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Is Seeing Believing? Perceptions of Wildfire Risk Over Time

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Ongoing challenges to understanding how hazard exposure and disaster experiences influence perceived risk lead us to ask: Is seeing believing? We approach risk perception by attending to two components of overall risk perception: perceived probability of an event occurring and perceived consequences if an event occurs. Using a two-period longitudinal data set collected from a survey of homeowners living in a fire-prone area of Colorado, we find that study participants' initial high levels of perceived probability and consequences of a wildfire did not change substantially after extreme wildfire events in the intervening years. More specifically, perceived probability of a wildfire changed very little, whereas the perceived consequences of a wildfire went up a bit. In addition, models of risk perceptions show that the two components of overall risk perception are correlated with somewhat different factors, and experience is not found to be one of the strongest correlates with perceived risk. These results reflect the importance of distinguishing the components of overall risk and modeling them separately to facilitate additional insights into the complexities of risk perceptions, factors related to perceived risk, and change in risk perceptions over time.

KEY WORDS: Consequence; natural hazard; probability; risk perceptions; wildfire

"After the event, even the fool is wise." Homer

1. INTRODUCTION

A growing number of studies have focused on the factors related to perceived risks of hurricanes, floods, earthquakes, wildfires, and other natural hazards. In these contexts, there is often a distinction between two aspects of risk perception: the probability of an event happening and the consequences of the event conditional on it happening. Research suggests that individuals view probability and consequence differently. In the context of wildfire, an individual has little control over the start and spread of a wildfire across the landscape. However, research and experience suggest that an individual has some control over fire behavior on his/her land parcel, and can take actions to substantially reduce the risk of his/her home being destroyed.[(1–3)] Despite the distinctness of probability and consequence, studies vary widely in the types of risk perception measures developed, and may collect data on only one of the risk perception measures, ask about both components in one question, or ask about concern, vulnerability, or potential severity of an event as proxies for risk perception. In the context of wildfire, little is known about how perceptions of probability and consequence are related to other factors or how they change after major wildfire events.

One factor that may influence risk perceptions is experience with wildfire. Although it may seem logical to assume that wildfire experience influences perceptions of wildfire risk, research has shown mixed findings that may be a result of the wide range of ways in which event experiences and risk

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perceptions are conceptualized and measured.[4,5] When the two aspects (probability and consequence) of risk perceptions are considered, it is not clear *a priori* how one would expect wildfire experience to affect each risk component or whether the effects would be similar for each risk component. Two possible phenomena, postexposure wakeup call and postexposure letdown, are possible.[6] Greater risk awareness that increases levels of risk perception following first-hand experience with a wildfire would suggest a postexposure wakeup call. An opposite effect, in which risk perceptions are dampened because individuals feel they already experienced their low probability disaster, analogous to the "lightening does not strike twice" notion, is also possible.

In this article, we examine how two components of perceived risk, probability and consequence, change over time when there were major wildfire events in the intervening years. We find that perceptions of the probability and consequences of wildfire are initially high. After some major wildfire events, we do not observe a significant change in the probability measure but perceptions of the consequences of a wildfire increase. In addition, multivariate models of the two risk perception measures that control for both time-varying and time-invariant factors suggest the risk measures are correlated with factors somewhat differently. Of the 15 explanatory variables included in the models, five are significantly correlated with both the probability and consequence measures. Seven additional variables are significantly correlated with perceptions of the probability of wildfire but not perceptions of the consequences of wildfire. In addition, no single factor is correlated with a substantial change in perceived risk. However, certain combinations of factors are associated with substantially higher perceptions of the probability of a wildfire. For example, being a female respondent who reported a high level of wildfire risk mitigation, had neighboring properties with dense vegetation, and talked with a neighbor about wildfire was associated with substantially higher perceptions of the probability of a wildfire compared to respondents with none of those attributes. Interestingly, neither having been evacuated nor having a wildfire within 10 miles of the residence is among the factors most highly correlated with perceptions of the probability or consequences of wildfire; rather, neighbors' influences, which did not change over the study period, appear to be a stronger correlate with risk perceptions.

In Section 2, we review the literature on measuring risk perceptions as well as factors related to risk perceptions. Then, in Section 3, we build on existing risk perception models to present a model that addresses perceived probability and consequences separately. In Section 4, we describe the study context and data. In Section 5, we present summary statistics and the risk model results, and in Section 6, we discuss the study findings. Conclusions and caveats are described in Section 7.

2. LITERATURE REVIEW

2.1. Risk Perceptions and Experience

Early tenets in the risk field asserted that past experience plays a role in shaping beliefs about risk[7] in part, through becoming more familiar with a hazard, the hazard may be more "available" in the cognitive processes required to assess risk.[8] Frequent interactions with a hazard are thought to increase both the accuracy of risk assessments and the prevalence of risk reduction actions. Empirical research, however, demonstrates a mixed record on the relationship between hazard-related experiences and risk perceptions.[4] For example, Kellens *et al.*[9] found that flood experience predicted risk perceptions, whereas storm surge experience did not.

Inconsistent findings regarding the effect of experience on risk perception also characterize studies focused on wildfire. Some studies found experience to be positively related to risk perceptions,[10,11] whereas others found no statistical relationship between experience and risk perceptions.[12–14] However, recent work has found that the experience of being evacuated was positively related to perceived wildfire probability but not perceived consequences.[15] A recent qualitative study of individuals who lost their homes in the Fourmile Fire in Boulder, CO, found that most of the study participants thought that both the probability of a fire occurring and the risk to their (rebuilt) home went down after the fire.[16]

To our knowledge, only a few studies have examined the relationship between perceived risk and experience over time. For example, Cross[17] found stability in hurricane risk perceptions over time, whereas Baker and Shaw[18] and Shaw and Baker[19] found a slight decrease in perceived risk one year after a major disaster compared to immediately after the event. Trumbo *et al.*[20] used panel data to explore hurricane risk perception over time, and found that risk perception decreased over an uneventful time period whereas optimism bias increased. The authors found that experiences predicted risk perceptions, but that they were associated with lower perceived risk and higher optimism bias.

2.2. Probability and Consequence

Risk is broadly understood as the probability of an event occurring and the consequences, given the occurrence. Risk perception, however, is measured in many ways, and related research demonstrates inconsistent findings on the relationship between risk perception and experience. It is unclear, however, to what extent varied findings are related to differing approaches in measuring perceived risk or to contextual factors that may be influencing different outcomes. For example, much of the literature that addresses wildfire risk perceptions uses measures related to perceived wildfire risk levels[21–23] or hazard ratings[24–27] in order to gauge overall wildfire risk perceptions. Other recent wildfire studies have examined perceived likelihood of damages or destruction to private property,[10,28–32] as well as to forest resources and scenic beauty,[12] environmental health, economy, and recreation,[6] rather than specific probability and consequence components of perceived risk.

Of the work that examined perceived probability of a wildfire event, Martin *et al.*[33] found that risk perceptions varied across study area, and were related to knowledge level and wildfire experience. Winter and Fried[34] found perceived probabilities of an event within 10 years were related to willingness to participate in a hypothetical market to reduce risk. Some research included measures for aspects of perceived risk, but did not necessarily present the measures as probability and consequence.[13,33] For example, measured as vulnerability and likelihood of catastrophic fire potential, Hall and Slothower[13] found that risk perceptions were not related to willingness to reduce risk. Measured as perceived risk severity and vulnerability, Martin *et al.*[33] found risk perceptions were related to wildfire experience (and knowledge), and found that willingness to take action was related to protecting the forest as well as personal property. Fischer[12] measured perceived wildfire risk as concern and perceived consequences as they relate to direct and specific potential losses in assessing factors contributing to mitigation implementation.

2.3. Risk Perceptions and Social Interactions

Social cues are also important in interpreting disaster experiences and assessing related perceptions of risk. For example, being in contact with friends and relatives who are also trying to prepare is related to higher levels of preparedness.[35] In addition, cues about risks and options to mitigate them are influenced by framing and order effects that are often related to the types and sources of information available or used.[36,37] The influence of sources of information, along with dynamic social processes, may amplify or attenuate risk perception.[38] Brenkert-Smith *et al.*[15] used the social amplification of risk framework[39] to examine the relationships between information sources, social interactions, and wildfire risk perceptions while controlling for personal characteristics. The study demonstrated that perceived likelihood of an event and perceived consequences exhibit different strengths and directions of associations with different types of social interactions and sources of information.

2.4. Risk Perceptions and Interdependency

In the context of wildfire, risk spills over from one land parcel to another creating risk interdependencies.[40] Research on public acceptability of land and fire management approaches[41–43] or forest disturbances[44,45] served as early proxies for exploring perceptions of risk interdependency by examining how management on nearby public lands is related to public perceptions of one's own risk. Between private land parcels, Brenkert-Smith *et al.*[15] found that perceiving neighboring parcels as having dense vegetation (high wildfire risk) is related to higher levels of risk mitigation on one's own parcel.

2.5. Risk Perceptions and Risk Mitigation Behaviors

The wildfire literature regarding the link between perceived risk and risk mitigation behaviors demonstrates cases of positive relationships in some studies[11,12,31,32] and no statistical relationship in other studies.[13,32,46] Champ *et al.*[23] found parcel-level wildfire risk perceptions to be jointly determined with risk mitigation behaviors, and speculate that as individuals learn about wildfire risk they also learn about how to mitigate that risk.

The broader hazards literature shows a similar pattern. For example, some studies have found that perceptions of seismic hazards do not predict hazard adjustments.[47,48] A review of studies on flood risk perception and mitigation behavior finds the same.[49] Other studies, however, identify causal chains that link perception of seismic hazards to hazard adjustments via hazard intrusiveness or the frequency of thinking about, discussing, or receiving information about a hazard[4,50] and similar causal chains in relation to flood, hurricane, and toxic chemical release from hazard proximity, through experience and perceived risk and eventually to hazard adjustment.[51]

3. MODELING WILDFIRE RISK PERCEPTIONS

Wildfire risk perception models vary greatly in the literature. The models differ with respect to how risk perceptions are defined and measured. In addition, the explanatory variables included in the models also vary. Martin *et al.*[11] posited a model of overall risk (e.g., incorporates probability and consequence into one measure) as a linear function of subjective knowledge, fire experience, self-efficacy, responsibility, type of residency (year round/seasonal), and a location dummy. McFarlane *et al.*[29] put forth a structural equations model of perceived wildfire risk as a function of wildfire experience, controllability of fire, and perceived effectiveness of wildfire mitigation. Champ *et al.*[23] estimated a model of perceived parcel-level wildfire risk based on parcel characteristics, respondent characteristics, experience, and knowledge.

3.1. A Model of Perceived Risk Over Time

In this study, we posit a risk perception model that departs from the existing literature in a few aspects. First, the model accommodates risk perceptions over time and accounts for unobserved effects. In addition, two different measures of perceived wildfire risk are considered: the probability of an event happening for individual i at time t (R_{it}^{p}) and the probability of negative consequences if an event happens:

$$R_{it}^{p,c} = \alpha_0 + \beta_1 S_i + \beta_2 Z_t + \beta_3 X_{it} + v_i + \varepsilon_{it}. \quad (1)$$

In this model, perceived risk is a function of an intercept α_0, variables that vary across individuals but are constant over time ($\boldsymbol{S}_i$), variables that only vary over time but are constant across individuals $\boldsymbol{Z_t}$, and variables that vary over individuals and time $\boldsymbol{X_{it}}$. The error term v_i is an individual-specific residual, whereas ε_{it}, the idiosyncratic or time-varying error, is uncorrelated with v as well as $\boldsymbol{S}$, $\boldsymbol{Z}$, and $\boldsymbol{X}$. We look to the risk perception literature summarized in the previous section for guidance on the specific explanatory variables to include in the model.

4. LIVING WITH WILDFIRE IN BOULDER AND LARIMER COUNTIES

The area where wildfire is of greatest concern is where wildland fuels intersect with human communities, putting lives and values at risk. This area is referred to as the wildland-urban interface (WUI).[52] Based on the number of square miles of developed land in the WUI, Boulder and Larimer counties in Colorado are among the top 25 counties in the United States with respect to wildfire risk (10th and 19th, respectively).[53][3] Using the same metric, Boulder and Larimer counties are among the top counties at risk of wildfire in Colorado. The area is ideal for studying wildfire risk perceptions over time. In addition to ongoing interagency wildfire risk education efforts, the residents of Larimer and Boulder counties have experienced devastating wildfires that would likely influence perceptions of the probability of a wildfire event as well as the consequences of such an event. Particularly relevant to this study was that 2010 was a difficult wildfire season for both counties. Late that summer, the Fourmile Canyon Fire in Boulder County destroyed 169 homes and was at that time the most destructive wildfire, in terms of total losses, in Colorado's history. That same month in Larimer County, the Reservoir Road Fire burned 700 acres, destroyed two homes, and led to the evacuation of 400 residents. Subsequently, the High Park Fire in Larimer County burned through portions of the study area in June 2012 resulting in one fatality, the loss of 259 homes, and 87,284 acres burned.

4.1. Data

The data come from the Living with Wildfire in Larimer County and Living with Wildfire in Boulder County surveys that were administered in 2007 and

[3] A reviewer pointed out that there are many options for defining and measuring "wildfire risk." For example, Haas *et al.* (2014 RA) model "risk transmission" for the entirety of Larimer and Boulder counties. Similarly, CoreLogic (2015) examines residential properties exposed to wildfire risk and identifies Fort Collins (a community in Larimer County) in the top 10 areas in the United States in terms of homes at very high risk. The study area is considered to be at risk of wildfire by most measures of wildfire risk, but the relative ranking compared to other areas along the front range of the Colorado Rockies differs with the definition of "wildfire risk."

2010 in these adjacent counties along the front range of the Rocky Mountains in Colorado. It is a paired panel data set in that the same individuals were surveyed in both years.

The 2007 survey sample frame was developed using geographic information systems, geo-coded data from the county assessor's offices, as well as county wildfire-risk maps to populate Boulder and Larimer counties' fire-prone WUI areas with parcel information for private residential properties. For each county, a random sample of 1,750 parcels with homes was selected, yielding a total sample of 3,500 residential parcels with homes (Table I).

The survey was implemented simultaneously in both counties in the summer of 2007. A mixed-mode approach gave potential participants a choice of completing an online version of the survey or a paper survey.[54] All potential participants were mailed a first-class envelope with a letter of invitation to participate in the survey, a unique identifying number, a response card for those who wanted to participate using a paper survey, and a web address and instructions for those who were interested in participating online. Participants who returned the response card were sent a survey, a letter with instructions, and a postage-paid envelope for returning the survey. Two follow-up mailings were sent to nonrespondents. There were four statistical differences between the completed mail and online surveys: number of people under the age of 18 living in the current residence, race, employment status, and age.

In November 2010, two months after the Fourmile Canyon Fire in Boulder County and the Reservoir Road Fire in Larimer County, a survey was administered to the respondents to the 2007 survey (Table I). The structure was largely consistent with the 2007 survey. The initial sample for the 2010 survey consisted of the 745 Larimer and Boulder County respondents to the 2007 survey. Similar to the 2007 survey, respondents were given the option to complete a paper survey or online. However, departing from the 2007 approach, a paper survey was included in the initial mailing. Two follow-up mailings were sent to nonrespondents. Interestingly, of the respondents who completed the survey in 2007 and 2010, 68% completed the online version in 2007, but only 13% chose to complete the online version in 2010. Table I describes the response rates for the 2007 and 2010 surveys. The surveys and additional details of the implementation procedures are more fully described in Brenkert-Smith *et al.*[55,56]

5. RESULTS

5.1. Summary Statistics

An extensive description of every variable in the 2007 and 2010 data can be found in Champ *et al.*[57,58] and Brenkert-Smith *et al.*[55,56] Table II provides summary statistics by year for the variables included in the risk models. Two risk indices were created from the survey measures following the approach in Brenkert-Smith *et al.*[15] The probability risk index (probindex) was generated using principal components analysis on two Likert-scale items: "A wildfire is unlikely to happen within the time period you expect to live here" and "Your property is not at risk of a wildfire." The intent of these measures was to capture respondents' perceptions of the probability of a wildfire event that could affect them. As described below, in the multivariate models we control for individuals who plan to move in the next five years (move), given the probability index is premised on the probability of a fire during a respondent's tenure in the area. The consequence index (consindex) was developed based on responses to four Likert-scale items that were designed to gauge what respondents thought would happen if a wildfire was on their properties. The four items covered the likelihood of smoke damage to home, physical damage to home, home being destroyed, and landscape being burned. Comparing the simple means of these two risk measures between 2007 and 2010 is interesting (Table II). We see that the probability index is higher than consequence index in both 2007 and 2010, and both indices are well above 50, suggesting that on average the respondents think it probable that a wildfire could occur and that if there is a wildfire on their properties, they are likely to experience negative consequences. Somewhat surprising, when we compare the probability index in 2007 to 2010 there is little change. However, the mean consequence index increases from 65.17 in 2007 to 70.49 in 2010. As might be expected, all the variables used to construct the indices have patterns of change over time similar to the indices.

The other variables included in Table II are the explanatory variables for the risk models detailed in the next section. These variables fall into three categories consistent with Equation (1): variables that are constant over time and vary across individuals; variables that vary over time and are constant across individuals; and variables that vary over time and across

Table I. Survey Responses in 2007 and 2010

	Boulder County	Larimer County	Total
No. of developed, residential WUI parcels	8,300	13,880	22,180
2007 initial sample size	1,750	1,750	3,500
Undeliverable	602	845	1447
Completed online	316	205	521
Completed paper survey	105	121	226
Response rate	36% ([316+105]/[1750−602])	36% ([205+121]/[1750−845])	36% ([521+226]/[3500−1447])
2010 initial sample size	421	324	745
Undeliverable	26	24	50
Completed online	38	17	55
Completed paper survey	221	166	387
Response rate	66% ([38+221]/[421−26])	61% ([17+166])/[324−24])	64% ([55+387]/[745−50])

Note: Two of the Larimer County surveys returned in 2007 had too many incomplete responses to be included in the 2010 sample.

individuals. The variables that are constant over time include the county in which the respondent resides, respondent gender, and lot size. There were slightly more respondents from Boulder County (59% of the respondents) than Larimer County (41%). More of the respondents were male (around 55%) than female, and slightly more than half of the respondents lived on land parcels larger than two acres. The small differences across the years on these variables arise from individuals not responding to that particular question in one of the two years (Table II).

The variables that vary over time and across individuals are also interesting. The small number of respondents who expected to move in 2007 (17%) went down slightly in 2010 (15%). The high level of fire activity between 2007 and 2010 with the two major fire events in 2010 (Fourmile Canyon and Reservoir Road Fires) in addition to numerous smaller events was reflected in the significant increase in the number of respondents who said they had ever evacuated due to wildfire from 19% in 2007 to 43% in 2010. Similarly, there was a significant increase over the time period from 76% to 87% in the percent of respondents reporting a wildfire less than 10 miles from their properties. Smaller changes are observed in the percent of respondents getting wildfire information from the local fire department (64% in 2007 and 70% in 2010); the county wildfire specialist (29% in 2007 and 32% in 2010); and neighbors, friends, or family (37% in 2007 and 40% in 2010). Almost all the survey participants had talked with a neighbor about wildfire (78% in 2007 and 80% in 2010), but far fewer had attended a wildfire-related event (22% in 2007 and 52% in 2010). However, the increase from 2007 to 2010 in the number respondents reporting attendance at a wildfire-related event was statistically significant. In the survey, respondents were also asked whether they had completed 12 different risk mitigation behaviors (see Appendix). The list of behaviors was developed in consultation with the wildfire specialists in each county, and reflects the steps residents are typically advised to undertake to reduce the risk of negative consequences in the event of a fire. These steps are largely consistent with Firewise recommendations for the home ignition zone.(3) Responses to the risk mitigation behaviors list were categorized into three different levels of mitigation: low (0–4 actions); mid-level (5-9) actions; and high (≥10 actions). Compared to 2007, there were fewer low and mid-level mitigators and significantly more high mitigators in 2010. The complete list of mitigation actions listed in the Appendix shows that respondents reported higher levels of vegetation thinning/management in 2010 compared to 2007. However, no change in installation of fire-resistant roofs or siding, actions that are significant one-time investments, was observed over time.

5.2. Risk Perception Models

Following Equation (1), we estimated models with two different dependent variables: the probability index (probindex) and the consequence index (consindex). To accommodate the nature of the panel data with variables that change over time and those that do not, random effects maximum likelihood models are estimated.(59) Random effects models are applicable to a large class of problems and are often used with panel data. One of the benefits of the model in the current context is that it accounts

Table II. Summary Statistics

		N	Values	Mean 2007	Mean 2010	Difference in Means Significantly Different from 0?
Dependent Variables						
Probindex	Index generated using principal components analysis	648	0–100	74.68	74.27	No
	Input variables: A wildfire is unlikely to happen within the time period you expect to live here		1 = Strongly agree to 5 = Strongly disagree	3.83	3.78	No
	Your property is not at risk of wildfire			4.14	4.14	No
Consindex	Index generated using principal components analysis	626	0–100	65.17	70.49	Yes
	Input variables: If there is a wildfire on your property, how likely do you think it is that the following would occur?					
	There would be some smoke damage to your home		1 = Not likely to 5 = Very likely	3.85	4.09	Yes
	There would be some physical damage to your home			3.55	3.80	Yes
	Your home would be destroyed			2.84	3.08	Yes
	Your trees and landscape would burn			4.12	4.27	Yes
Explanatory Variables						
Variables that are constant over time ($\boldsymbol{S}_i$)						
Boulder	County	666	1 = Boulder; 0 = Larimer	0.59	0.59	a
Sex	Gender	640	1 = female; 0 = male	0.44	0.45	a
Lot size	Lot size greater than 2 acres	666	1 = greater than 2 acres; 0 = otherwise	0.57	0.54	a
Variable that only varies over time (Z_t)						
Yr2010	Year survey completed	666	1 = 2010; 0 = 2007	0	1	

(Continued)

Table II. (Continued)

		N	Values	Mean 2007	Mean 2010	Difference in Means Significantly Different From 0?
Variables that vary over time and across individuals (X_{it})						
Move	Plan to move from current residence in next 5 years	657	1 = yes; 0 = no	0.17	0.15	No
Evac	Ever evacuated from your current residence due to a wildfire	665	1 = yes; 0 = no	0.19	0.43	Yes
Fire10	Closest a wildfire has come to your property since you lived at your current residence,	665	1 = less than 10 miles; 0 = otherwise	0.76	0.87	Yes
Localfiredept	Local fire department	661	1 = received wildfire information from this source; 0 = otherwise	0.64	0.70	Marginal ($p = 0.06$)
Countyspec	County wildfire specialist	661		0.29	0.32	No
Neighbfriend	Neighbors, friends, or family members	661		0.37	0.40	No
Neighbdens	Reported vegetation on neighboring property is "dense" or "very dense"	646	1 = yes; 0 = otherwise	0.36	0.33	No
Talkfire	Ever talked to neighbor about fire	635	1 = yes; 0 = otherwise	0.78	0.80	No
Fireevent	Participated in wildfire-related event	656	1 = yes; 0 = otherwise	0.22	0.52	Yes
Low mitgators	Reported implementing 0–4 actions	664	1 = 0–4 actions; 0 = >4 actions	0.25	0.20	Marginal ($p = 0.08$)
Mid-level mitigators	Reported implementing 5–9 actions	664	1 = 5–9 actions; 0 ≤ 5 or >9 actions	0.56	0.50	No
High mitigators	Reported implementing 10+ actions	664	1≥10 actions; 0 < 10 actions	0.18	0.29	Yes

[a]By definition these variables do not change over time.

Table III. Random Effects Maximum Likelihood Models

	Probindex	Consindex
	Estimated Coefficient (SE)	
Intercept	54.489*** (2.995)	53.879*** (3.356)
Boulder	4.121** (1.928)	2.190 (2.328)
Female	4.801*** (1.753)	7.608*** (2.127)
Lot size	−0.306(1.778)	−2.119(2.142)
Yr2010	−3.191** (1.335)	4.562*** (1.478)
Move	−3.545* (2.108)	1.550(2.422)
Evac	4.520** (1.835)	3.805* (2.113)
Fire10	1.226 (2.046)	0.580 (2.344)
Localfiredept	1.891(1.804)	−1.162 (2.086)
Countyspec	3.274* (1.732)	−0.909 (1.960)
Neighbfriend	4.072*** (1.581)	2.244 (1.812)
Neighbdens	4.768*** (1.572)	5.917*** (1.834)
Talkfire	7.525*** (1.945)	4.373** (2.176)
Fireevent	−0.792 (1.478)	−0.989 (1.637)
Mid-level mitigator	3.915** (1.980)	1.352 (2.258)
High mitigator	8.428*** (2.421)	0.778 (2.818)
σ_ν	11.660 (0.988)	15.230 (1.038)
σ_ε	13.787 (0.636)	14.648 (0.681)
ρ	0.417	0.048
Wald $\chi^2_{df=15}$	104.54 ($p = 0.000$)	56.74 ($p = 0.000$)
Log likelihood	−2489	−2495
N	583	567

Notes: Wald χ^2_{15} statistic and p-value are for F test of whether all coefficients in model are different from zero; ρ is a measure of the fraction of variance due to υ_i. Dependent variables are probindex and consindex (0–100).
*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$.

for unobservable measures (υ_i) that may influence risk perceptions. As we are interested in how some of the specific time-invariant measures are correlated with perceptions of risk, we estimate a random effects model rather than a fixed effects model that collapses the time-invariant measures into one term. The restrictive aspect of the random effects model is that we must assume that the omitted time-invariant measure (υ_i) is not correlated with the time-varying variables ($\boldsymbol{Z_t}$ and $\boldsymbol{X_{it}}$). The results are shown in Table III.

Looking first at the time invariant variables, we see that holding all else constant Boulder County residents had significantly higher perceptions of the probability of a wildfire relative to Larimer County residents, but similar perceptions of the consequences of a wildfire. Female respondents had higher perceptions of both the probability and consequences of a wildfire. Respondents living on larger parcels (greater than two acres) did not perceive a higher probability or consequences of a wildfire compared to those living on smaller parcels. One interesting result is the sign of the estimated coefficient on the Yr2010. In the probability model, the coefficient on year (Yr2010) is negative and significant, suggesting that compared to 2007, survey respondents thought the probability of a wildfire had gone down by 2010. However, the opposite effect is seen in the consequence model. Compared to 2007, respondents perceived a higher probability of negative consequences of a wildfire in 2010.

We see a marginal negative correlation ($p = 0.10$) between planning to move in the next five years (move) and the perceived probability of a wildfire. The relationship between first-hand experience with wildfire and risk perceptions is similar for the two models. Experiencing a wildfire within 10 miles of the residence (fire10) was not found to be correlated with perceptions of the probability or the consequences of wildfire. However, we observe a positive, significant coefficient on the having ever evacuated due to a wildfire (evac) variable in both models. Respondents with first-hand experience of evacuation due to a wildfire perceive both a higher probability of a wildfire and a higher probability of negative consequences if a fire is on their properties.

It is also noteworthy that getting wildfire information from the local fire department does not seem to be related to wildfire risk perceptions nor is attending a wildfire-related event (fireevent). However, there is a weak relationship between getting information from the county wildfire specialist and the probability index. Another difference between the probability and the consequence models is that the estimated coefficient on neighbors and friends as a source of wildfire information (neighbfriend) is positive and highly significant in the probability model but not in the consequence model. However, having neighbors with dense vegetation on their properties (neighbdense) and talking with a neighbor about wildfire (talkfire) are both positively associated with higher perceived risk of a fire happening and negative consequences.

Finally, the risk mitigation behaviors variable was transformed into three dummy variables for each level with the low mitigators as the excluded dummy. The relationship between mitigation behavior and risk perception is another difference between the probability and the consequence models. Relative to low mitigators, we see that mid-level and high mitigators perceive a higher probability of a wildfire. No such effect is observed in the consequence model. This result is a bit surprising as mitigation is aimed at reducing the consequences of a wildfire, but would likely have no effect on the probability of a fire happening.[4]

6. DISCUSSION

We set out to examine how risk perceptions, specifically probability and consequences, change over time when there are major wildfire events in the intervening years. A simple comparison of the mean index values (Table II) suggests that the probability index did not change over time, but the consequence index went up significantly. The results from the multivariate models show that controlling for the independent variables in the model, the consequence index was higher in 2010 compared to 2007, and the probability index was lower in 2010 compared to 2007. However, the practical significance of the change in the indices related to the two periods may not be substantial as both indices are on a 100-point scale with means above 50 in both periods, suggesting that on average in both 2007 and 2010 respondents thought there was a high probability of a wildfire that could affect them and negative consequences were likely. The coefficient estimates on the year variables are relatively small in magnitude (-3.191 in the probability model and 4.562 in the consequence model); therefore, we would not describe the change as a reflection of an "Aha!" moment where respondents moved from not thinking a wildfire would have negative consequences to understanding that there could be significant negative consequences. However, after major fire events such as those occurring in 2010 in the study area, the conventional wisdom is that risk perceptions increase substantially. Certainly, that may be the case in some situations, but it was not observed in these data with respondents who already perceived a high probability that a fire could occur and that they would likely experience negative consequences. One might also speculate that the probability and/or consequences of fire could go down after a major wildfire if residents were to believe that "lightning doesn't strike twice" or that the fires reduced available fuels dramatically. The catastrophic fires on the front range of the Colorado Rockies in recent years, including the Fourmile Canyon and the Reservoir Road fires in 2010, likely reduced fuels associated with wildfire risk near homes located within the perimeters of those fires.[1,60] However, less than 5% of the survey respondents lived within the perimeters of these fires. In addition, for both 2007 and 2010, respondents reporting a wildfire less than 10 miles from their residence had significantly higher mean perceived probability indices compared to those who reported a wildfire 10 or more miles from their residence. Therefore, it does not appear that the reduction in wildfire risk related to the 2010 wildfires influenced respondents' perceived wildfire risk. In the context of postexposure wakeup calls and letdowns,[6] we found the initial levels of risk perception to be high for both the probability and the consequence measures. Therefore, the notion of a "wakeup call" might be an exaggeration as we did not find the respondents to be sleeping in the first place. Similarly, a postexposure letdown in the context of the probability measure might also be an overstatement.

[4]We also ran a model with the main effects described here plus a full set of interactions of year by each of the other independent variables that could change between the two periods (i.e., we could not include interaction terms for Boulder, female, and lot size). None of the coefficient estimates on the interaction effects were significantly different from zero. In other words, the relationship between the risk indices and each of the independent variables did not change significantly over time.

In addition to examining the changes in risk perceptions over time, some of the factors related to risk perceptions also changed over time. We found that many more respondents reported having evacuated due to a wildfire in 2010 (43%) compared to 2007 (19%), and that having evacuated was positively and significantly related to perceptions of the probability of a wildfire and consequences. However, compared to other factors included in the multivariate models, experience in the form of having evacuated was not one of the most highly correlated factors. As noted previously, although the relationship between risk perception and hazard-related experience has garnered much attention, results from empirical studies have been mixed. Similarly, more respondents reported a fire less than 10 miles from their residences in 2010 compared to 2007. However, being less than 10 miles from a wildfire was not found to be correlated to either the probability or the consequence index. This result begs the question of how near would a wildfire need to come to a property to influence risk perceptions, if at all? Unfortunately, the data analyzed in this study are not sufficient to respond to that question.

Two of the measures that did not change significantly over time but were found to be positively and significantly correlated to both the probability and consequence measures were reporting dense vegetation on neighboring properties and having ever talked with a neighbor about wildfire. Wildfire operates in such a manner that neighbors' mitigation behaviors may have a major impact on the probability and potential consequences of a wildfire event. The results of this study suggest that respondents see what is happening on neighboring properties and most (78% in 2007 and 80% in 2010) had talked with a neighbor about wildfire. Furthermore, respondents who reported receiving wildfire information from neighbors, friends, or family members perceived a higher probability of a wildfire but not higher perceptions of the consequences of a wildfire. In other words, it appears that receiving information from neighbors and friends amplifies the perceived probability but not the perceived consequences. One possibility is that residents engage with these social sources of information and talk with neighbors during conditions of high fire probability, for example, during particularly dry and windy periods, or even on specific red flag days when information about fire risk is circulating through various formal and informal networks, in which case the content of such information may be more focused on fire probability than on consequence. Future research, including time series studies and intervention studies, could help identify the content of such interactions as well as trace out the timing and direction of causal pathways.

In addition, these results suggest that wildfire education programs may be able to leverage neighbor networks to get information out about wildfire risk. Interestingly, although reported participation in a wildfire event increased significantly over time, it was not found to be correlated with perceptions of either consequence or probability. In the context of this study, it appears that informal information sources are more strongly related to risk perceptions than the formal networks such as the local fire department, the county wildfire specialist, or wildfire events.

Another interesting result from the multivariate analyses was the correlation between mitigation level and risk perceptions. Although we cannot attribute causality, the result that mitigation level was significantly correlated to the probability measure but not the consequence measure is counterintuitive. One might expect that individuals who are worried about having their home damaged or destroyed in a wildfire would be more likely to mitigate or that those who mitigate believe the mitigation reduces the risk of their home being damaged or destroyed. However, neither of these speculations appears to be a dominant phenomenon with the respondents in this study as we did not find a significant correlation (positive or negative) between mitigation level and perceptions of the consequences of a wildfire. It is also interesting that there was a significant increase in the number of reported mitigation behaviors, but there was not a decrease in reporting neighboring properties as having dense vegetation. Although it is possible that none of the survey respondents are neighbors, it seems somewhat unlikely that most of them were individuals who had undertaken greater efforts to reduce wildfire risk whereas their neighbors had not.

7. CONCLUSIONS

At a broad level, the results of this study highlight the importance of specifying the specific dimension of wildfire risk being examined as we found that the different measures of risk were related to different explanatory variables. This result draws attention to the need to examine intuitively plausible relationships with data. Although it is easy to assume that everyone has increased awareness of wildfire after an event, the perpetuation of such anecdotes may be a disservice to efforts aimed at reducing the risk of wildfire on private land. In addition, the results of this study suggest that risk perceptions are influenced by multiple factors that have small correlations with risk perceptions individually, but in combination with other factors may be associated with a large change in perceptions. Finally, the results of this study suggest that neighbors might have a strong influence on risk perceptions. It is possible that homeowner wildfire education programs could be designed to leverage the influence that neighbors have on each other.

As usual, we provide a few caveats to this study. First, we created indices as measures of the perceived probability and consequence of wildfire. It may be better to directly ask individuals about these two components of risk. Indeed, we recommend that future wildfire surveys include direct questions about probability and consequence. Second, we cannot make inferences to populations beyond the scope of this study. One might expect different results if the study participants did not have initially high levels of perceived risk, there were fewer wildfire programs in the area, the wildfires were different, or the surveys were five years apart, to name a few aspects of the context that could influence results. A third caveat is that we do not know the "actual" probability and consequence of a wildfire at the parcel level. In turn, we cannot speculate on the accuracy of survey respondents' perceptions of the probability and consequence. To our knowledge, there are no wildfire probability models at the parcel-level scale. Current models of wildfire probabilities do not allow for downscaling to individual parcels. However, there are many efforts to estimate parcel-level wildfire risk that are somewhat akin to the "consequences" measure described in this study. Such efforts take into consideration many attributes, such as the building materials of the structures, the type and density of the vegetation, and other flammable materials near the structure, proximity to dangerous topography, slope, etc. Such efforts are largely based on the notion of the home ignition zone.[3] However, we did not have parcel-level assessments that could be matched to the survey responses in this study. Ultimately, human behavior is influenced by perceptions of the severity of a potential problem/hazard rather than the "actual" severity of the potential problem/hazard. Therefore, although such data might enrich the analyses, they remain beyond the scope of the inquiry.

Is seeing believing? The results of this study suggest that perceptions of the probability and consequences of a wildfire are distinct, so it matters how we define "believing." "Seeing" in the form of first-hand experience with wildfire may not be a major correlate with higher risk perceptions. However, learning from neighbors or recognizing how wildfire risk spreads across property lines, factors that did not vary much over time, were stronger correlates with risk perceptions.

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APPENDIX:

COMPLETE LIST OF MITIGATION ACTIONS AND MEANS BY YEAR

Description of Actions (1 = completed; 0 = otherwise)	Means 2007	Means 2010	Difference in means significantly different from 0?
Pruned limbs so lowest is 6–10 feet from ground in 30-foot perimeter from house and other buildings	0.588	0.659	Marginal ($p = 0.06$)
Removed dead or overhanging branches in 30-foot perimeter from house and other buildings	0.706	0.779	Yes
Thinned trees and shrubs in 30-foot perimeter from house and other buildings	0.597	0.743	Yes
Cleared leaves and pine needles from roof and/or yard	0.636	0.734	Yes
Mowed long grasses	0.730	0.792	Marginal ($p = 0.06$)
Pruned limbs so lowest is 6–10 feet from ground 30–100 feet from house and other buildings	0.435	0.532	Yes
Removed dead or overhanging branches 30–100 feet from house and other buildings	0.510	0.574	Marginal ($p = 0.10$)
Thinned trees and shrubs 30–100 feet from house and other buildings	0.495	0.586	Yes
Installed a fire-resistant roof	0.552	0.604	No
Installed fire-resistant siding	0.204	0.218	No
Installed screening over roof vents	0.246	0.332	Yes
Installed a house number in clearly visible place	0.739	0.782	No

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