Estimating Private Incentives for Wildfire Risk Mitigation: Determinants of Demands for Different Fire-Safe Actions

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Abstract

In this article we develop a general conceptual model of a property-owner's decision to implement actions to protect his property against wildfire threat. Assuming a prospective-utility maximizing decision maker, we derive a system of demand functions for fire-safe actions that characterizes factors affecting individual decision making. We then empirically estimate the demands for various fire-safe actions functions using survey data of property owners facing a wildfire threat in Nevada. We find that the probability of individuals implementing some fire-safe action increases with value of the residence, previous experience with wildfire, the property being used as the primary residence, positive attitude towards wildfire management methods on public lands, and connectedness of community members. A lower probability of implementing fire-safe actions is found for those who value pristine nature and privacy that nature provides.

Introduction

The severity and size of wildfires on public lands in the United States has increased steadily over the past decades, with a corresponding increase in wildfire suppression costs (Stephens and Ruth 2005; Calkin et al. 2005; Gebert, Calkin, and Yoder 2007; Westerling et al. 2006; GAO 2004; GAO 2007). Because wildfire suppression efforts are more complex when residential areas are threatened than on unoccupied wildlands (Calkin et al. 2005), residential developments that border public wildlands, along with the federal mandate that wildfire suppression strategies must prioritize protecting private property second only to protecting human safety, have contributed to the escalation of wildfire suppression costs. To counteract the increase in wildfire suppression costs, programs have been developed to encourage private property owners to create and maintain 'defensible space'[1] around homes and other structures (Denis 2006). In this article we use "fire-safe actions" to refer to defensible-space creation and other actions taken by the property owners to protect their properties and mitigate the potential losses due to wildfire. These fire-safe actions provide benefits to the individual property owners, to their neighboring property owners through their spillover effects, and to society in general through reduced public expenditures on wildfire suppression.

A common observation, however, is that private property owners tend to invest less than expected or socially-desirable levels in fire-safe actions (Brenkert-Smith, Champ, and Flores 2006; Winter and Fried 2000; Winter, Vogt, and Fried 2002). Several potential reasons have been suggested. First, wildfire suppression costs accrue to public agencies and reduction of these costs is not likely internalized in the private decision-making objective, thus resulting in private underinvestment relative to socially optimum levels (Kobayashi, Rollins, and Taylor 2010). Second, in addition to the cost externality, physical externalities or spillover effects of fire-safe actions on one property to neighboring properties can result in a suboptimal community-level fire-safe outcome (Butry and Donovan 2008; Shafran 2008). Third, occurrence, spread, and severity of wildfire are probabilistic, and risk preferences of individual property owners can affect their fire-safe investment decisions. In particular, a property owner may exhibit a risk-seeking attitude in that he prefers a "gamble" (i.e. betting on the chance that a wildfire will not occur or, should it occur, the damage will be small) to a "sure loss" in terms of expenditures on fire-safe investments (Rollins and Kobayashi 2010). Fourth, the private cost of fire-safe investment is not necessarily only monetary. For example, changes in aesthetic qualities of a property caused by fire-safe actions may be utility-reducing for those who purchased properties because of aesthetic qualities that are also correlated with wildfire risk (Nelson, Monroe, and Johnson 2005). Lastly, homeowners' ignorance about the danger of wildfires and potential benefit of fire-safe actions may likely contribute to underinvestment (Brenkert-Smith, Champ, and Flores 2006). Given these potential reasons for private underinvestment and disincentives for fire-safe investments, it is imperative to systematically analyze and empirically investigate what motivates property owners to invest in fire-safe actions. In this article, we build a general conceptual model of decision making of a property owner regarding fire-safe actions and empirically estimate their determinants using survey data.

The literature includes relatively few attempts to theoretically model homeowner incentives to implement fire-safe actions. Shafran (2008) models homeowners' decisions to create defensible space in a game-theoretic framework, where the spillover effects of neighbors' actions are taken into account in the individual maximization of utility generated from income minus the investment cost and expected loss from wildfire. In contrast, Butry and Donovan (2008) hypothesize that homeowners typically do not take into account spillover effects of one's own action onto the others in the community when making fire-safe decisions and show the impacts of the exclusion of spillover effects from decision making on the fire outcomes at the community-level using a stochastic fire-behavior simulation model. Butry and Donovan (2008) also argue that the externality of one's fire-safe action can be positive or negative depending on the spatial configuration of fire-safe implementation within a community as well as weather factors such as wind speed, suggesting that more action may not be always welfare enhancing.

Empirical analyses on the determinants of property owner fire-safe actions are also scarce. Most prior studies are restricted to presenting anecdotal evidence or summary statistics of survey data (e.g. Brenkert-Smith, Champ, and Flores 2006; Daniel, Weidemann, and Hines 2003; Nelson, Monroe, and Johnson 2005; Vogt 2003; Vogt, Winter, and Fried 2003; Winter and Fried 2000, Winter, Vogt, and Fried 2002), and inferences that can be made about decision making of individual respondents are limited. We are aware of only two studies where the determinants of fire-safe actions are empirically estimated. Shafran (2008) tests the predictions of a game-theoretic conceptual model using data for Colorado homeowners and finds that the decision to invest in defensible space is positively correlated with actions of adjacent neighbors who undertake the same investments. Schulte and Miller (2010) present results of logistic regressions, using a set of explanatory variables similar to the set in our empirical models, but they do not present a theoretical justification of their empirical model specification.

The contribution of this article to the literature is twofold. First, we develop a conceptual model of individual decision making that is general and can accommodate a wide variety of factors that potentially affect fire-safe action decision making. In doing so, we consider two categories of fire-safe actions: those actions that reduce the probability of a wildfire reaching the structure (e.g. residence) on one's property and those actions that reduce losses given a wildfire reaches the structure. We use a prospective-utility maximization framework (Kahneman and Tversky 1979; Tversky and Kahneman 1992) to model the decision process regarding the two types of fire-safe actions. This framework allows us to model three crucial features: 1) disutility from probabilistic losses due to wildfire and sure loss of investment costs at the same time as 2) utility or disutility of implementing fire-safe actions (satisfaction or dissatisfaction that is non-monetary) as well as 3) subjective evaluation of wildfires risks through non-linear probability transformation. We derive a system of demand functions for fire-safe actions that characterize the potential factors that explain individual choices of fire-safe actions.

Second, the theoretical predictions are empirically tested using survey data. We estimate the parameters of the demand functions for fire-safe actions, which also reflect parameters of risk preferences, using data collected through a survey of homeowners who live in wildfire-prone areas in Nevada. In contrast to Shafran (2008) and Schulte and Miller (2010), where fire-safe actions are aggregated without theoretical or empirical justification to form single dependent variables, we estimate a system of demand functions for individual fire-safe actions. This increases the scope for policy implications that can be derived from the estimation results. Our key empirical findings include the following. The probability of individuals implementing some fire-safe action increases with the value of the residence, previous experience with wildfire, the property being used as the primary residence, a positive attitude towards wildfire management methods on public lands, and the degree of connectedness of community members,. A lower probability of implementing fire-safe actions is found for those who value pristine nature and the privacy that nature provides.

Conceptual Framework

We model the decision problem facing a property owner in choosing whether and how much of each specific fire-safe action to implement on his own property. We differentiate among three fire-related probabilities: 1) the probability that a wildfire threatens[2] the decision maker's property (p), 2) conditional on the occurrence of a wildfire, the probability that the fire reaches the border of the decision maker's property (p^b), and 3) conditional on the occurrence of a wildfire and its reaching the property boundary, the probability that the fire reaches the structure(s) on the property (p^s). These are *perceived* probabilities by the decision maker, the formation of which is based on information available to him and on other conditions and processes that are unobservable to the researcher. The demand for fire-safe actions that we will derive is conditioned on the decision-maker's perception of these risks and the perceptions of the contribution of each action toward reducing the losses due to wildfire. In the empirical application, we make inferences about what influences perception formation, e.g. what types of information decision makers use to make the risk judgment.

We assume that property owners distinguish exogenous risks, over which they have no influence, from those that they can influence. We consider that the first two probabilities, p and p^b, cannot be influenced by the decision maker. The objective levels of these probabilities depend on exogenous factors that are known to increase or decrease the threat that a wildfire will occur in or near one's community and affect how the fire will spread within the community if it does occur. These exogenous factors include vegetation (or fuel) types within the decision-maker's community as well as in the surrounding areas; topography, especially slope as fires tend to spread more rapidly upward; general weather factors such as wind speed, temperature, and humidity in the area; and for our application in the Great Basin whether the community is adjacent to public wildlands. Proximity to public lands is important for formulation of policies to reduce wildfire suppression costs on these lands because fire-safe actions on bordering private properties can create firebreaks that prevent wildfire from advancing into the interior of communities, and thus have great impact on the overall costs of wildland fire suppression. Additionally, the probability p^b is affected by the capacity and effectiveness of firefighting in the community (e.g. proximity to a fire station, accessibility of the decision-maker's property to fire crews, and availability of water sources); community characteristics such as housing density and neighborhood spatial layout, which may depend on building codes and other regulations; and whether or not (as well as how) much other community members invest in fire-safe actions. To what extent these exogenous factors are incorporated in the decision maker's perception of the probabilities and the resulting decisions about fire-safe actions is an empirical question.

On the other hand, we assume that the property owner has discretion to take fire-safe actions to influence the perceived probability p^s. Let $\tilde{p}^s$ denote the decision-maker's belief regarding the *joint* probability that a wildfire occurs, it reaches the property boundary, and it reaches the structure, such that

(1) $$\tilde{p}^s = \tilde{p}^s(x_1, \dots, x_I; p, p^b, \boldsymbol{\alpha}),$$

where $x_1, \dots, x_I$ denote the amount of actions taken to reduce the probability of a wildfire reaching the structure on one's property (e.g. trimming low tree limbs, planting low growing and non-flammable plants, maintaining a well-watered landscape) and $\boldsymbol{\alpha}$ is a vector of exogenous factors, other than p and p^b, affecting probability $\tilde{p}^s$. For example, the parameter vector $\boldsymbol{\alpha}$ includes the lot size of the property, as well as most of the factors that influence p and p^b.

While $x_1, \dots, x_I$ affect the probability of a fire reaching the structure, we also consider a second set of fire-safe actions that a property owner can take. Let $y_1, \dots, y_J$ denote the amount of actions that reduce the losses given a wildfire reaches the structure. Examples of these actions include installation of fire-resistant windows, roof, and siding materials. Without any of fire-safe actions $y_1, \dots, y_J$, the property owner is assumed to incur a financial loss of d_0 ($d_0 \leq 0$) if a fire reaches the structure. We consider that d_0 is the uninsured portion of property losses and do not explicitly model the insurance decision in this study. With fire-safe actions, the decision maker is assumed to believe that the loss is reduced to d_1 ($d_0 \leq d_1 \leq 0$) such that

(2) $$d_1 = d_0 + f^d(y_1, \dots, y_J; \boldsymbol{\beta}),$$

where $f^d(\cdot) \geq 0$ is the benefit of fire-safe actions $y_1, \dots, y_J$ measured in terms of reduced financial losses and $\boldsymbol{\beta}$ is a vector of exogenous factors affecting the loss reduction. Parameter vector $\boldsymbol{\beta}$ includes characteristics of the structure that cannot not be easily altered (e.g. surface area of the structure, its condition at the time of purchase; fire-safe actions required by building codes, covenants, conditions and restrictions (CC&Rs), etc.; and the homeowner's own capacity to fight a fire (e.g. health of residents, the number of residents, and availability of natural water sources). Again, whether these factors are incorporated in the decision-maker's perception of the effectiveness of fire-safe actions is empirically investigated.

As in Rollins and Kobayashi (2010), we model individual decision making using prospect theory (Kahneman and Tversky 1979; Tversky and Kahneman 1992), which explicitly differentiates utilities from gains and losses. Using the terminology of Kahneman and Tversky (1979) the prospect considered in this study is strictly negative, where both outcomes of the two events (fire reaching the structure or not) are negative and the probabilities of the two events add up to unity. Prospect theory also accommodates nonlinear preferences in probabilities, where an objective probability may be evaluated differently and nonlinearly by different individuals or by the same individual under different contexts and situations. Accordingly, in prospect theory, risk attitudes are jointly determined by the utility function $v(\cdot)$ and probability weighting function $w(\cdot)$, whereas in expected utility theory risk attitudes depend solely on the shape of the utility function.

In this study, we extend the interpretation of probability transformation and apply it to perceived joint probability $\tilde{p}^s$. We consider an indirect utility function for losses $v(m;\boldsymbol{\gamma})$, $m \leq 0$, and a probability transformation function $w(\tilde{p}^s;\boldsymbol{\delta})$, where $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$ are vectors of parameters that affect individual risk attitudes. Rollins and Kobayashi (2010) find that $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$ are associated with demographic characteristics of the property owners and past experience with wildfires. The prospective utility for our problem is thus defined as:

(3) $$PU = w(\tilde{p}^s, \boldsymbol{\delta})v(d_1 + c; \boldsymbol{\gamma}) + \left(1 - w(\tilde{p}^s, \boldsymbol{\delta})\right)v(c; \boldsymbol{\gamma}),$$

where $c = \sum_{i=1}^{I} c_i^x x_i + \sum_{j=1}^{J} c_j^y y_j$, and $c_i^x, i = 1, .., I$, (or collectively vector $\boldsymbol{c^x}$) and $c_j^y, j = 1, \dots, J$, (collectively $\boldsymbol{c^y}$) are the unit costs of taking action x_i and y_j, respectively. Finally, anticipating an empirical application to cross-sectional data, we argue that individuals may incur additional utility or disutility from implementing fire-safe alternatives. For example, those who value the natural surroundings and privacy from trees and shrubs close to their residence may receive disutility from fire-safe actions that involve altering the native vegetation (Rollins and Kobayashi 2010; Nelson, Monroe, and Johnson 2005). Individual characteristics that directly affect the prospective utility through fire-safe actions are included in parameter vector $\boldsymbol{\theta}$.

By assuming that the property-owner's objective is to maximize PU, the first-order conditions result in the following system of demand functions for fire-safe actions:

(4) $$x_i^* = f_i^x(\boldsymbol{c^x}, \boldsymbol{c^y}; p, p^b, d_0, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}, \boldsymbol{\theta}), i = 1, \dots, I$$

(5) $$y_j^* = f_j^y(\boldsymbol{c^x}, \boldsymbol{c^y}; p, p^b, d_0, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}, \boldsymbol{\theta}), j = 1, \dots, J.$$

These functions are decreasing in own unit prices but the cross-price effects, i.e. whether the actions are substitutes or complements, are not known *a priori*. Similar conceptual models developed by Butry and Donovan (2008) and Shafran (2008) focus on modeling strategic interactions between neighboring decision makers. Our model implicitly accommodates intra-community strategic interactions as long as levels of investment by other community members are included as a factor affecting p^b. Butry and Donovan (2008) also differentiate between two fire-related probabilities (probabilities of "attack" and "ignition" on houses), where they suggest that a structure that is on fire can "attack" nearby residences through direct flame contact, radiant heat or spots. Therefore, while the number of times a house will be attacked by fire is a function of its surroundings, the probability of ignition depends solely on the house's flammability. The authors incorporate those two probabilities in their stochastic fire-spread model to simulate the impacts of various levels of individual actions on the overall outcomes at the community level.

Data and Estimation Strategy

To empirically investigate the nature of the demand functions for fire-safe actions, we use data collected through a survey of homeowners that face a threat of wildfire in Nevada. A previous study ranked every community in Nevada according to objective measures of wildfire threat (Resource Concepts Inc. 2005). Among these communities 20 were rated as facing the highest risk of wildfire, and in 2006, a survey was mailed to owners of property located in these 20 communities. Most of these communities are located adjacent to public lands that contain high desert rangelands and mountain forests in the Lake Tahoe area. Out of the 2,236 questionnaires that were mailed out, 234 were undeliverable and 383 were returned completed, resulting in an overall response rate of 19%. For the purpose of the article, six observations of renters (as opposed to property owners) and an observation with an unrealistic response for lot size are dropped, resulting in 376 observations used in the analysis. Respondents represent a variety of income ranges and a wide variation in other social and demographic characteristics.

The questionnaire described 21 specific fire-safe actions that could be undertaken to reduce losses to homes in the case of a wildfire. We classify the 21 actions into four groups depending on a) whether the actions correspond to x_i or y_j, i.e. whether the actions reduce the probability of a fire reaching the structure (p^s) or they reduce damage if a fire does reach the structure; and b) whether the actions represent routine activities or one-time investments. Roughly, actions representing x_i are applied to yards and those representing y_j are applied to houses. Descriptions of the 21 actions and their summary statistics are provided in Table 1. Respondents were asked whether each of the 21 actions had been implemented on their property, and if so, at what cost.

They were also asked to identify their reasons for 'no' responses from the following list: 1) the action would not apply to my house, 2) the action applies to my house but I rent, 3) I don't want to or can't, 4) I plan to in the future, or 5) I need more information. Respondents chose among the following to explain 'yes' responses: 6) it was done prior to moving in, 7) done after moving in to reduce fire risk, or 8) done after moving in for other reasons. We discard observations with responses of 1) and 2) from the analysis. Because the questions asked whether the fire-safe actions were either implemented or not, we construct a binary variable for each fire-safe action with reasons for 'yes' responses 6) through 8) coded as 1 and explanations for 'no' 3) through 5) coded as 0.

Accordingly, we approximate the system of reduced-form demand functions (4) and (5) with dichotomous choice of 'yes' or 'no' for each action instead of continuous specification of x_i^* and y_j^*. We use these binary variables constructed for x_i^* and y_j^* as the dependent variables and specify probit models for each of the 21 demand functions for fire-safe actions.[3]

Independent variables included in the probit models are chosen to represent the demand function variables and parameters identified in the previous section. The selection of variables for the final models was challenging because of missing values and because many variables are correlated or simultaneously determined. Table 2 lists the variables included in the final models. Here we discuss how explanatory variables were selected with reference to the reduced-form demand functions (4) and (5). First, a great many responses are missing for questions regarding the cost of each fire-safe action. This is not surprising given that many actions were performed prior to ownership, as part of the building costs, or as part of a larger renovation that was done for other reasons. Missing prices pose a difficult problem for estimating a system of demand functions. Respondents were asked additional qualitative questions about whether time and money prevented them from doing more actions in general; however, this qualitative information is not useful in determining the own-price elasticity of demand for each action or to identify complementarity and substitutability between fire-safe alternatives through cross-price effects. Alternatively, we argue that other explanatory variables, namely *lotsize* and *nature*, capture some effects of costs associated with certain types of fire-safe actions. For example, lot size of property, all else equal, is positively associated with the cost of actions implemented on the yard. Thus, we expect the variable *lotsize* to capture some of the effects of missing $\boldsymbol{c^x}$ in the model. The variable *nature* likely reflects non-monetary cost of certain fire-safe actions (see below). Nonetheless we expect lower explanatory power from these models compared to the case where $\boldsymbol{c^x}$ and $\boldsymbol{c^y}$ were included.

Of the exogenous factors that affect p, p^b, and p^s identified in the previous section, we include in the probit models distance from public lands (*publand*) and lot size (*lotsize*) of the respondent's property. We argue that the variable *publand* captures the property owner's perceived risk of wildfire given that they have no means to control the vegetation on public lands (risk increases with proximity to public land). The property owner may react to this threat in one of two ways: given the higher risk, he may be more likely to invest in each of the fire-safe actions or he may decide that the risk is so great that fire-safe actions are not effective. Therefore, whether a property owner responds to a higher threat of wildfire due to proximity to public lands by increasing or decreasing his own fire-safe actions is an empirical question. This is similar to the strategic interactions among private homeowners as studied by Butry and Donovan (2008) and Shafran (2008), but the relevant interaction here is between private property owners and public land managers.

Most of the exogenous factors that characterize the general risk levels of the communities and their surrounding areas and thus potentially affect p and p^b are physical features identified in fire behavior science (Andrews 1986; Andrews 2009; Rothermel 1983; Finney 2004). Information on some of these factors is available from a study that was conducted to determine wildfire risk levels for all communities in Nevada (Resource Concepts Inc. 2005). We constructed a series of community-level variables based on the information found in that study, including average slope and aspect of a community, firefighting capacity, water availability, road width and grade, and the number of houses within the community that have adequate defensible space. However, many of these variables are collinear among themselves and with individual-level variables from the survey that we believe are important determinants of individual fire-safe actions. For example, a community fire-risk variable constructed based on topography and vegetation (fuel) type is highly correlated with community firefighting capacity, as fire stations are often built in high-risk areas. Community firefighting capacity in turn is found to be highly correlated with individual experiences of wildfire (*experience*; see below). In order to include the variable *experience* as an individual characteristic, we did not include the community-level risk variables constructed from the secondary data.

We also would have wished to analyze strategic interactions among private property owners, which would have required information about fire-safe actions of immediate neighbors for each property owner. However, such information was not available, and the community-level information that is available from the secondary source (Resource Concepts Inc. 2005) measured the proportion of houses with adequate defensible space within each community. Attempts were made to use this variable as a proxy for neighbors' actions in regressions, but no significant results were obtained. It is possible that this variable, constructed based on expert assessment, does not reflect the property owners' own assessments of fire-safe levels of other community members. As a result, the final models do not include a variable that represents neighbors' actions.

The market value of the residence (*resvalue*) is included to control for the magnitude of potential financial losses (d_0). It is expected that, all else equal, incentives to implement fire-safe actions would increase with the value of the residence. Respondents were asked whether they had homeowner's insurance policies, but this variable is not included in the model because it has a very low variability (93% of respondents had homeowner's insurance) and its inclusion did not add to the explanatory power of the models.

To characterize the parameters of prospective utility ($\boldsymbol{\gamma}, \boldsymbol{\delta}, \boldsymbol{\theta}$), we include the following five variables: whether the respondent has past experience with wildfire (*experience*), whether the property is the primary residence (*primary*), whether and to what extent the respondent approves of controlled (prescribed) burns as a land management method (*control-burn*), whether and to what extent the love for nature and privacy discourages the property owner from taking fire-safe actions (*nature*), and how respondents rate neighbors' safety as a motivation for implementing fire-safe actions (*neighbor*).

The variable *experience* is represented as a dummy variable that takes the value of one if the respondent reported to have had any wildfire on their current or previous property, a wildfire had come within 10 miles of their residence, or they had ever been evacuated due to a wildfire threat. This variable likely influences how property owners subjectively assess probabilities of wildfire threat. In a companion paper, Rollins and Kobayashi (2010) find that the subjective evaluation of objective wildfire probabilities by those with fire experience is more "sensitive," which makes the general tendency of overvaluation of small probabilities and undervaluation of large probabilities more prominent for this group of property owners. If the observation applies to subjective evaluation of the perceived probability $\tilde{p}^s$, this in turn implies that, for a sufficiently small perceived probability of wildfire, those with fire experience tend to place a higher decision weight on the outcome with fire (the first term in equation (3)) and thus on the value of fire-safe actions. Thus, as long as the perceived fire probabilities are sufficiently small, we expect positive coefficients on the variable *experience* in the regressions.

We include the remaining four variables to capture additional utility or disutility associated with implementing fire-safe actions. We expect that homeowners for whom the property is their primary residence receive higher utility from fire-safe actions than those who state that the property is not their primary residence. Based on a survey of California residents, Vogt (2003) reports that full-time residents invested more than seasonal residents in defensible space creation. In our survey, respondents were asked if they approved of the use of various fuels management methods, such as controlled burns, on public lands. We expect that those who approve likely receive additional utility from their own fire-safe actions. On the other hand, those who value pristine nature and privacy likely receive disutility from fire-safe actions that involve altering native vegetation (Nelson, Monroe, and Johnson 2005). The variable nature is created as a result of factor analysis where a strong correlation is found among the following three out of 19 reasons for not implementing more fire-safe actions: "I like the trees and natural vegetation," "Conflict with beauty/aesthetics of the property," and "I like the privacy from trees close to my house." Similar factor analyses are conducted by Bright et al. (2003). The variable *neighbor* is constructed as the average rating within each community of the importance of neighbors' safety as a motivation for implementing fire-safe actions. This variable is intended to capture how tightly knit each community is. We expect that residents of tightly knit communities receive additional utility from implementing fire-safe actions.

Finally, a dummy variable for one community, Virginia Highlands (*VH*), is included in each of the probit models. This community had previously received a community-wide grant from the U.S. Forest Service to implement a mass clean up of fuels. Property owners in the community had to work together in order to receive the grant. Thus, we expect a higher probability of implementing fire-safe actions in this community.

No demographic variables could be included in the final estimation models. One reason is that many of the demographic variables collected in the survey represent those of the respondents while the actual fire-safe decision making may occur at the household level (Brenkert-Smith, Champ, and Flores 2006). Household income may be a reasonable household-level demographic variable to include in the estimation models. However, the household income variable has many missing values and its inclusion would force us to give up approximately 13% of our observations. We nonetheless estimated such models, but the coefficients on the income variable were not statistically significant from zero. Schulte and Miller (2010) also report that no individual or household demographic variable is statistically significant in estimating the probability of implementing similar fire-safe actions.

The resulting probit model for each action is:

$$\text{(6)} \qquad \text{Prob}(yes_k) = \Phi(\boldsymbol{X}_k'\boldsymbol{\beta}),$$

where subscript *k* indicates respondent, $\Phi(\cdot)$ is a normal cumulative distribution function, $\boldsymbol{X_k}$ is the vector of explanatory variables that include *publand*, *lotsize*, *resvalue*, *experience*, *primary*, *control-burn*, *nature*, *neighbor*, *VH*, and a constant term, and $\boldsymbol{\beta}$ is the vector of coefficients to be estimated.

Estimation Results

A total of 21 probit models are estimated to determine the factors that explain a property owner's decision to implement fire-safe actions. We report the results for five actions, with at least one action representing each of the four groups in Table 1. The five fire-safe actions we focus on are:

(2) Remove low tree limbs or prune down tall shrubs under them (*Pruning*), group A

(6) Plant low-growing and less-flammable plants within 30 feet of the house (*Planting*), group B

(10) Trim tree limbs away from house and chimney (*Trimming*), group C

(15) Install at least double paned or tempered glass windows (*Window*), group D, and

(19) Install fire-resistant roofing (*Roof*), group D.

Actions *Pruning* and *Planting* are undertaken on the property to reduce the probability of a wildfire reaching the structure on one's property and thus are representative of x_i. Actions *Trimming*,[4] *Window*, and *Roof* are implemented on or close to the house to reduce the losses given that a fire reaches the structure and therefore are representative of y_i. While *Pruning* and *Trimming* are maintenance activities that are implemented routinely and repeatedly, *Planting*, *Window*, and *Roof* are one-time investments.

The estimation results for these five actions are presented in Table 3. For the ease of interpretation of the results, marginal effects of the explanatory variables on the probabilities of implementing the fire-safe actions are presented. In each of the five probit models, the Likelihood Ratio Chi-Square test rejects the null hypothesis that all of the regression coefficients are simultaneously equal to zero at the 0.1 significance level. A higher pseudo-R^2 value is obtained for the *Window* model (0.146) than for the other four models (0.0572-0.0767).

Coefficients on *publand* are statistically insignificant in all of the five probit models. The sample in this dataset is drawn from the 20 communities at highest risk of wildfire threat, where the original risk rating was in part influenced by their proximity to public lands (Resource Concepts Inc. 2005). Thus, it is possible that the variation in the distance from public land observed in this dataset is unimportant in explaining the variation in the level of fire-safe actions by the property owners in these communities. However, looking across models, the P-values for the coefficients on *publand* are 0.12 and 0.15 in the *Pruning* and *Planting* models, respectively, while the P-values in the other models are over 0.8. This may indicate that the distance from public land influences property-owner decision making more importantly for fire-safe actions in the yard than for the house, and that property owners react to the increased risk from proximity to public lands by reducing fire-safe actions on the yard. (Because the value for *publand* is the distance to the nearest public land and the coefficient sign is positive, the probability of implementing *Pruning* and *Planting* decreases with proximity to public lands). Shafran (2008) also considers proximity of homes to public lands in his empirical modeling of homeowner defensible space creation decisions and finds that adjacency to public lands negatively affects a property owner's incentive to mitigate wildfire risk.

Variable *lotsize* has a statistically significant coefficient only in the *Roof* model. However, we find a clear pattern in the sign of the coefficients between actions for the yard (negative) and those for the house (positive). Lot size of property conceivably has a positive influence on the cost of fire-safe actions implemented in the yard. Thus, the result for the yard actions is consistent with own price effect. The opposite result for the house actions may indicate that yard and house actions are in fact substitutes. According to the estimates, a one-acre increase in the lot size is associated with an increased probability of investing in fire-resistant roof by 2.11%.

As expected, the estimated coefficients on *resvalue* are positive in all models but one (*Planting*). Statistical significance is obtained only for the *Window* model, where a million dollar increase in property value is estimated to increase the probability that a property owner installs at least double paned or tempered glass windows by 13.8%.

The estimated coefficients on *experience* are positive in all five models, with significance obtained for the *Trimming* model at the 5% level. The result is expected and is consistent with the predictions of the prospect theory as discussed in the previous section and more in detail in Rollins and Kobayashi (2010). Those with wildfire experience likely overvalue wildfire probabilities and thus adopt more fire-safe actions. Recall also that this variable is correlated with general risk levels and the firefighting capacity at the community level. It is likely that the response of property owners to both perceived general risk levels and personal experiences are confounded in the marginal effects of *experience* reported in Table 3.

When significant, the coefficients on *primary* are always positive, which is consistent with our prediction. The coefficients are significant in all three "investment" models (*Planting*, *Window*, *Roof*), whether in yard or on house, but not in the "routine activity" models (*Pruning*, *Trimming*). This indicates that fire-safe investment motives are strongly associated with the importance of the property as the primary residence. This is not surprising if one considers that for an insured homeowner, a primary residence is more likely to contain items with personal value that are not insurable, contrary to properties that are owned for their investment value or as vacation homes.

As expected, the coefficients on *control-burn* are positive in all models, with significance attained in the *Planting* model. On the other hand, the coefficients on *nature* are negative in all models, with significance observed in *Pruning* and *Trimming* models. While *Planting* also alters the natural landscape, *Pruning* and *Trimming* involve the removal of live vegetation. It is likely that the disutility from these two actions is more prominent than from the other fire-safe actions for those who value nature and privacy.

The variable *neighbor* has significant and positive coefficients in the *Window and Roof* models. While we do not have clear interpretations of this result, social relationships among community members in the dissemination of knowledge about wildfire risks and promotion of fire-safe actions could be playing a role here. Similar findings are reported by Brenkert-Smith, Champ, and Flores (2006). As expected, the coefficients on *VH* (Virginia Highlands community dummy) are consistently positive.

Lastly, we comment on which factors influence property owners' perceptions about wildfire risks and the effectiveness of fire-safe actions. Many variables that characterize community-level general wildfire risks could not be included in the estimation models due to collinearity with other variables. Several regressions included variables that are considered to be important in their influence on wildfire behavior, such as slope and aspect, but these lacked explanatory power in predicting property-owner fire-safe decisions. On the other hand, there was some evidence that the number of outreach and educational materials received about wildfire risks are positively associated with the probability of implementing some fire-safe actions, especially those that could be considered as low-cost one-time investments (e.g. placing a spark arrest on the chimney, enclosing decks with a fire-resistant, solid skirt and covering vents with 1/8'' metal wire mesh). While their identification is econometrically challenging, investigating the determinants of property-owner perceptions of wildfire risks and fire-safe effectiveness strengthens the analyses on the fire-safe decision making.

Conclusions and Discussions

In this article we develop a general conceptual model of a property-owner's decision to implement actions to protect his property against wildfire threat. We model the decision problem in a prospect theory framework, where the decision maker maximizes prospective utility that depends on the utility function and the nonlinear transformation function of perceived wildfire probabilities as well as functions that determine the perceived consequences of the chosen fire-safe action levels. We consider two types of fire-safe actions: those that reduce the probability that a wildfire reaches the structure on one's property and those that reduce the losses given a fire reaches the property. Through the systematic analysis of the decision problem, a system of demand functions for fire-safe actions is derived that characterizes factors that potentially explain individual choices of fire-safe actions.

We then empirically estimate the fire-safe action demand functions using survey data of property owners facing a wildfire threat in Nevada. Building upon the conceptual model of individual decision making, the empirical models specified in this article include all of the theoretically important factors as available in the data. While most prior studies are restricted to presenting anecdotal evidence or summary statistics of survey data (e.g. Brenkert-Smith, Champ, and Flores 2006; Daniel, Weidemann, and Hines 2003; Nelson, Monroe, and Johnson 2005; Vogt 2003; Vogt, Winter, and Fried 2003; Winter and Fried 2000; Winter, Vogt, and Fried 2002), two studies report empirical analyses comparable to those presented in this article (Shafran 2008; Schulte and Miller 2010). The work by Shafran (2008) shares motivation and a conceptual modeling approach similar to ours, but his empirical application includes only one dependent variable, "defensible space" (which actions are actually taken is left rather vague, relative to our specification), and the estimation model does not include individual or household characteristics. Schulte and Miller (2010), on the other hand, use data that contain variables that are similar to those in our dataset, and the authors consider five fire-safe actions that are almost identical to those we focus on. However, in their logit specification, the five actions are aggregated into a binary variable that takes the value of zero if only one action is taken and one if two or more actions are taken. No theoretical model of individual decision making is presented. In contrast, we estimate demand functions for individual fire-safe alternatives. In particular we differentiate between four important groups of actions: routine activities implemented in the yard, investments in the yard, routine activities on/around the house, and investments on the house. Because of this empirical approach, we can analyze how adoption of each type of fire-safe action is influenced by various factors and identify complementarity or substitutability between fire-safe alternatives. In fact, we find substitutability between actions implemented in the yard and those implemented on the house.

Other empirical findings of this article include the following. The probability of individuals implementing some fire-safe action increases with value of the residence and if the property is the primary residence. Previous experience with wildfire, a positive attitude towards wildfire risk management methods on public lands, and connectedness of community members are also positively associated with the probability of fire-safe actions. A lower probability of implementing fire-safe actions is found for those who value pristine nature and the privacy that nature provides.

The most serious reservation of our empirical results, however, is the low explanatory power of the estimation models, with pseudo-R^2 ranging between 0.0572 and 0.1460. This may be because of the fact that the sample is drawn from communities that are all under extreme wildfire risks and that fire-related variables collected in the survey may not explain much of the variation in the fire-safe incentives of the property owners from these communities. Instead, the variation may originate at the community level, due to community specific characteristics and individual's choices of which communities to purchase homes in. Although sample selection bias introduced by individuals' community choice is beyond the scope of the present article, it is an important component to the future extension of this study. In future data collection efforts, communities that represent a wider variation in wildfire risk levels will be sampled. Moreover, collection of geo-referenced data will allow estimation of strategic interactions among neighboring private-property owners (Shafran 2008), and will permit the survey data to be supplemented with existing GIS data, thus expanding the scope of the analyses.

Finally, our survey was conducted in 2006, one year before the devastating Angora Fire in Lake Tahoe. It is likely that property owner perception and reference points about wildfire risks have shifted since then. Therefore, our survey can be used as a baseline for future assessments of property owner fire-safe decision making in this area. Schulte and Miller (2010) make a similar argument with regards to the fact that their work serves as the reference point in the context of climate change perception.

Overall, we believe that further research on private investment in wildfire preparedness needs to be conducted in the context of behavioral models, such as the one we present here, in order to enhance the usefulness of programs and policies that are designed to reduce the overall cost of wildfire suppression. Elevated wildfire severity is likely to be a continuing concern in the context of climate change. The socially optimal level of costs of wildfire and wildfire suppression likely involves a mix of both public and private investment in fire-safe actions. This and future research will contribute to a better understanding of the incentives that affect private property owners in their decision to invest in wildfire prevention and ultimately lead to better informed policies.

Footnotes

[1] Defensible space is "an area around a structure where fuels and vegetation are treated, cleared or reduced to slow the spread of wildfire towards the structure, and to provide room for firefighters to do their jobs" (Denis 2006).

[2] A fire threat in this context implies that a fire may occur in or near one's community.

[3] We also estimated count models where the binary fire-safe action variables were aggregated to form count variables that represent the number of actions taken for the four groups of fire-safe activities and investments. However, the model fit was poor and we are not reporting the results in this article.

[4] Although this and action 11 (removing combustible material within 3 feet of the house) are not applied directly to the house, these actions, implemented in a close proximity to the structure, effectively reduce the probability of ignition for the house (Butry and Donovan 2008), thereby reducing the expected financial losses. Therefore they are included in group C.

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Table 1. 21 Fire-safe Actions Listed in the Nevada Property-Owner Survey

	Fire-safe Action	*n*	Mean[a]	S.D.
A. Routine actions that aim to reduce the probability of a fire reaching the structure				
1	Maintain a well pruned, well watered landscape	303	0.851	0.356
2	Remove low tree limbs or prune down tall shrubs under them	303	0.779	0.416
3	Clear dead vegetation from the yard	317	0.839	0.368
4	Thin dense stands of native trees or shrubs within 100 to 200 feet of the house	232	0.685	0.465
5	Remove vegetation and overhead obstructions from the driveway for a 15ft vertical clearance	191	0.796	0.404
B. One-time investments that aim to reduce the probability of a fire reaching the structure				
6	Plant low-growing and less flammable plants within 30 feet of the house	279	0.681	0.467
7	If driveway is long, have a turnaround area suitable for large fire equipment	162	0.691	0.463
8	Ensure road leading to house is at least 12 ft wide	233	0.858	0.349
C. Routine actions that aim to reduce damage if the fire does reach the structure				
9	Needles and leaves cleaned from gutters, roofs and eaves	273	0.828	0.378
10	Trim tree limbs away from house and chimney	313	0.824	0.381
11	Remove combustible material within 3 ft of the house	289	0.827	0.379
D. One-time investments that aim to reduce damage if the fire does reach the structure				
12	Fire-resistant materials for decks and railings	273	0.249	0.433
13	Decks enclosed with a fire-resistant, solid skirt	227	0.159	0.366
14	Fire-resistant siding	262	0.332	0.472
15	Windows at least double paned or tempered glass	323	0.817	0.387
16	All vents covered with 1/8'' metal wire mesh	287	0.697	0.460
17	Eaves enclosed with fire-resistant materials	247	0.360	0.481
18	Spark arrest on the chimney	289	0.844	0.363
19	Fire-resistant roofing	324	0.830	0.376
20	Outdoor structures made of fire-resistant materials	185	0.476	0.501
21	Add reflective non-flammable house numbers	253	0.538	0.500

[a] Proportion of respondents that indicated to have implemented each action

Table 2. Independent Variables Used in Probit Modes

Variable	Definition	*n*	Mean	S.D.
publand[a]	Distance from public land (miles)	371	0.966	1.647
lotsize[a]	Lot size (acres)	370	2.952	9.084
resvalue	Market value of the residence ($million)	361	0.655	0.493
experience	1 if experience with wildfire; 0 otherwise	376	0.635	0.481
primary	1if primary residence; 0 otherwise	373	0.686	0.464
control-burn	Approve control burns as a land management method (1 No!! - 5 Yes!!)	369	3.693	1.211
nature[b]	Love for nature and privacy as a reason for not implementing fire-safe action (1 No!! - 5 Yes!!)	318	3.175	0.978
neighbor	Average rating within each community of the importance of neighbors' safety as a motivation for implementing fire-safe actions (1 Not at all important – 5 Extremely important)	376	4.146	0.294
VH	1 if community is Virginia Highlands; 0 otherwise	376	0.191	0.393

[a] Continuous variables constructed using mid-points of ranges provided in survey.
[b] Variable created according to a factor analysis.

Table 3. Selected Probit Estimation Results: Marginal Effects on Probability of Implementing Fire-safe Actions

	x_i (Yard)		y_j (House)		
	Pruning (2)	Planting (6)	Trimming (10)	Window (15)	Roof (19)
publand	0.0389	0.042	0.00259	0.00697	-0.00152
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)
lotsize	-0.00123	-0.00285	0.00349	0.0114	0.0211*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
resvalue	0.00477	-0.0239	0.0262	0.138**	0.0151
	(0.06)	(0.07)	(0.06)	(0.05)	(0.05)
experience	0.0759	0.0608	0.122**	0.0439	0.0421
	(0.06)	(0.07)	(0.06)	(0.05)	(0.05)
primary	0.0517	0.151*	-0.0606	0.184***	0.115*
	(0.07)	(0.08)	(0.05)	(0.07)	(0.07)
control-burn	0.0285	0.0629**	0.0315	0.015	0.0198
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
nature	-0.0499*	-0.0095	-0.0631**	-0.0204	-0.00714
	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)
neighbor	0.0323	0.17	-0.0223	0.199**	0.206**
	(0.10)	(0.13)	(0.09)	(0.09)	(0.08)
VH	0.0619	0.157	0.134*	0.136**	0.00212
	(0.10)	(0.11)	(0.08)	(0.07)	(0.10)
Observations	251	234	257	266	266
Pseudo-R^2	0.0572	0.0703	0.0767	0.1460	0.0620
Chi^2	15.24	20.64	19.64	38.38	15.56
Prob>Chi^2	0.0846	0.0143	0.0203	0.000	0.0767

Notes:
Standard errors in parentheses.
Significance levels of 0.01, 0.05, and 0.1 are denoted by three, two, and one asterisks (***, **, *), respectively.