Using GIS to Test the Relationship Between Homeowner Willingness to Pay to Reduce Wildfire and Landscape Characteristics[1]

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Abstract

We evaluate whether wildland urban interface households willingness-to-pay for fire prevention is influenced by forest fire risk variables calculated using Geographic Information Systems (GIS). Specifically, we use spatial modeling to calculate estimated fire danger of homes in Colorado and then enter those variables in our logit model of household willingness-to-pay. Including the spatial variables in the models, we found that having a defensible space zone of 10 meters and having a high fire danger in the 100 meter area surrounding their home had a statistically significant influence on willingness-to-pay for fire prevention. For fire suppression, the weighted average fire danger within one mile of their home was the spatial variable that had an influence on willingness-to-pay. The explanatory power of the logit models was noticeably higher with the GIS fire risk variables included.

Introduction

Landscape characteristics such as vegetation type highly influence wildfire behavior. This study was undertaken to better understand how the role of landscape characteristics influence homeowner perceptions of fire danger and willingness-to-pay for two wildfire management practices: fire prevention and fire suppression. Fire prevention includes removing underbrush and cutting down some standing trees to thin the forest and reduce the chances of a large fire. Fire suppression includes having larger fire crews on standby and having more fire crews closer to fire prone areas of forests. The purpose of fire suppression crews is to extinguish all fire starts immediately before fires are given the chance to spread.

Over the years, due to the increase in risks, the cost of fire management has increased significantly (Ingalsbee, 2003). The increases in costs include, but are not limited to, helicopters, fuel, firefighter wages, and the ever-increasing costs of fire suppression and prevention.

Most recently, public opinion has become a required part of the decision criteria for federal land management. Since public opinion on fire management is becoming very important, this paper will focus on how the public perceives that fires should be managed. The public of interest are homeowners that live within a few miles of public lands (The Wildland Urban Interface) that bear the risk of landscape fires damaging property.

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Wildfire Home Danger and Prevention

The population of the Wildland Urban Interface is growing. The increase in the number of homes increases the chance that a home will get caught in a wildfire and burn. In the wildland-urban interface, a home will catch on fire typically in one of two ways, ignition by wildfire flames and ignition by lofted burning embers called firebrands (Cohen, 2001). To reduce the chances of home burning, a defensible space should be established.

Defensible space is a "designated area around a home that is intentionally maintained so as to be free of any features that would tend to increase the risk of damage from wildfire (WHIMS, 2002; Larimer County, 2002)." As stated, having defensible space does not guarantee there will be no property loss from wildfire, but it does significantly reduce the chances. The proper defensible space zone should include all the land between the edge of the home and 100 meters surrounding the home, however, many studies show that 30 meters surrounding the home is adequate. Within this defensible space zone, a person should keep flammable material out; water lawns, mow grass, remove all debris from roofs and gutters, screen vents and chimneys, store gas and propane tanks a minimum of 9 meters away from the home, remove dead limbs and brush, and prune trees so no limbs are below 2 meters. In short, all flammable material should be removed from the area. This will significantly reduce chances of homes burning (WHIMS, 2002; Larimer County, 2002; Vicars, 1999; Alexander et al., 1998)

It has been found that homes with maintained defensible space zones that were hit by the 2002 Colorado Missionary Ridge Fire were all saved (Binkley, 2003). Some homes with defensible space that were hit by the 2002 Hayman fire were also saved. While defensible space has been shown to save homes from wildfire, defensible space is not mandatory in most of Colorado. Of the four counties involved in the Hayman fire, Teller, Park, and Douglas do not have any defensible space regulations for wildland-urban fire risks. Jefferson county has defensible space regulations but only on homes built after 1996 (Cohen and Stratton, 2003).

Fire Hazard Area

While defensible space will reduce the chances of your home catching on fire, it is not a complete determinant of wildfire, you must also be aware of the fire danger of the area in which you live. In assessing various fire models, it seems that the most important variable in determining fire hazard is dominant vegetation. The type of vegetation significantly impacts whether a fire will be present. Vegetative fuel types vary significantly, and therefore some types are more flammable than others. For instance, dense conifer forests are ideal conditions for crown fires. Deciduous forests, however, are unlikely to sustain crown fires.

In 2001, Romme et al. created a model of wildfire risk for La Plata County, Colorado. Using vegetation classifications, they were able to determine three parameters that seem to be key in fire behavior: total potential heat release, rate of fire spread, and flame length. They used GIS along with the fire behavior model "Behave" to create their wildfire hazard assessment and map (Romme et al., 2001).

Fire, Economics and GIS

In this paper, we are combining information from three disciplines: fire ecology, resource economics, and spatial modeling. While there have been many studies completed in each of the individual disciplines and including two of the three disciplines, there have not been as many that have combined all three.

When combining wildfire issues, economics, and minimal GIS information, only two people have completed research in the area: Jeremy Fried and Greg Winter. Their research hypotheses were that people living in wildfire frequenting areas would be willing to pay to reduce their risk of wildfire. Potential participants were located by using a GIS program to create a buffer of 100 square miles around the center of a jack pine forested area known for frequent wildfires. The potential participant homes were all located within this buffer (Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000). It was believed that there were three ways that people living in the 100 mile buffer zone could reduce their risk of home burning: mowing the 30 foot defensible space zone around their homes regularly, removing all debris, such as brush piles, from the defensible space zone, and removing all jack pine trees that were adjacent to their homes. Respondents were told about wildfire risk reducing tactics. They were then asked what they felt the probability of fire was in the vicinity and the probability of their home burning. Fried and Winter used these two probabilities to calculate fire risk. Respondents were then were asked if they would be willing to pay for one and/or two of the risk reductions (Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000).

Once all information was obtained, they used a logit model to allow calculation of willingness-to-pay. Variables used included: initial risk level, perceived risk, and property tax tolerance. Results showed initial risk level, perceived risk and property tax tolerance to have a significant influence on respondent willingness-to-pay. Overall results showed that respondents preferred to reduce property risk themselves than to pay an annual tax increase to have someone do it for them (Fried et al., 1995; Winter and Fried, 2001; Fried et al., 1999; Winter and Fried, 2000).

Methods

In this project, we tested the hypothesis that homeowner willingness-to-pay (WTP) to reduce fire risk is directly related to the fire danger of the area in which the homeowner lives:

WTP to Reduce Fire= f (area fire danger)

Where fire danger consists of both perceived and actual fire danger.

Hypothesis testing required three major elements: (a) survey regarding perceived fire risk; (b) contingent valuation questions to determine willingness to pay; (c) spatial modeling to determine objective or actual fire danger.

Contingent Valuation Survey

Contingent valuation is a method in which the value of non-market goods are assessed by measuring a person's willingness-to-pay (Hanemann, 1994). Contingent valuation has been recommended by the National Oceanic and Atmospheric Administration (NOAA) Panel as a legitimate method for non-market good valuation (Arrow et al., 1993). Information is typically gathered by in-person, phone, or mail surveys (Hanemann, 1994).

A mail survey was developed through a series of focus groups and then pre-tested. This survey was conducted in the summer of 2001 to obtain contingent valuation information. This survey encompassed eight pages of questions and two color pictures (Douglas fir forest in Colorado one year after a prescribed burn and Douglas fir forest in Colorado one year after a wildfire) that were inserted into the survey for use with some of the questions. The survey questions included demographics, willingness-to-pay for various fire prescriptions, and various other questions referring to how people feel about wildfires, prescribed fires, and fire suppression.

Survey participants were contacted randomly during the summer of 2001 through numbers in the phone book. Names were selected from various towns in Colorado that are on the border of public lands. The data from 73 respondents were used in this study. These respondents were from Leadville, Nederland, Rollinsville, Estes Park, Masonville, and Red Feather Lakes.

While many of the questions in the survey related to homeowners' opinion, the specific questions we will be focusing our attention on include:

> "Q11a. If fire prevention would reduce the frequency of a wildfire in the area where you live to half as often as it does now, would you pay an increase of $___ a year more in taxes for fire prevention each year?"
>
> "Q11b. If fire suppression would reduce the frequency of a wildfire in the area where you live to half as often as it does now, would you pay an increase of $___ a year more in taxes for fire suppression each year?"

The blank spaces ($___) on each survey were filled in with values ranging from $5 through $1500. While the dollar amount between participants was different, the values for the willingness-to-pay question in any one survey were the same. The yes/no answers to these willingness-to-pay questions are the dependent variables we will be using in the logistic regression models.

The independent variables we will be using include two perceived fire risk variables obtained from the following questions:

> "Q3. Are you concerned that a fire on public lands may endanger your home?
> (Circle One) Yes No"
> "Q7. Take a look at the wildfire photo. In your opinion, how often does a wildfire such as shown in the Wildfire Photo occur in the are where you live. For example, once every 5 years, once every 10 years, twice a year, etc. ________Fire Frequency."

Spatial Modeling

In this project we used ArcMap, a GIS program, to conduct the spatial analysis of the data. This process consisted of four map layers: vegetation, home point locations, slope, and fire locations. The first dataset is the vegetation layer, a fine grained statewide landcover map of Colorado. The Colorado Vegetation Map (CoVMap) was created at Colorado State University by David Theobald, Nate Peterson and Bill Romme. CoVMap is currently the best available statewide vegetation map for Colorado as it takes into account elevation, precipitation, slope, aspect, Bailey's ecoregions and soil. Vegetation types were cross referenced with Romme et al., 2001 La Plata County vegetation type to determine fire hazard. Use of GIS and Behave (a fire behavior model) aided Romme in calculation of heat release (BTU/ft^2), spread rate (chains per hour, a chain is 66 feet), and flame length (feet). We used the average heat release, spread rate and flame length for each of the fuel categories.

The second layer in the spatial model consisted of home point locations. To obtain the best available information at respondent home locations, each individual home was visited and the UTM coordinates were recorded. In addition, information on the 9 meter (approximately 30 foot) defensible space and general vegetation information were observed. Out of the original 99 data observations collected, 73 were able to be digitized in ArcMap. Twenty-seven of the observations were not able to be mapped as post office boxes were the contact information given and therefore home locations were not available. Out of the 73 homes, 23 had either the proper defensible space and/or were located in a downtown area where there was no fire danger. This information was entered into the database where "1 = minimum of 30 foot defensible space" and "0 = defensible space zone is not adequate to protect home from wildfire." Once UTM information was obtained for the 73 homes, home point locations were entered into an Excel database. The database was then saved as a dBaseIV file and added to ArcMap.

The next data layer was slope. Slope was calculated from a Colorado Digital Elevation Model (DEM) (USGS, 2001). The final layer of data consisted of overlaying wildfires from the year 2000 to a Colorado County Map. Homepoints were placed onto the county map and a proximity analysis was conducted. The four Colorado wildfire shapefiles represented the Bobcat Gulch, High Meadow, Bircher, and Pony fires.

Empirical Model Combining Survey and Spatial Variables

We created a buffer of 100 meters (328 feet) surrounding each home structure. This is the recommended defensible space zone. Since wildfires can travel great distances from where they begin, we not only considered the fire danger of the immediate area, but also of the surrounding area. This second buffer zone was one mile in radius.

Analyzing the two buffer zones yield information on both the type of vegetation and how much of each vegetation type was located in each home area buffer. Once this information was obtained, we were able to cross-reference it with Romme's heat release, flame length and fire spread to determine potential wildfire danger. We first did this for the fire danger of the immediate area (100 meter buffer). This yielded three variables: Heat100 – average heat release in the 100 meter buffer; Spread100 – average spread potential in the 100 meter buffer; Flame100 – average flame length in the 100 meter buffer.

Then came the complicated task of determining the danger of the surrounding area. We used the EucDistance procedure along with vegetation information to create a weighted fire danger average. To do this, we weighted the area closest to the home more than the area furthest away from the home. As suggested by Theobald, 0 distance would be weighted as 1, 402 meters (¼ mile) as 0.75, 804 meters (½ mile) as .5, and 1609 meters (1 mile) as .25 (Theobald, 2003). For this study, zero distance was the 100 meter buffer zone. This resulted in three weighted averages of wildfire danger over a one mile radius surrounding the homepoints: Avgheat - weighted average of heat, Avgspread – weighted average of spread, Avgflame - weighted average of flame.

The next data layer to consider was slope. Slope, in percent, was calculated from a Colorado DEM (USGS, 2001). Homepoints were then layered onto the slope map. Average slope was then calculated for the one mile buffer zone using the same procedure as for the weighted one mile buffer vegetation estimate.

Once all spatial variables were calculated, we were then able to create the willingness-to-pay empirical models. The hypothesis is that homeowner willingness-to-pay to reduce wildfire is related to the perceived and actual fire danger of the area in which they live. The model consists of data obtained from the spatial analysis, data from the survey, and calculated variables. In order to test the hypothesis we will be using a binary dependent logistic model. The logistic model is the most appropriate model to use since the dependent variable is binary in which "1 = the respondent is willing to pay for the particular activity" and "0 = the respondent is not willing to pay."

Four logistic regression models were estimated: the first two represented willingness-to-pay using just perceived fire risk variables and the second two represented willingness-to-pay for perceived and actual fire risk calculated from the GIS. The two willingness-to-pay variables are: willingness-to-pay for fire suppression (WTPFS) and willingness-to-pay for fire prevention (WTPFP). These two dependent variables were coded where "1= yes, they are willing to pay," and "0= no, they are not willing to pay." The independent variables are:

Bid: the dollar amount the homeowner is asked to pay

Danger: whether the homeowner believes there is a chance their home will catch fire, 1= yes; 0= no.

Freq: perceived frequency of a wildfire, where once every 10 years =10, etc.

Firedist: GIS estimated distance in meters from the homepoint to the edge of the closest fire in 2000.

Defspace: If home has a 9 meter defensible space, where 1= yes, 0=no.

Heat100, Spread100, Flame100, Avgheat, Avgspread, Avgflame.

Slope: Weighted average slope coefficient within 1 mile of home.

We expect the bid coefficient to be negative because as the bid amount increases, the respondent would be less likely to pay. We expect that as the distance to the nearest fire increases, the respondent would be less willing to pay, therefore, a negative coefficient is expected. The frequency or fire interval coefficient is expected to be negative, as the occurrence of a fire takes longer, the respondent is expected to be less willing to pay. We expect the coefficient on Danger to be positive, because if the homeowner perceives more danger, they would be more likely to pay. We expect the coefficients on Spread100, Heat100, Flame100, Avgspread, Avgheat, and Avgflame to all be positive, because as the fire danger in the immediate and more distant area increase, the respondent should be more likely to pay for a fire management prescription. We also expect the coefficient on slope to be positive because as the slope increases, the fire danger increases and therefore the respondent should be more likely to pay for a fire management prescription.

Prior to running the regressions, we checked the correlations of the variables, many of which had high correlations. Therefore, we will not be using all of them in the same model. The two most highly correlated variables were Avgflame and Avgheat (0.8799) and Flame100 and Heat100 (0.8738).

Results

For the first part of the analysis, two logit models using just perceived fire risk were run, one each for WTP for fire prevention and fire suppression (Equation 1, Equation 2). We find that the likelihood or probability of being willing to pay for fire prevention and fire suppression is influenced by whether the respondent feels their home is in danger. The perceived frequency of fire or fire interval is negative as expected, but insignificant. Note one asterisk indicates significant at the 10% level and two asterisks denotes significance at the 5% level.

Equation 1:

WTP Fire Prevention = 0.945C – 0.004Bid** + 1.353Danger** – 0.018Freq
(Z-Statistic) (1.497) (-2.018) (2.017) (-1.174)

Equation 2:

WTP Fire Suppression = 0.251C – 0.002Bid* + 1.173Danger* – 0.007Freq
(Z-Statistic) (0.432) (-1.656) (1.927) (-0.460)

The next set of logistic regressions represent not only the perceived fire danger reported by the respondents, but also the estimated actual fire danger calculated using the spatial models. As different variables influenced the various fire management prescriptions, we will be presenting the best models from each of the management prescriptions (Equation 3, Equation 4).

Equation 3:

WTP Fire Prevention =
-0.686C – 0.004Bid** + 0.919Danger – 0.026Freq + 1.458Defspace* + 0.002Heat100*
(-0.675) (-2.263) (1.185) (-1.383) (1.665) (1.630)

Equation 4:

WTP Fire Suppression =
-2.142C – 0.003Bid* + 0.480Danger – 0.013Freq + 0.227Defspace + 0.008Avgheat**
(-1.719) (-1.782) (0.681) (-0.711) (0.354) (2.216)

In the fire prevention model, we find that if the respondent has a defensive space surrounding their home, then they are more willing to pay for fire prevention. We also found that if the average heat within the 100 meter area immediately surrounding the home increases, that the respondent will more likely be willing to pay for fire prevention. For the willingness-to-pay for fire suppression, we find the respondent is more willing to pay if the weighted average heat measure within one mile surrounding the home increases.

As interpretation of the coefficient in the logit models may be difficult, we converted the coefficients to willingness-to-pay values. To convert logit coefficients to willingness-to-pay values, coefficients were divided by all values except the bid amount by the absolute value of the bid coefficient. In the perceived fire risk model, the respondent will increase their willingness-to-pay for fire prevention by $338.25 annually if the respondent feels their home is in danger of wildfire. When the spatial variables are included in fire prevention we find that the respondent will increase their willingness-to-pay by $364.50 if their home has a defensible space. We also find that the respondent will increase their willingness-to-pay by $0.50 per unit of heat value (BTU/ft^2) if the average heat value in the 100 meter area surrounding their home increases.

For the perceived fire risk model of willingness-to-pay for fire suppression, we find that the respondent is willing to pay $586.50 more if they feel their home is in danger of wildfire. In the model with the spatial variables, we find that the respondent will increase their willingness-to-pay by $2.64 per unit of heat value

(BTU/ft^2) if the weighted average heat fire danger in the one mile area surrounding their home increases.

Conclusion

A survey was conducted to see if Colorado homeowners living within 10 miles of public lands would pay for fire prevention and fire suppression. It was determined that the respondents were likely to pay for both methods due to their perception of fire danger. We extended this model by adding objective measures of fire risk calculated from spatial modeling layers. Using GIS data we calculated an objective measure of fire hazard. In particular, we measured the distance between fires and respondents homes. We then calculated fire danger within the immediate area around the home, 100 meters, and the weighted average of fire danger within a 1609 meter (one mile) radius of the home. The weighted average slope within a 1609 meter (one mile) radius of the home was also calculated. This information enabled us to construct the potential fire hazard facing each homeowner in our sample. Fire hazard calculation in conjunction with on-site calculations of defensible space and survey responses enabled us to develop a more complete logit model for willingness-to-pay.

For the perceived fire danger models we find that whether the respondent feels that their home is in danger significantly affects willingness-to-pay for fire prevention and fire suppression. For the full model including spatial variables we find that defensive space and the wildfire heat value both have an effect on fire prevention willingness-to-pay. For fire suppression, the average weighted heat value for the area has an affect on willingness-to-pay. Overall, the inclusion of the landscape variables reflecting objective measures of fire risk increased the explanatory power of the logit willingness-to-pay models by about one-third for the fire prevention program and nearly double for the fire suppression program. This suggests that inclusion of landscape characteristics may be important explanatory variables in models of willingness-to-pay for natural resource protection.

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