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A Mixed Logit Model of Homeowner Preferences for Wildfire Hazard Reduction[1]

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Abstract

People living in the wildland-urban interface (WUI) are at greater risk of suffering major losses of property and life from wildfires. Over the past several decades the prevailing view has been that wildfire risk in rural areas was exogenous to the activities of homeowners. In response to catastrophic fires in the WUI over the past few years, recent approaches to fire management and prevention in the WUI have emphasized activities that can be taken by landowners and communities to reduce the risk of catastrophic wildfires. These activities include fuel reduction via mechanical thinning and controlled burning of forests surrounding communities and the creation of defensible space around homes. Promotion of community and homeowner-based risk reduction activities represents a new direction in wildland fire management and prevention. We developed a survey instrument to evaluate the value to homeowners in Florida of public and private programs to reduce wildfire risk. A random stratified random sample was drawn to evaluate potential differences in preferences between people living in low, medium, and high fire risk zones. A choice experiment was designed that allowed respondents to choose between public and private fire risk reduction programs that varied across three attributes: wildfire risk, economic loss, and program cost. The survey was implemented using a phone-mail-phone protocol. Results show that people living in communities they considered to be at high risk of wildfires were willing to pay a substantial premium for public wildfire mitigation programs, but had modest willingness-to-pay (WTP) for fuel reduction programs on their own property. Risk preference is related to demographic characteristics, and households that are risk seeking are more likely to make risky choices regarding wildfire mitigation programs. The results suggest that low income households, households without homeowners insurance, and African-American households living in the WUI may be good candidates for assistance.

Introduction

Wildfires pose a risk of catastrophic loss of life and property to people living in the wildland-urban interface (WUI). The increasing frequency and severity of wildfires in residential neighborhoods in the United States has caused fire managers and policy-makers to emphasize the role of homeowner and community mitigation activities to reduce the hazards associated with wildfires. Mitigation activities include fuel reduction via mechanical thinning and controlled burning of forests surrounding communities and the creation of defensible space around homes. In

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some locations, fuel reduction activities are currently being subsidized through federal cost-sharing programs.

The promotion of homeowner and community hazard reduction activities represents a new direction in wildland fire prevention and management. However, little is known about the efficacy of these approaches and the degree to which homeowners and communities are willing to invest time, effort, and money in hazard mitigation. Further, community-based wildfire hazard mitigation programs represent a weakest-link public good wherein each member of a community has a “kind of veto power over the extent of collective achievement” (Hirshleifer 1983, p. 373). Just as the strength of a chain depends upon its weakest link, or the protection provided by a system of levees depends upon its lowest height, the aggregate provision of wildfire protection is compromised by forest landowners within a community who fail to take hazard mitigation actions, thereby increasing the risk for other forest landowners in the community. Understanding the economic factors that influence decisions of whether, and how much, to invest in wildfire risk mitigation activities will help to identify obstacles to efficient and effective fire mitigation in the WUI.

In this paper, we investigate homeowner preferences and willingness-to-pay (WTP) for public and private wildfire risk reduction programs in Florida using an attribute-based choice experiment. Following the introduction we review the economic literature that has used stated preference methods for estimating homeowner WTP to mitigate the risk of catastrophic losses to private property, including losses from wildfires. We then present the survey sampling methods we used followed by a description of the empirical model used to analyze homeowner preferences for wildfire hazard mitigation. The paper continues with a presentation of the empirical results and a conclusions section.

Literature Review

The risk of a wildfire damaging or destroying a home in the WUI is very low, and yet very consequential to the homeowner.[5] Low-risk, high-consequence (LRHC) events have posed problems for expected utility (EU) theory. This limitation was recognized by Morgenstern (1979), one of the early designers of EU theory:

… one should now point out that the domain of our axioms on utility theory is also restricted… For example, the probabilities used must be within certain plausible ranges and not go to 0.01 or even less to 0.001, then to be compared with other equally tiny numbers such as 0.02, etc. (Morgenstern 1979, p. 178).

In a meta-analysis of 23 data sets, Harless and Camerer (1994) present a test for conformance of actual choices with EU theory. Their results confirm that decision-making under conditions of low risk are not consistent with the predictions of EU theory, and suggest that “nonlinear weighting of small probabilities is empirically important in explaining choice behavior” (p. 1285).

The failure of EU theory to explain and predict economic decisions for events in the range of wildfire risk faced by homeowners in the WUI suggests that people respond in ways that are not well understood. Camerer and Kunreuther (1989)

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[5] In temperate forests, natural disturbances (e.g. fires, insect epidemics, windstorms) affect, on average, about 1% of the forest landscape per annum, a value that ranges between about 0.5% and 2% across a variety of ecosystems (Runkle 1985).

showed that, under conditions of low risk, people tend to use ad hoc decision rules. Some people tend to discount the risk entirely, thinking that "it can't happen to me". Other people tend to overestimate or exaggerate the risk. Both types of responses have been identified in research on perceived wildfire risk subsequent to an actual wildfire event.[6]

Similar behavioral responses to LRHC events were observed by McClelland et al. (1993) in a laboratory economic experiment where a sample of university students were instructed to bid on a fixed number of insurance policies that, although costly, would protect their wealth if a catastrophic event did in fact occur. Expected bids were close to their expected value except at the lowest probability of 0.01, at which a bimodal distribution of values was observed. These results are consistent with the idea that some people tend to ignore very low risks, while others worry too much about them.

Experimental economic methods were also used by Ganderton et al. (2000) to investigate insurance purchasing decisions for disaster-type risks. To begin, the authors hypothesized that the bimodal value distribution reported by McClelland, Schulze, and Coursey (1993) might be attributable to dual focal points. That is, when people are confronted with low probability, high consequence events, some people might focus on the probability that the event will occur, and will tend to ignore low probability events if the risk falls below some threshold. Other people might focus on the magnitude of the potential loss, and decide that the consequences are worth avoiding even at a large cost. Data from this experiment were analyzed using a binary logit model (subjects purchased insurance or not). The authors found that subjects were more responsive to the variation in loss probabilities than the variation in loss amounts. Also, they were unable to identify a bimodal distribution of values – perhaps because subjects were focusing primarily on loss probabilities and not loss amounts.

Economists have used contingent valuation methods for estimating WTP for measures that mitigate wildfire hazards. Winter and Fried (2001) asked households how much of an increase in property taxes they would pay for a 50% reduction in the probability of a wildfire. On average, households were willing to pay $57 per year. Talberth et al. (2006) conducted a CVM study that elicited homeowner WTP for private land fire risk reduction, neighborhood fire risk reduction, and public land wildfire risk reduction. The annual WTP amounts were greatest for protecting one's house ($240), followed by protecting other homes in the neighborhood ($95) and, finally, protecting public forests ($64). Loomis and González-Cabán (2008) evaluated WTP for wildfire risk mitigation in the wildland-urban interface in 3 states – Montana, Florida, and California. The statistical results suggest that households have a substantial WTP for a prescribed burning or mechanical fuel reduction program that would decrease the number of acres burned by wildfires in their respective states by, at least, 25 percent. In particular, average WTP by household ranged from approximately $400-$500 in California, from $250-$400 in Florida, and from $190-$300 in Montana.

[6] For example, Cortner et al. (1990) found that homeowners surveyed in a California community recently impacted by fire perceived less risk of future fires than another community not impacted by fires. In contrast, Abt (1990) reported that homeowners surveyed in Palm Coast, Florida after a wildfire impacted their community thought that future wildfires were the greatest threat facing their community.

Empirical Methods

Based on the literature review, a choice experiment was designed to estimate homeowner WTP for programs that reduce the (separable) risks and economic losses from wildfires. We designed our study to test the hypothesis that homeowner preferences regarding risks and losses are heterogeneous. In particular, we test the hypothesis that preferences regarding the risk and economic consequences related to wildfire mitigation programs reflect underlying attitudes towards risk, and that some people in the population are risk seeking, while others are risk averse. Such a distribution of preferences would be consistent with a bimodal distribution of preference parameters for LRHC events.

The theory of risk preference, based on expected utility theory, generally categorizes decision-makers as either risk averse, risk neutral, or risk seeking. To clarify these concepts, consider a lottery with an equal probability of receiving $100 or nothing. A decision-maker is risk averse if they would accept a payoff of less than $50 with certainty rather than entering the lottery. The decision-maker is risk seeking if they accept the certain payment only if it exceeds $50. If the decision-maker is indifferent between entering the lottery and accepting $50, they are risk-neutral.

Barsky et al. (1997) speculated that attitudes towards risk might be quite heterogeneous across the population and devised a series of utility theoretic questions that would identify an individuals' risk attitude from their responses to a series of stated preference questions regarding gambles over lifetime income. Further, they sought to link stated risk preference with observed behavior. We used a simplified version of the series of risk preference questions posed by Barsky et al. (1997) to isolate respondents in our survey who were risk seeking. We then tested whether respondents identified as risk seekers had statistically different preference parameters regarding risk and loss from wildfires than respondents we identified as risk averse. The identification of structurally different preferences regarding wildfire hazard mitigation programs thus constitutes a test of the McClelland et al. (1993) finding that WTP for risk reduction has a bimodal distribution.

In particular, we identified respondents as risk tolerant based on their response to the following utility theoretic question:

Suppose that you are the only income earner in the family, and you have a good job guaranteed to give you and your current family income every year for life. You are given the opportunity to take a new and equally interesting job. The new job may be better (a 50-50 chance that it will double your family income) or it may be worse (a 50-50 chance that it will cut your family income by one-half). Would you take the new job?

1. *YES* ***2***. *NO*

A respondent is risk seeking, according to the definitions given above, if they respond YES to the above question, because

$$\frac{1}{2}U(2c)+\frac{1}{2}U(0.5c) > U(c) \tag{1}$$

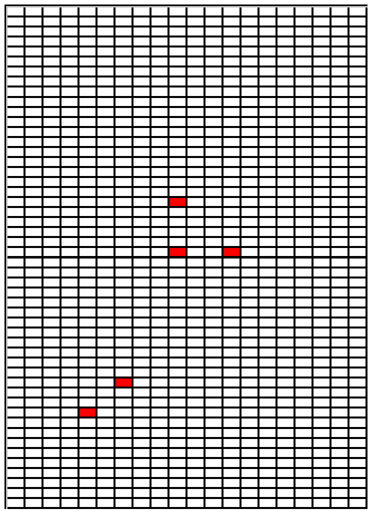
where U is a utility function and c is the stream of current income.

One of the difficulties associated with evaluating heterogeneous preferences regarding risk, alluded to above, is the fact that the risk of a home being damaged or destroyed by wildfire is very low. Fortunately, survey methods have been developed by economists studying WTP for mortality risk reduction where the risk of mortality is very low. In particular, we reference the research conducted by Krupnick et al. (2002) who developed a contingent valuation format to study of the impact of age and health status on WTP for mortality risk reductions. They used an innovative, visual method for communicating baseline risk of death (on the order of 10^{-3}) and risk changes (on the order of 10^{-4}) using a rectangular grid containing 1, 000 squares where white squares represented a healthy state and red squares represented death. We modified this format by posing a situation where the risk of a home being damaged by a wildfire was represented, on a 1,000 square lattice, by a red square and the risk of being undamaged was represented by a white square. Further, to simplify the conceptualization of the risk of a wildfire damaging a home, we asked respondents to consider the risk of various wildfire risk mitigation programs that would be in effect during the subsequent 10 years. This approach (Figure 1) was used to convey to respondents the actual risk that their home might be damaged by wildfire during the next decade.

Our experimental design varied the risk of private property damage during a 10 year period over five levels, from 1-5%, where 5% was the baseline risk associated with no investments in hazard reduction activities. Damages from wildfires were posed in terms of economic losses to real property values (e.g., homes, cars, landscape trees), and dollar amounts ranged from $10,000-$100,000. Two types of wildfire mitigation programs were included in the experiment: (1) a public program, and (2) a private program. The public program would include three activities for managing vegetation and reducing fuels throughout the community where the respondent resided (prescribed burning, mechanical treatment, and herbicide treatment), and would be funded by a tax increase. The private program would increase the defensible space on the respondents’ property by managing vegetation, such as removing trees close to the house. The cost of these programs varied from $25-$1,000 for the public program and from $50-$1,000 for the private program.

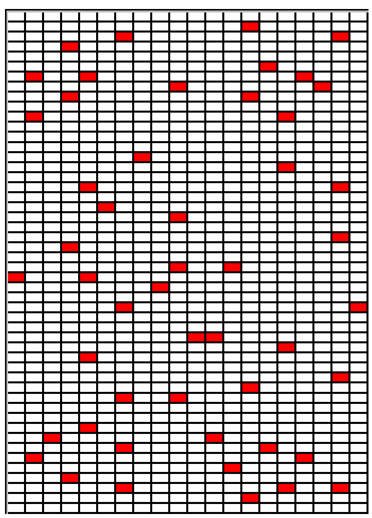
Figure 1. Chance grids used to depict wildfire risk

(1) UPPER CHANCE GRID: Annual chance



One way to illustrate the Average Annual Chance of a wildfire damaging your house is shown in the diagram to the left. The "chance grid" shows a neighborhood with 1000 houses, and each square represents one house. The white squares are houses that have not been damaged or destroyed by wildfire, and the red squares are houses that have been damaged or destroyed. Consider this to be a typical, or average, occurrence each year for this neighborhood. To get a feeling for this chance level, close your eyes and place the tip of a pen inside the grid. If it touches a red square, this would signify your house was damaged or destroyed by wildfire.

(2) LOWER CHANCE GRID: Ten year chance



The chance that your house will be damaged by wildfire during a **ten year period** is approximately 10 times the chance that it would be damaged or destroyed in a single year. The Average Ten Year Chance is shown for the same neighborhood over a ten year period, where red squares represent houses that have been damaged or destroyed during a ten year period and white squares are houses that have not been damaged or destroyed.

A completely randomized experimental design was used in constructing the choice sets (Holmes and Adamowicz 2003). An example of a choice question used in the questionnaire is shown in Figure 2. A status quo alternative, representing the typical current situation, was provided for each choice scenario. A series of three choice questions were asked to each respondent.

Figure 2. Example choice question

Question 20	**Alternative #1** **Public Fire Prevention**	**Alternative #2** **Private Fire Prevention**	**Alternative #3** **Do nothing additional**
Chance of your house being damaged in next 10 years	40 in 1,000 (4%)	10 in 1,000 (1%)	50 in 1,000 (5%)
Damage to property	$40,000	$80,000	$100,000
Expected 10 year loss = Chance x damage	$160 during 10 years	$800 during 10 years	$5,000 during 10 years
One time cost to you for the ten-year program	$300	$100	$0
I would choose: Please check one box	☐	☐	☐

To investigate the importance of preference heterogeneity in stated preference responses to wildfire hazard mitigation programs, we used a mixed (random parameters) logit model for analysis. Mixed logit (ML) is a generalized form of the standard multinomial logit (MNL) model, and allows for random variation in preferences, unrestricted substitution patterns, and correlations among unobserved factors (Train 2002). The ML model can be motivated from a utility function

$$U_{nj} = \sum_{k=1}^{K} \beta_{nk} x_{jnk} + \varepsilon_{jn} \qquad (2)$$

where x_{jnk} is a vector of K explanatory variables observed by the analyst for alternative j and respondent n, β_{nk} is a vector of preference parameters, and ε_{jn} is an unobserved independent and identically distributed (IID) stochastic variable that is distributed extreme value type I across respondents and alternatives. Because the IID assumption is restrictive in that it does not allow the error components of various alternatives to be correlated, this restriction may be relaxed by introducing additional stochastic components to the utility function through β_n. These components allow the preference parameters for the x_{jnk} explanatory variables to be heterogeneous and correlated over the sample. In particular,

$$\beta_{nk} = \beta_k + \Delta z_{nk} + \Gamma v_{nk} \qquad (3)$$

where β_k is the mean value for the k^{th} preference parameter, z_{nk} is a vector of demographic or other data observed for respondent n, v_{nk} is a random variable with zero mean and variance equal to one, Δ is a vector of parameters providing an estimate of how the observed data z shift the mean of the distribution of the preference parameter, and Γ is a lower triangular matrix that provides an estimate of the standard deviation of the preference parameter across the sample and the correlation with other preference parameters.

Probabilities in the mixed logit model are weighted averages of the standard logit formula evaluated at different values of β, where the weights are determined by the density function $f(\beta)$. Let P_{ni} be the probability that an individual n chooses alternative j from set J, such that

$$P_{ni} = \int L_{ni}(\beta) f(\beta)\, d\beta \tag{4}$$

where

$$L_{ni}(\beta) = \frac{e^{V_{nj}(\beta)}}{\sum_{j=1}^{J} e^{V_{nj}(\beta)}} \tag{5}$$

and $V_{nj}(\beta)$ is the observed portion of utility (Train 2002). The model's name comes from the statistics literature, where a weighted average of several functions is called a mixture function.

The function $f(\beta)$ can be simulated using random draws from various functional forms. For the analysis reported in this paper, we use 500 Halton (intelligent) draws from the normal distribution to estimate Γ for the random parameters associated with the *risk* and *loss* variables. Further, a dummy variable was created using responses to the risk attitude question. The influence of risk attitude on the mean of the preference parameters for the *risk* and *loss* variables was evaluated by estimating Δ. The parameter estimate on the *cost* variable for wildfire mitigation programs is treated as non-random in the analysis reported here. We specify alternative-specific constants for the public (*public-program*) and private (*private-program*) wildfire mitigation programs. Because the value of these programs may vary according to the respondents' subjective evaluation of the fire risk they face in their community, we created a dummy variable to identify respondents who indicated that they perceive that their home is located in a high (versus medium or low) fire risk area. This variable is then interacted with the alternative specific constants to create two new variables (*hi-risk-public*, *hi-risk-private*).

Survey Sample

A stratified random sample of households was drawn from the population of households in Florida. Because it was thought that people living in areas that have a higher risk of damage from wildfires would be both more aware and more concerned regarding wildfire mitigation programs, the sample was stratified to sample more heavily from high and moderate risk areas. The weighting scheme used was 1-2-3, where for each household sampled from low risk communities (as defined by the Florida State Fire Management Agency), two households were sampled from medium risk communities, and three households were sampled from high risk communities. Households were recruited using random digit dialing, and basic information was recorded during the initial phone call. Then, households that were willing to participate in the survey were mailed a survey booklet. Within two weeks of receiving the booklet, a return phone call was made to households and responses to the survey questions were recorded by the phone interviewer. For this stage of the research, 395 interviews were completed.

Empirical Results

Responses to the stated preference question regarding a gamble over lifetime income indicated that about 21 percent of the sample had risk seeking preferences. Attitudes towards risk are shown in table 1, broken down by various demographic categories. Tests of independence were conducted using the χ^2 statistic. Results of these tests indicated that households with lower levels of income and who do not have home insurance are risk seeking. Because very few observations were available for African-American and Hispanic households, we were unable to conduct a full statistical analysis of the influence of race and ethnicity on risk tolerance.[7] None-the-less, the results in table 1 indicate that risk preferences are heterogeneous across the population – a conclusion similar to that found by Barsky et al. (1997).

The results of the multinomial logit (MNL) and mixed logit (ML) models are reported in table 1. As expected, the parameter estimate on the cost, risk and loss variables were negative and statistically significant in the MNL model. These results suggest that, on average, respondents preferred wildfire hazard mitigation programs that decreased both risk and economic loss.

Implicit prices (marginal WTP estimates) are computed by dividing the parameter estimate of an attribute by the absolute value of the parameter estimate on cost. Using this formula, the implicit price of a one percent decrease in the risk of wildfire damage to a private home in Florida, using the MNL parameter estimates, is $146.25. Recall that this is a one-time payment for a program that would reduce fire risk for 10 years from the baseline risk (5 percent). Thus, the annual implicit price is roughly $14.63 for a one percent reduction in risk from the baseline. Homeowners would be WTP roughly $36.58 for a 50 percent reduction in wildfire risk from the baseline (from 5 percent to 2.5 percent). This is smaller than, but similar to, the estimated annual WTP ($57) to reduce wildfire risk in Michigan by 50 percent reported by Winter and Fried (2001).

The implicit price of damage reduction in the MNL model is roughly $7.50 for a $1,000 reduction in losses. Is this reasonable? The average annual home insurance premium in Florida is $786/year and the median house price (in 2004) was $170,800. Thus homeowners were paying about $4.60 for every $1,000 in home value protected. As our implicit price estimates are for a 10 year program, annual WTP to reduce damage by $1,000 would be about $0.75. Of course, there are other risks to homes besides wildfires (hurricanes, domestic fires), so we might expect the annual WTP to reduce wildfire damage would be less than the total WTP to reduce damages from all potential sources of risk.

[7] The sample included 18 African-American households and 9 Hispanic households. A plausible interpretation of the data suggests that African-American households are risk seeking, whereas Hispanic households are risk averse. A more rigorous test of this hypothesis awaits further data collection.

Table 1. Risk profiles by demographic categories

Variable	Risk averse (%)	Risk tolerant (%)
Homeowner insurance***		
No	33	67
Yes	82	18
Household income***		
$22,500-$37,499	50	50
$37,500-$67,499	67	33
$67,500-$82,499	71	29
> $83,000	88	12
Race (NA)		
African-American	0	100
Not African-American	80	20
Ethnicity (NA)		
Hispanic	100	0
Not Hispanic	76	24

Chi-square values for tests of independence: * denotes significance at the 0.10 level, ** denotes significance at the 0.05 level, *** denotes significance at the 0.01 level. NA indicates that the chi-square test was not applicable because of zero values in some of the cells.

The sign and statistical significance of the parameter estimates on the attribute-specific constants in the MNL model indicate that, in communities viewed as low or medium fire risk by households residing there, respondents preferred the do-nothing, status quo alternative to either a public program or private program for mitigating wildfire hazards. However, the parameter estimates indicate that households residing in subjectively-valued high fire risk areas preferred a public program to the status quo, but were neutral regarding their preference for a private program. Mean willingness to pay for a 10-year public program of wildfire mitigation by residents living in subjectively-valued high fire risk communities, holding other attribute levels constant, was $550. This value "premium" is similar to, but somewhat larger than, the WTP value reported in the contingent valuation study discussed above for Florida households (Loomis and González-Cabán 2008).

An examination of the parameter estimates for the ML model (table 2) show that the parameter estimates for the risk and loss variables are heterogeneous across the sample, as indicated by the statistically significant parameter estimates for the standard deviations of these parameters. Although the estimates for the mean parameter values for these variables are negative and statistically significant (which is consistent with the MNL model), the estimated wide dispersion on the risk parameter estimate indicates that a substantial proportion of the respondents were risk tolerant. The estimates of the Δ parameter estimates show that respondents who were identified as risk seeking, based on the stated preference question regarding a lottery over lifetime income, were risk seeking in their choices regarding wildfire hazard mitigation programs. Thus, the responses to the risk attitude question were consistent with respondent choices regarding risk-loss tradeoffs in wildfire mitigation.

Table 2. MNL and ML preference parameters for wildfire hazard mitigation programs

Variable	Multinomial logit model	Mixed logit model (mean)	Mixed logit model (std. dev.)
risk (%)	-0.117***	-0.138***	0.335**
	(0.033)	(0.045)	(0.136)
$risk_{risk\_seeking}$ (%)	--	0.203**	--
		(0.084)	
loss ($1,000)	-0.006***	-0.004**	0.009
	(0.002)	(0.002)	(0.006)
$loss_{risk\_seeking}$ ($1,000)	--	-0.006*	--
		(0.003)	
cost	-0.0008***	-0.0008***	--
	(0.0001)	(0.0001)	
public_ program	-0.28**	-0.074	--
	(0.13)	(0.17)	
private_ program	-0.45***	-0.26	--
	(0.14)	(0.18)	
hi_risk_public	0.72***	0.83***	--
	(0.22)	(0.27)	
hi_risk_private	0.45*	0.55*	--
	(0.24)	(0.29)	
N	395	395	--
pseudo-R^2	0.042	0.056	--

Note: standard errors in parentheses. * indicates significance at the 0.10 level,
** indicates significance at the 0.05 level, *** indicates significance at the 0.01 level.

The identification of risk-seekers in the sample induces a bimodal distribution of preferences regarding risk – which is consistent with results reported by McClelland et al. (1993) – and a bimodal distribution of preferences over economic losses. The risk-loss trade-offs exhibited by risk averse respondents were very different than the trade-offs exhibited by risk seeking respondents. Clearly, the ML logit model provides a much richer description of preferences regarding risk than does the MNL model.

Conclusions

WTP estimates for reductions in risk and economic losses from wildfires were estimated from a choice experiment and were found to be roughly consistent with WTP estimates derived from contingent valuation studies and from estimates of home insurance premiums. People living in communities that they considered to be at high risk of wildfires were willing to pay a substantial premium for public wildfire mitigation programs, but had modest WTP for fuel reduction activities on their own property. This dichotomy may be due to the visual impact of fuel reduction programs close to ones home.

Economic surveys can be used to identify segments of the population living in fire prone landscapes that may be reluctant to support fire hazard mitigation programs due to their risk preferences. Our analysis revealed that roughly 20 percent of the respondents to our survey were risk seeking, while roughly 80 percent were risk averse. We found that risk preferences are related to demographic characteristics, and that households that are risk seeking are more likely to make risky choices regarding wildfire mitigation programs. These households might be considered the weak-link in the provision of community wildfire protection programs. Consequently, our results suggest that a special effort should be made to assist those segments of the population that may be reluctant to participate in wildfire mitigation programs in order to strengthen the weakest links to wildfire protection. Our results suggest that low income households, households without homeowner insurance, and African-American households living in the WUI may be good candidates for assistance.

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