County, Colorado in 2012 (Meldrum et al., 2014). WRWC is a nonprofit organization that promotes wildfire preparedness, prevention, and mitigation education throughout six Colorado counties (see https://www.cowildfire.org). The WiRē Team is a long-running collaboration among wildfire risk mitigation practitioners and researchers that works with organizations like WRWC to collect data to inform their efforts to reduce wildfire risk to homes and communities at actionable scales (Champ et al., 2021).

In 2017, WRWC repeated data collection in the communities covered by the 2012 data. This present paper analyzes the more recent data for these communities along with data for other locations collected by WRWC and another organization, FireWise of Southwest Colorado (FWSC) (now known as Wildfire Adapted Partnerships), in six separate projects in western Colorado from 2013 to 2017. Combined, these six projects focus on all residential homes within each of 95 practitioner-selected communities that are dispersed throughout twelve different fire protection districts (FPDs) in six western Colorado counties (Archuleta, Delta, La Plata, Montezuma, Ouray, and San Miguel) (Fig. 1). Although definition of a "community" can and does vary, most of these communities are either clearly defined by local geography or else named as subdivisions within county assessor records. In consultation with the WiRē Team, partners used varied criteria for selecting communities to study; typical factors are that partners perceived the communities as facing significant wildfire risks and thus that partners had a particular interest in increasing engagement with the residents of these communities. Previous analysis has demonstrated otherwise significant variation across these communities in many related variables, including basic demographics, residents' expectations about the outcomes of wildfire, and both resident-reported and professional-observed preparation and mitigation for wildfire (Meldrum et al., 2018).

The WiRē Team supports partners such as WRWC and FWSC in implementing a systematic data collection and integration approach for all residential properties within selected communities. After collaborating on selecting focal communities for a given project, the WiRē Team supports the partner in conducting a parcel-level rapid wildfire risk assessment. Over time, the WiRē Team has adapted the rapid wildfire risk assessment to reflect the latest wildfire science; for the projects analyzed here, either ten or eleven attributes related to defensible space, structural hardening, property access, and localized wildfire hazards were measured by a trained professional and aggregated via weighted sum into an overall parcel-specific risk rating (see Meldrum et al., 2022 for more details). This parcel-specific risk rating provides a snapshot of relative wildfire risk at the time of the assessment, and it reflects a combination of factors both within and outside of the property owner's control.

The WiRē Team also supports the partner in administering a household survey to all assessed properties using a modified Dillman approach (Dillman, 2000) that includes an introductory letter, mailed paper surveys with postage-paid return envelopes, and follow-up mailings of additional paper surveys and postcard reminders. Household surveys are adapted to address partners' specific priorities and information needs while also maintaining consistency across projects. The surveys include a series of question batteries that address residents' attitudes toward wildfire risk and its management, perceived wildfire risks and barriers toward addressing those risks on respondents' property, preferred information sources, basic demographics, and other related content.

After removing non-deliverable addresses, surveys were sent to the address on record for 5750 residences across the six projects providing data here. Of these, 2408 surveys were returned for an overall response rate of 41.9%. Trimming for item non-response on key variables for this analysis, which include questions on income and other potentially sensitive demographic data, leaves 1689 useable responses (29.4% of surveys sent). Surveys were sent concurrently to all residences within a study community, and mailings occurred within from one to nine months of the rapid assessment, with timelines driven by project partners' capacity and related concerns. This time delay may introduce some measurement error in wildfire risk ratings when matched to survey data if risk changed in the intervening period. More details on data collection processes and complete summary results are available in a series of project-specific research notes (Brenkert-Smith et al., 2019a, 2019b; Donovan et al., 2022; Meldrum et al., 2019; Meldrum et al., 2017; Meldrum et al., 2015); we include the subset of questions providing data for the present study in the Appendix Exhibit A.1.

Variation across the study area is pronounced. Communities were selected for inclusion in the original studies by practitioners not to be representative of broader geographies but rather to meet their programs' information needs. Studied communities vary in many ways, including exposure to wildfire hazards, fire protection and related

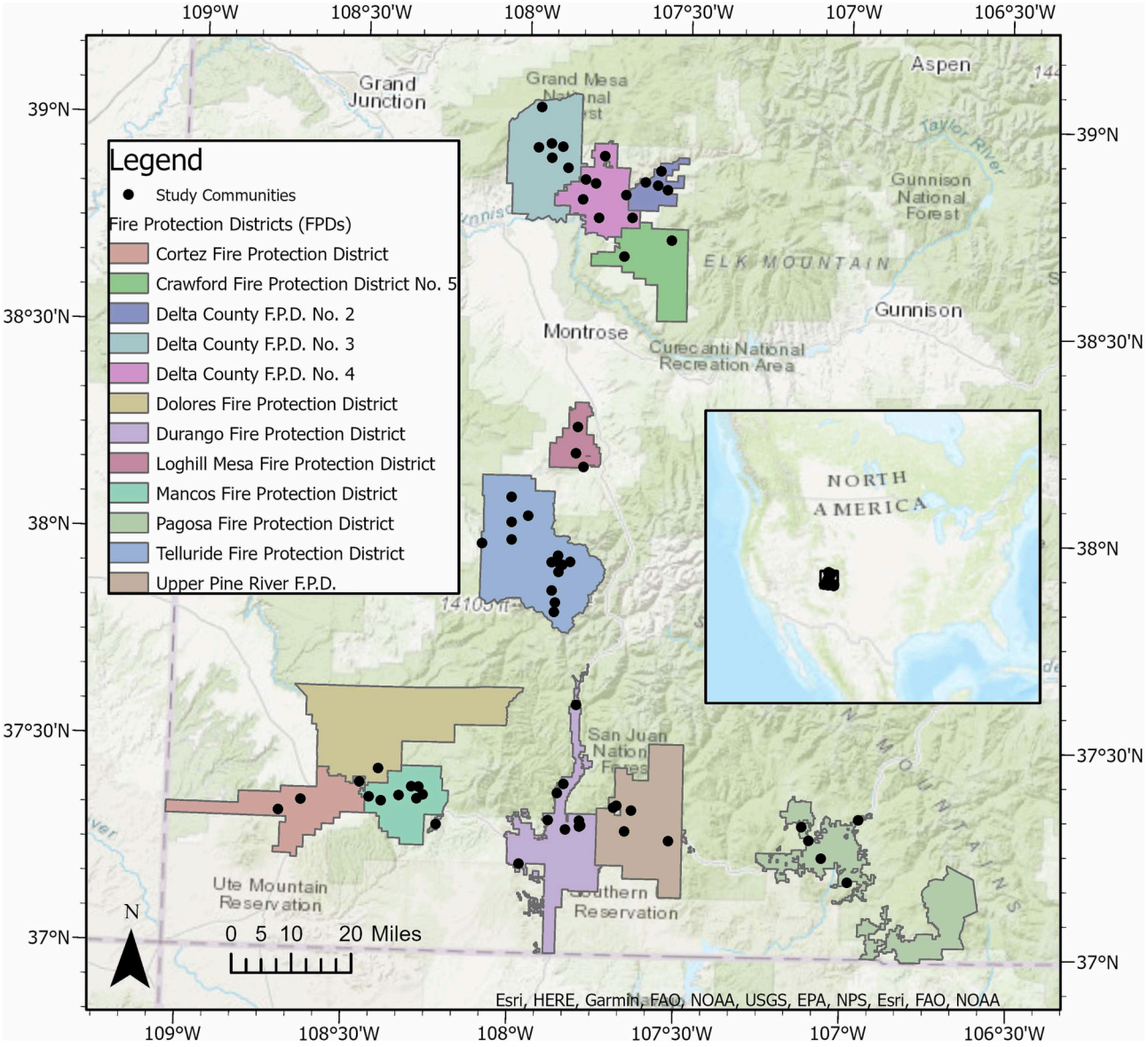

Fig. 1. Map showing location of study communities and the fire protection districts (FPDs) to which they belong. Inset map shows study location within North America. Map image is the intellectual property of Esri and is used herein under license. Copyright © 2020 Esri and its licensors. All rights reserved. [color for online only].

capacities, existing levels of parcel- or community-level mitigation, and existing wildfire education and outreach programs. Included communities are often small, with between 1 and 125 observations available per community. General wildfire hazards as well as information and resources regarding wildfire risk, which are often managed at the FPD level, are likely relatively consistent across the communities within a given FPD. Finally, data collection procedures were consistent across all observations within any given FPD.

3.2. Data

This study focuses on variables describing self-reported incomes, parcel-level wildfire risk, perceived barriers to wildfire risk mitigation, and willingness to participate in and pay toward a cost share mitigation program. Table 1 shows relevant descriptive statistics for the observations within this study, organized by self-reported income levels. Survey respondents chose among nine income brackets (see Table A.1 in the Appendix), which we collapse to the five levels shown. Incomes range widely; 399 respondents (24%) report incomes of less than $50,000 whereas 325 (19%) report incomes of $200,000 or higher. The most common income level is $50,000 to $99,999, with 561 (33%) of all respondents. In 15 of the 95 communities, at least 50% of respondents report incomes less than $50,000, whereas in 19 communities, at least 50% of respondents report incomes of $200,000 or more. Most survey respondents (97%) own their properties; by income, that ranges from 95% for the lowest income bracket to 98% for the highest income bracket.

The first panel of Table 1 shows overall parcel-level wildfire risk levels, as assessed by wildfire professionals as part of the approach described above. Most properties are rated as either High (30%) or Very High (33%) risk. Respondents with higher incomes are less likely to have properties with wildfire risks rated as Low, Moderate, or High risks, and more likely to have properties with Extreme wildfire risk. The second panel of Table 1 shows basic demographics; respondents with lower incomes are slightly older on average and are more likely to be retired versus those with higher incomes. Higher income respondents are much more likely to have completed college than those with lower incomes, although college completion is still common (53%) even among

Table 1
Descriptive statistics for parcel-level wildfire risk, select self-reported demographic variables, barriers for not reducing wildfire risk on one's property, and responses to two questions about a cost share program for vegetation reduction, as reported by all respondents in the study communities in western Colorado. Responses presented by self-reported income bracket. Percentages for risk levels report the distribution of parcel-level wildfire risk levels (rows) across respondents within each income bracket (column). All measures except for "Mitigation barrier: perceived effectiveness" and "Mitigation barrier: visual effects of mitigation" are significantly different ($p \leq 0.005$) across income levels according to Kruskal-Wallis tests for "Age" and "Willingness to pay…" and Pearson χ^2 tests for all other measures.

	Less than $50,000 ($n = 399$)	$50,000 to $99,999 ($n = 561$)	$100,000 to $149,999 ($n = 274$)	$150,000 to $199,999 ($n = 130$)	$200,000 or more ($n = 325$)	Overall ($n = 1689$)
Overall percentage	24%	33%	16%	8%	19%	100%
Low risk	16%	13%	12%	10%	5%	12%
Moderate risk	8%	5%	6%	5%	5%	6%
High risk	35%	33%	31%	25%	22%	30%
Very high risk	29%	34%	36%	38%	34%	33%
Extreme risk	13%	15%	15%	22%	34%	19%
College graduate	53%	70%	82%	90%	92%	74%
Retired	55%	47%	46%	40%	32%	45%
Age (years)	63.8	61.9	61.7	60.6	60.0	61.9
Mitigation barrier: financial cost	44%	32%	27%	21%	13%	29%
Mitigation barrier: time	33%	25%	27%	26%	20%	26%
Mitigation barrier: physical difficulty	48%	35%	36%	33%	21%	35%
Mitigation barrier: specific information about how to reduce risk	25%	25%	25%	19%	45%	28%
Mitigation barrier: perceived effectiveness	17%	13%	15%	12%	18%	15%
Mitigation barrier: visual effects of mitigation	20%	19%	24%	23%	25%	22%
Mitigation barrier: options for slash removal	24%	23%	25%	25%	38%	27%
Would participate in cost share program for vegetation reduction on own property	68%	72%	74%	80%	81%	74%
Willingness to pay toward cost share as percentage of stated overall cost	32%	41%	51%	48%	66%	47%

respondents with the lowest reported incomes.

The third panel of Table 1 reports the percentage of respondents who indicated "yes," the listed factor acts as a barrier to conducting wildfire risk mitigation on their own properties. The proportion of respondents responding "yes" ranges from 15% to 35% across different potential barriers, with the fewest reporting perceived effectiveness and the most reporting physical difficulty. Fewer than one-third of respondents (29%) report financial cost as a reason they do not conduct mitigation on their own property. Most reported barriers, with the exceptions of perceived effectiveness and visual effects of mitigation, vary significantly across reported income levels (Pearson χ^2 test $p \leq 0.005$). Respondents with lower incomes are more likely to report financial cost, time, or physical difficulties, although even for the lowest income group, financial cost is reported as a barrier by less than half (44%) of respondents. In contrast, respondents in the highest income bracket are substantially more likely than others to report a lack of specific information about how to reduce risk on one's property and a lack of known options for removal of vegetative material (i.e., "slash") after conducting mitigation.

Finally, the surveys asked about participation in a cost-share program for reducing vegetation near the home. One question asked about willingness to participate: "While costs vary with the features of a property, such as density and location of the trees, local contractors charge about $[estimate] to reduce dense vegetation around the typical residence in [location]. If grants were available to help pay for the cost of thinning vegetation near your [location] residence, would you participate in the program?" The cost "estimate" depended on location; three of the studies listed $1000 and three listed $2000, based on partner organizations' expectations. Of those respondents who answered "yes" to participation, the surveys then asked about willingness to pay: "Assuming that the $[estimate] estimate is accurate for your [location] residence, what is the highest amount that you would be willing to pay to have a contractor remove vegetation near your home?" Respondents answered by circling their choice on a payment card format that explicitly listed both the amount they would pay and the corresponding amount the grant would pay, with the two summing to [estimate]. The fourth panel of Table 1 reports responses to these two questions. About three-quarters of respondents (74%) agreed they would participate in the cost-share program, ranging from a low of 68% of those in the lowest income bracket to 80% and 81% of those in the two highest-income brackets, respectively. Among those who would participate, the average willingness to pay toward a cost share ranged from 32% of the stated overall cost for respondents with lowest incomes to 66% for respondents with highest reported incomes.

3.3. Empirical analysis

Our analysis focuses on further understanding the answers to the two questions asked in the household surveys regarding willingness to participate and to pay for vegetation reduction through a cost-share program. Although the decisions for participation and for supported payment level are potentially related, they also are separable decisions, particularly when the hypothetical willingness to pay options include 0% and 100% funding from the cost share. Accordingly, the original study on which we build our approach (Meldrum et al., 2014) estimated responses to those two questions with a joint two-equation model that allows for separate but correlated decisions. Here, we replicate the same basic approach by estimating a logistic regression (logit) model for the participation decision and an interval regression model for willingness to pay, with both models specified as a function of parcel-level overall wildfire risk rating, demographic data, and perceived barriers to mitigation (see Meldrum et al., 2014 for details). In contrast to the original study, here we report the two models separately after estimating a joint version of our preferred models and finding no meaningful correlation in the error terms (-0.025 with standard error of 0.125; $p = 0.843$). That is, we find no evidence to support a joint specification for our full model with the present dataset.

We further modify the model presented by Meldrum et al. (2014) to accommodate the larger and multi-site dataset available for analysis here. Whereas the original study estimated willingness to pay in dollar terms, here we estimate willingness to pay as a percentage of the cost estimate to accommodate the variation in the estimate provided in different study sites. The original study transformed reported income data from a nonlinear set of nine categories into a continuous measure that represented the natural log of the midpoint of each category; we now include a set of five indicator variables for reported incomes to relax assumptions about functional form. This allows us to observe

different proportional effects among levels, such as stronger possible effects at lower income levels versus other income levels. We include as potential explanatory variables a set of full indicator variables for barriers that respondents report as keeping them from "undertaking actions to reduce wildfire risk on your property," allowing observation of the effects of individual barriers on decisions about the cost-share, whereas the previous study used factor scores for stated barriers to reduce the dimensionality of related data at the cost of some loss of information. We also now include an indicator variable for whether respondents report having graduated from college. Finally, we cluster standard errors at the community level to account for potential unobserved correlation among observations within a community. Fixed effects were considered but omitted based on results of Hausman tests. We estimate all models in Stata/SE 16.0[2] using the *logit*, *eintreg*, and *margins* commands. Full model specification is provided in Table A.2 the Appendix.

4. Results

4.1. Willingness to participate

We first consider the decision to participate in the cost-share program, independent of willingness to pay. Motivated by the potential for equity concerns related to those presented in the introduction, we estimate a simplified model that includes only respondents' income levels and their properties' overall wildfire risk ratings (Model 1), as well as a richer model that further includes household survey results on barriers to mitigation and whether respondents graduated from college (Model 2). As shown in Table 2, Akaike information criterion (AIC) and Bayesian information criterion (BIC) statistics indicate that Model 2, estimated with the full set of potential variables, is preferred. Coefficients for overall parcel-level wildfire risk rating are jointly significant in both models, as are coefficients for income in Model 2, with odds ratios generally increasing for higher risk ratings or incomes. All self-reported barriers other than time were significant and in the expected directions. Specifically, respondents who do not conduct mitigation because they do not perceive it as effective or to avoid its visual effects are less likely to participate in the cost-share program, whereas those constrained by financial costs, the physical difficulty, or a lack of specific information about effective risk reduction activities are more likely to participate. College graduates are also more likely to participate.[3]

Next, we calculate the average marginal effects of self-reported income bracket on participation (Fig. 2) based on the results of the preferred Model 2. Participation increases with higher self-reported incomes, with respondents reporting incomes of $150,000 or more being about 11 percentage points more likely to participate (78% chance, with 95% confidence interval from 73% to 84%) than those with incomes below $50,000 (68% chance, with 95% confidence interval from 64% to 72%). Table A.3 and Fig. A.1 in the Appendix suggest this result is driven primarily by respondents in the lowest (less than $15,000) and the highest two ($150,000 to $199,999 and $200,000 or more) original income brackets from the household survey, with average marginal effects from the lowest to highest income bracket of more than 25 percentage points. Further, Fig. A.2 in the Appendix shows the predicted probability of participation by self-reported income bracket separated by overall parcel-level wildfire risk rating. Predicted probability of participation increases as parcel-level wildfire risk ratings increase, and the income effect is apparent within all risk rating levels.

Table 2
Odds ratios estimated for logit models for willingness to participate as a function of data for survey respondents in select western Colorado communities. Cluster-robust standard errors (std. err.) for 95 communities shown. Joint χ-squared test p-values shown for overall parcel-level wildfire risk rating and income. Adjustment for multiple comparisons (Benjamini and Hochberg, 1995) indicates that all p-values of $p = 0.006$ or less for Model 1 and $p = 0.058$ or less for Model 2 are significant with an assumed 10% false discovery rate. AIC = Akaike information criterion, BIC = Bayesian information criterion.

	Model 1			Model 2		
Logit model; y = 1 if willing to participate, = 0 otherwise	Odds Ratio	Robust Std.Err.	p-value	Odds Ratio	Robust Std.Err.	p-value
Overall parcel-level wildfire risk rating	joint test $p < 0.001$			joint test $p < 0.001$		
Low risk	[base]			[base]		
Moderate risk	2.037	0.440	0.001	1.671	0.366	0.019
High risk	1.814	0.268	<0.001	1.795	0.322	0.001
Very high risk	2.640	0.443	<0.001	2.315	0.471	<0.001
Extreme risk	3.175	0.664	<0.001	2.789	0.661	<0.001
Income level	joint test $p = 0.084$			joint test $p = 0.034$		
Less than $50,000	[base]			[base]		
$50,000 to $99,999	1.134	0.153	0.351	1.252	0.193	0.146
$100,000 to $149,999	1.254	0.206	0.167	1.374	0.230	0.058
$150,000 to $199,999	1.671	0.470	0.068	1.955	0.575	0.023
$200,000 or more	1.624	0.286	0.006	1.880	0.385	0.002
College graduate	–			1.830	0.263	<0.001
Mitigation barrier: financial cost	–			3.032	0.590	<0.001
Mitigation barrier: time	–			1.125	0.195	0.497
Mitigation barrier: physical difficulty	–			1.750	0.206	<0.001
Mitigation barrier: specific information about how to reduce risk	–			1.808	0.407	0.009
Mitigation barrier: perceived effectiveness	–			0.460	0.079	<0.001
Mitigation barrier: visual effects of mitigation	–			0.659	0.075	0.001
Mitigation barrier: options for slash removal	–			1.603	0.313	0.016
Constant	1.103	0.178	0.544	0.441	0.080	<0.001
n	1689			1689		
pseudo LL	−972.94			−847.29		
Wald test	$\chi^2(8) = 54.97$; $p < 0.001$			$\chi^2(16) = 255.10$; $p < 0.001$		
AIC, BIC	1904.5, 1953.4			1728.6, 1820.9		

4.2. Willingness to pay

We next consider respondents' willingness to pay toward the cost-share program, as a ratio of the total estimated cost provided in the survey. As above, Table 3 reports a simplified model that includes only respondents' income levels and their properties' overall wildfire risk

[2] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[3] Using all nine income indicator variables, instead of the five income levels reported in Table 2, leads to noisier results as expected with fewer respondents per category but still shows a clear trend of increasing participation at higher income levels (Table A.3 in the Appendix).

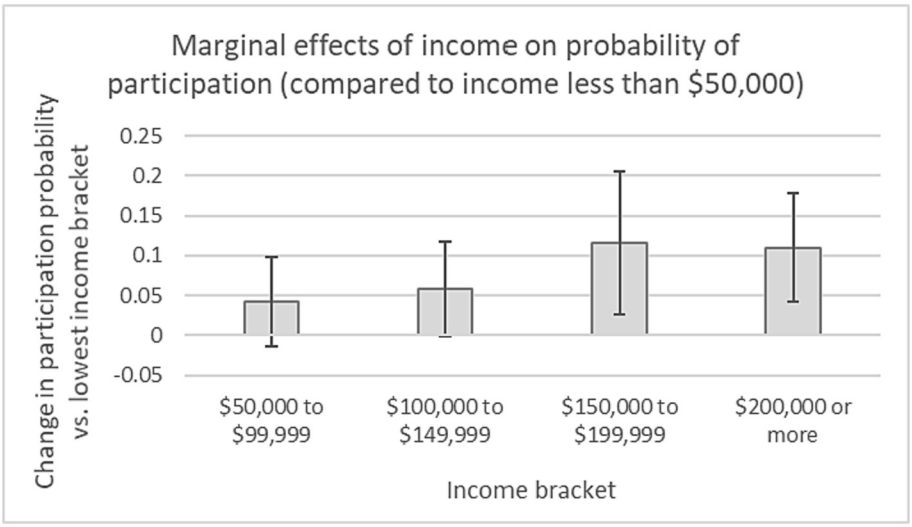

Fig. 2. Marginal effects on probability of participating in the cost-share program, by self-reported income bracket, based on the preferred Model 2 shown in Table 2. Error bars show 95% confidence intervals.

Table 3
Coefficients estimated for interval regression models for willingness to pay as a function of data for survey respondents in select western Colorado communities. Cluster-robust standard errors (std. err.) for 95 communities shown. Joint χ-squared test p-values shown for overall parcel-level wildfire risk rating and income. Adjustment for multiple comparisons (Benjamini and Hochberg, 1995) indicates that all p-values of $p = 0.06$ or less for Model 1 and $p = 0.030$ or less for Model 2 are significant with an assumed 10% false discovery rate. AIC = Akaike information criterion, BIC = Bayesian information criterion.

	Model 1			Model 2		
Interval regression model; y = willingness to pay as ratio of total	Coefficient	Robust Std.Err.	p-value	Coefficient	Robust Std.Err.	p-value
Overall parcel-level wildfire risk rating	joint test $p = 0.174$			joint test $p = 0.504$		
Low risk	[base]			[base]		
Moderate risk	−0.014	0.038	0.708	−0.016	0.034	0.636
High risk	0.036	0.027	0.192	0.031	0.027	0.249
Very high risk	0.028	0.027	0.301	0.024	0.029	0.413
Extreme risk	0.055	0.029	0.060	0.045	0.036	0.212
Income level	joint test $p < 0.001$			joint test $p < 0.001$		
Less than $50,000	[base]			[base]		
$50,000 to $99,999	0.078	0.020	<0.001	0.063	0.018	<0.001
$100,000 to $149,999	0.177	0.023	<0.001	0.153	0.023	<0.001
$150,000 to $199,999	0.137	0.029	<0.001	0.107	0.026	<0.001
$200,000 or more	0.305	0.022	<0.001	0.262	0.031	<0.001
College graduate	–			0.050	0.018	0.005
Mitigation barrier: financial cost	–			−0.061	0.017	<0.001
Mitigation barrier: time	–			−0.038	0.018	0.030
Mitigation barrier: physical difficulty	–			0.016	0.018	0.398
Mitigation barrier: specific information about how to reduce risk	–			0.021	0.015	0.162
Mitigation barrier: perceived effectiveness	–			0.010	0.018	0.601
Mitigation barrier: visual effects of mitigation	–			0.001	0.017	0.934
Mitigation barrier: options for slash removal	–			−0.004	0.018	0.799
Constant	0.374	0.027	<0.001	0.379	0.024	<0.001
Error variance	0.061	0.003		0.060	0.003	
n	1245			1245		
pseudo LL	−2605.76			−2574.45		
Wald test	$\chi^2(8) = 240.84$; $p < 0.001$			$\chi^2(16) = 212.91$; $p < 0.001$		
AIC, BIC	5231.5, 5282.8			5215.9, 5308.2		

ratings (Model 1) and a richer model that further includes survey results on barriers to mitigation and whether the respondent graduated college (Model 2). Sample size decreases versus Table 2 because only respondents who answered "yes" to the participation question answered the willingness to pay question.

AIC and BIC statistics differ; the former favors Model 2 whereas the latter favors Model 1. However, willingness to pay is not influenced by the overall parcel-level wildfire risk rating in either model, and income again has a strong effect in both models, with willingness to pay increasing as an approximately monotonic function of increasing income. Few other included variables are significant in Model 2. As expected, one exception is the perceived barrier to risk mitigation of financial expense, which is negatively associated with willingness to pay. Perceiving time as a barrier to mitigation also lowers expected willingness to pay, whereas having graduated college increases it.

Finally, we calculate the average marginal effects of self-reported income bracket on willingness to pay (Fig. 3), based on the results of the preferred model shown (Model 2 of Table 3) and with all other variables balanced. With the exception of the $150,000 to $199,999 income bracket, which is estimated with considerably less precision,

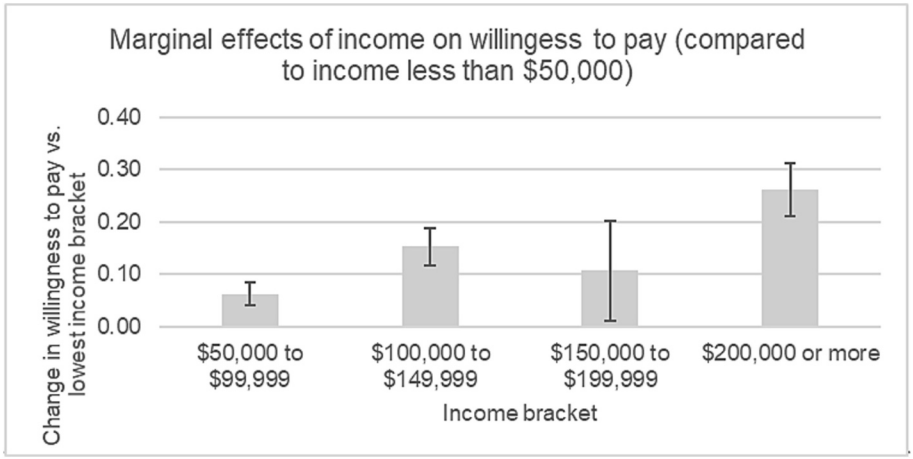

Fig. 3. Marginal effects on willingness to pay as a percent of the total cost, by self-reported income bracket, based on the preferred Model 2 shown in Table 3. Error bars show 95% confidence intervals.

willingness to pay increases with progressively higher self-reported incomes. On average, respondents with the lowest incomes (less than $50,000) are willing to pay substantially less toward the cost share (40% toward the total, with 95% confidence interval of 37% to 43%) than respondents with incomes of $200,000 or more (71% toward the total, with 95% confidence interval of 65% to 78%). As noted above, these results do not depend on overall wildfire risk rating levels.

5. Discussion

For our main result, we find that income predicts both willingness to participate and willingness to pay in a cost-share program (see Fig. 4). Basic economic theory predicts increasing willingness to pay as income increases, and this result is consistent with studies on willingness to pay for wildfire risk mitigation (Fried et al., 2000; Winter and Fried, 2001; Walker et al., 2007; Meldrum et al., 2014; González-Cabán and Sánchez, 2017; Sánchez et al., 2022). In contrast, the income effect on participation – independent of the amount a participant would be expected to pay toward the cost share and with it implied that the program could pay up to 100% of the costs – seems counterintuitive from a strict rationality perspective. All else equal, one would expect lower income residents to have an equal if not stronger incentive to participate in the program than higher income residents. However, medical economics studies similarly have found that even small amounts of cost sharing have been associated

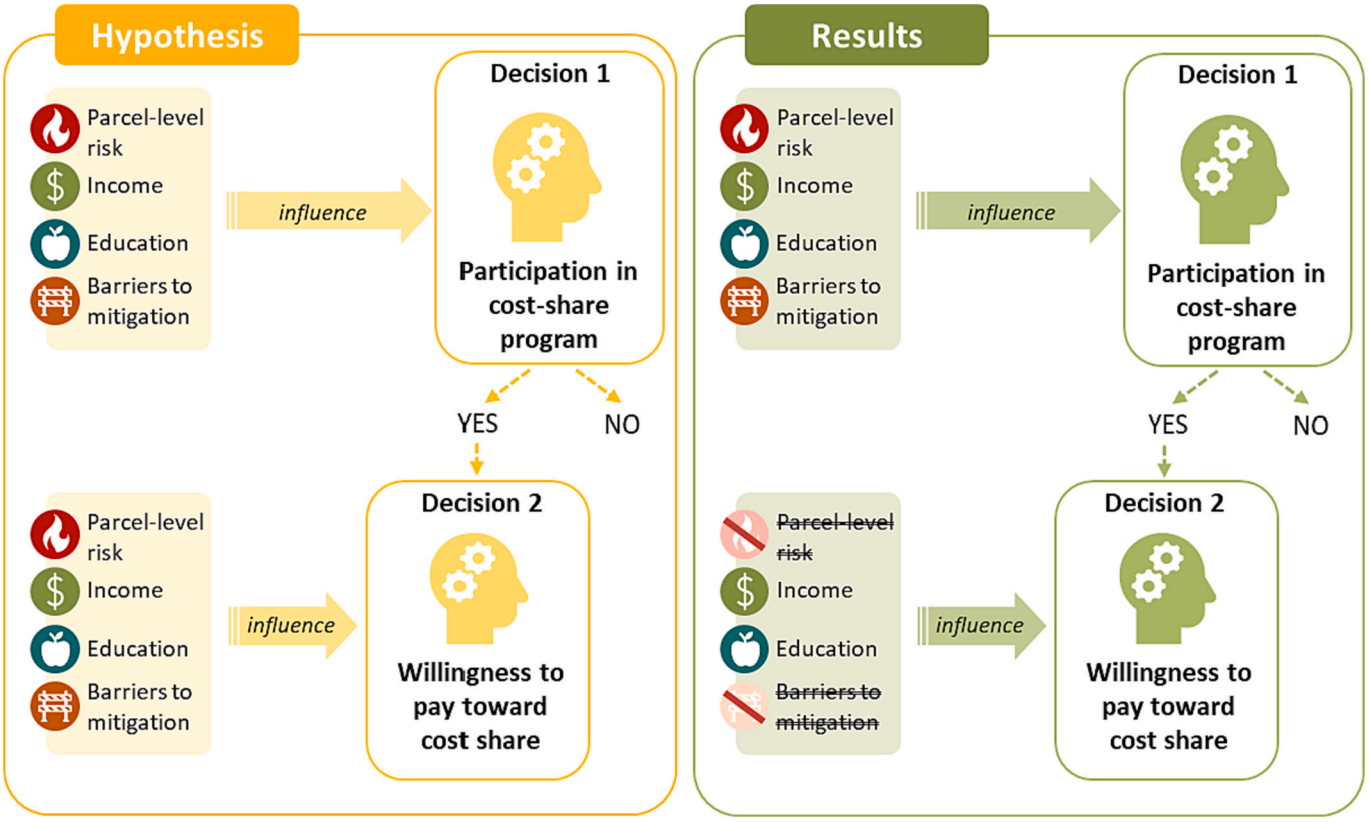

Fig. 4. Proposed (left) and refined (right) conceptual model of the joint decision process of (1) whether to participate in the cost-share program for wildfire risk mitigation on private property and (2) willingness to pay toward the cost share, reflecting reported results.

with reduced use of preventive and primary care (Fung et al., 2014) and with reduced health outcomes and access to needed care (Kostova and Fox, 2017; Zallman et al., 2015). Previous studies (Winter and Fried, 2001; Collins and Bolin, 2009) have also found lower participation in cost-share programs for wildfire risk reduction among lower income respondents, but these could not isolate participation from willingness to pay a non-zero amount.

The income effect on participation becomes even more pronounced after controlling for perceived barriers to mitigation, including financial costs. Although respondents with lowest incomes tend to have lower parcel-level wildfire risk ratings and are less likely to have completed college, both of which predict lower willingness to participate in our results, controlling for these factors does not reduce the observed income effect.

These results highlight the importance of considering heterogeneity not just between communities but also within them when considering equity concerns. Specifically, we find an income effect that relates not to community-wide average incomes but rather to the incomes of individual survey respondents. These results indicate that lower income respondents face additional constraints upon participation in the hypothetical cost-share program beyond finances and a general lack of willingness to conduct mitigation. This has important implications for the equity of cost-share and related program design. If organizations wish to avoid unintentionally excluding those with the lowest incomes from using financial assistance for wildfire risk mitigation, it is important to recognize and try to address other barriers that might constrain participation among individuals with low incomes.

One possible explanation for the income effect on participation relates to liquidity constraints. Respondents might anticipate that the proposed cost-share program would require a participant to spend their own funds and then apply and wait for reimbursement. Respondents, particularly those with lower incomes, might therefore assume that even if fully reimbursed, the proposed cost-share program would involve an initial outlay that they would be unable to afford. Indeed, national surveys show that large proportions of adults in the U.S. would be unable to directly cover an unexpected expense of $400 (Board of Governors of the Federal Reserve System, 2021), suggesting that even a relatively small outlay to receive the cost share might be beyond the reach of many respondents. Such a constraint could possibly be overcome by an organization offering a program through which lower income residents could directly submit a wildfire risk mitigation contractor's bill for an amount up to the full cost-share amount available, rather than relying on a "reimbursement" model that requires the resident to pay the bill upfront before receiving the cost share as a reimbursement.

Another possible explanation for the income effect on participation relates to the complexity of applications or associated technical requirements. For example, Cheng and Dale (2020) noted that although applications to Colorado Wildfire Risk Reduction Grant program were balanced between smaller community-based organizations and larger, better resourced organizations, applications from the latter tended to be more detailed, scientifically based, and ultimately successful, whereas applications from lower-income areas were more likely to be deemed incomplete, unrealistic, or missing important information that might have otherwise helped their chances of success. Such an effect might be expected in the context of individual cost-share programs, given our finding that respondents with the lowest incomes were substantially less likely to have graduated college. That is, if college education predicts the ability of a respondent to navigate bureaucratic processes including complicated paperwork or reporting requirements, respondents with less education and therefore lower incomes might be less likely to participate in the program due to a reasonable unwillingness to take part in a complex program. For example, higher income jobs might regularly entail paperwork tasks and reduce that perceived barrier relative to jobs providing the lowest income levels. However, our results show that while indeed college graduates are more likely to participate in the cost-share program, the income effect on participation is robust to inclusion of data on college education. This suggests that while reducing program complexity and providing "plain language" descriptions of cost-share programs might reduce barriers to participation for non-college graduates, this might not directly affect the participation of low-income residents.

Overall, lower expected participation in a cost-share program among the lowest income residents highlights a potential equity concern with using cost-share programs to support wildfire risk mitigation on private property. This suggests that further research into perceived constraints to participation among residents with low incomes could inform the development of more equitable programs for supporting wildfire risk mitigation on private lands.

Further, the positive effect of income on willingness to pay could highlight another equity concern depending on the amount of funding offered through a cost-share program. Our results predict an average willingness to pay exceeding 50% only for respondents earning $100,000 or more in income, suggesting that many respondents with lower incomes who would otherwise be willing to participate in a cost-share program might still be priced out of that program if it requires an equal or greater match from the resident. Conversely, respondents with the highest incomes are willing to pay more than 70% in a cost share, on average, suggesting that a program might be able to maximize the number of mitigation projects supported by scaling the percentage of cost share that it offers to residents' income levels.

Beyond the novel results from our focus here on financial equity considerations of using cost-share programs to encourage and support wildfire risk mitigation on private property, our results help validate through replication most of the findings originally reported by Meldrum et al. (2014). As in that paper, here we find that willingness to participate in a cost-share program is strongly related to stated barriers to conducting mitigation, while the amount a participant is willing to pay is largely independent of them. Participation is lower among respondents who do not perceive mitigation as effective or who want to avoid its visual effects, whereas participation is higher among those constrained by financial costs, the physical difficulty, or a lack of relevant information. Our present analysis expands the insights available by not needing to reduce the dimensionality through factor analysis, finding that participation in a cost-share program increases with perceived barriers related to either resource or information constraints, suggesting that respondents perceive cost-share programs as providing valuable assistance beyond just the financial support. However, here we also find that perceiving a lack of effectiveness of risk reduction actions and not wanting to change the looks of one's property both do limit participation; this suggests that simply providing a financial incentive cannot overcome certain attitudinal constraints to mitigation. Finally, whereas Meldrum et al. (2014) found a nuanced result of generally higher participation as risk ratings increased with the important exception of residents with the highest risk rating being less likely to participate, we do not find this nuanced result to be robust to replication. Here, instead, we find strong evidence of increasing willingness to participate in a cost-share program as the overall wildfire risk rating assigned to a property increases, which suggests a useful "self-selection" mechanism that naturally encourages participation among those with highest risk levels.

6. Conclusion

Equity with respect to income is about more than just pure affordability. Using data from a series of surveys conducted in fire-prone communities in western Colorado, we found that lower income respondents are less likely to participate in a cost-share program to support wildfire risk mitigation than respondents with higher incomes. That is, the very type of program that one might expect to help residents with the lowest incomes overcome their financial constraints for conducting risk mitigation could instead be disproportionately subsidizing the

efforts of residents with the highest incomes. Although we were unable to pinpoint one specific reason that lowest-income respondents are less willing to participate in the program, our results rule out some possible explanations by being robust to controlling for many potentially explanatory factors relating to different attitudes, barriers, or starting risk levels. One potential remaining explanation, liquidity constraints that might be most binding for those with lowest incomes, is speculative but nonetheless intuitive and a potentially fruitful avenue to consider for improving the equitable implementation of programs intended to reduce wildfire risks on private lands. That said, the out-of-pocket cost of participation may not be the only, or the most important, barrier to participation for individuals with lower incomes. For example, other potential explanations for the income effect we found could include differences in perceived transaction costs or in social norms such as those associated with a willingness to utilize government assistance. Thus, we encourage future research that delves more deeply into understanding the barriers to participation in cost-share programs faced disproportionally by lower-income residents.

Finally, this study demonstrates the benefits of revisiting a past study with a richer dataset if it becomes available. Here, we revisited previously published analysis that was based on a small sample from a single project (Meldrum et al., 2014). Drawing from a larger sample across a broader geographic region, we found most of the original results robust to replication, thereby providing more confidence in the generalizability of the findings. A few of the minor results did not hold up to replication, notably the previous result that respondents with the highest assessed risk levels were least likely to participate, underscoring the importance of maintaining caution when extrapolating results from a single case study. Most pertinent to the focus of this paper, only with the larger multi-site sample analyzed here did we find the important results demonstrating an effect of income on willingness to participate in cost-share programs for wildfire risk mitigation. While we cannot generalize results from this study to other cost-share programs, we hope our results spur additional research on how to overcome potential economic equity concerns in wildfire and other contexts.

Author contributions

Conceptualization, analysis, visualization, methodology—JRM; original draft preparation, writing—JRM, AM; review and editing—all. All authors have read and agreed to the published version of the manuscript. The findings and conclusions in this article do not necessarily represent the views of the USDA and should not be construed to represent USDA agency determination or policy.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

Patricia A. Champ reports financial support was provided by USDA Forest Service, State and Private Forestry. Patricia A. Champ reports financial support was provided by Joint Fire Science Program. Patricia A. Champ reports financial support was provided by U.S. Interagency National Fire Plan. Hannah Brenkert-Smith reports a relationship with Wildfire Research Center that includes: board membership.

Data availability

Data will be available at https://doi.org/10.5066/P9UC6WK9 upon publication. The surveys described in this report were organized and implemented by West Region Wildfire Council and Wildfire Adapted Partners (formerly FireWise of Southwest Colorado) and were not conducted on behalf of the U.S. Geological Survey. Data are managed by the Wildfire Research Center (https://wildfireresearchcenter.org/) and will be available upon publication through USGS data release (https://doi.org/10.5066/P9UC6WK9).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2023.108041.

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