University of Nevada, Reno

Money to Burn? Risk Attitudes and Private Investment to Mitigate Wildfire Risk

A thesis submitted in partial fulfillment of the
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Economics

By

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Chapter 1: Introduction

1.1 Background

Wildfire is a significant and growing problem in the United States with increasing numbers of fires, acres burned, suppression costs, and wildfire damages in the past decade (NIFC 2017, Stephens and Ruth 2005). A major driver of these recent increases in wildfire activity and costs has been the continued expansion of housing in the wildland-urban interface (WUI) (Kent et al. 2003). WUI communities account for 715,000 km^2 of land area, 38% of all housing structures, and 37% of the population in the United States; these communities are expected to experience significant growth in the Western and Southeastern United States through 2030 (Hammer et al 2009). WUI communities are at an increased risk of property damage because of the difficulty of protecting housing adjacent to wildlands from wildfire (Radeloff et al 2005; Cohen 2000; USDA 2014) and because human caused ignitions are more common in the WUI (Chas-Amil et al 2015; Syphard 2007; Cohen 2010).

Homeowners can make many fire-safe investments on their private property to reduce the risk that their home will be destroyed in a wildfire (defined in this thesis as a *homeowner's wildfire risk*)[1]. These actions include replacing any flammable building materials with fire resistant materials or designing and maintaining the vegetation immediately around their home to reduce the chance of structural ignition. The

[1] In WUI wildfires, most homes are either undamaged or destroyed; partial damage is relatively rare (Cohen 2000).

cumulative outcome of fire-safe actions to prevent the spread of fire from the edge of the property to the home is termed as defensible space (FEMA 2008). While studies have shown that defensible space is effective in reducing wildfire risk (Cohen 2000; Syphard 2014), many homeowners choose not to invest (Meldrum et al 2014; Cohen 2010). Previous literature has suggested several explanations for why homeowners choose not to invest. These explanations include that homeowners understand their wildfire risk but differ in what actions or investments they consider effective in reducing that risk (Monroe and Nelson 2004; Brenkert-Smith et al 2012; Vogt et al 2007), that homeowners do not want to lose the aesthetic utility of their landscaping, or reduce the privacy offered by their landscaping, as would be required with defensible space (Brenkert Smith et al 2006; McCaffery et al 2011; Monroe and Nelson 2005), and that homeowners have both monetary and non-monetary barriers (health, time, zoning regulation) to investment (USDA 2013; Schulte and Miller 2010; Taylor, Christman, and Rollins 2015). Homeowners can invest significant time and money to reduce fire risk in the inner zone of their property (defined as within 30ft from their housing structure) without achieving adequate defensible space because defensible space requires several fire-safe investments.

We use a unique data set collected from WUI communities in Nevada containing information on the components of the homeowners' decision problem to take fire-safe actions including the homeowners' expected monetary loss from a wildfire (defined in this thesis as the homeowners' *value at risk)*, risk tolerance, wealth, and preferences for the aesthetic and privacy utility of their landscaping. This data also contains variables related to the homeowners' subjective beliefs about their wildfire risk and their trust of fire-safe investments at reducing this risk. This thesis analyzes the extent the homeowners' decisions are affected by the components of their decision-problem versus their subjective beliefs about wildfire. If the homeowners' decision to make a fire-safe investments are driven primarily by the components of their decision-problem, it would suggest that homeowners' are making fire-safe investments based on their preferences. If homeowners' investments are driven by their subjective beliefs about wildfire, the questions of how these beliefs are formed and whether they lead to individually efficient fire-safe investments become relevant.

The data used in this thesis was made available through a previous project conducted at the University of Nevada, Reno. The data set contains merged data from three sources. First, it contains information on the objective wildfire risk and defensible space status of properties in 35 WUI communities in Nevada funded by the Nevada Agricultural Experiment Station. Second, 2011 Nevada County Tax Assessor data was merged to obtain financial characteristics of each homeowner. Finally, a survey based on Rollins and Evans (2006) was distributed to a subsample of homeowners in the 35 communities to obtain information on their attitudes and subjective beliefs towards wildfire. Chapter 3 describes the data in further detail.

There are two reasons why it is important to understand homeowners' fire-safe investment decisions. First, homeowners' fire-safe investments may be individually-inefficient if they are driven by the homeowners' subjective beliefs towards wildfire rather than the components of the homeowners' decision problem. If homeowners' subjective beliefs towards wildfire are driving the propensity to make fire-safe investments, then future work should focus on how homeowners' wildfire beliefs are formed and how to ensure these beliefs are in line with the homeowners' objective wildfire risk. Defensible space provides external benefits from risk reduction, and socially-inefficient underinvestment could occur in WUI communities even if homeowners were making individually-efficient investments (Shafran 2008; Taylor, Christman, and Rollins 2015). These risk externalities would be amplified by individually-inefficient underinvestment.

Second, a common goal of wildland fire policy in WUI communities is to increase homeowner fire-safe investment on private property. To achieve this goal, it is necessary to understand how homeowners make fire-safe investment decisions. It is important to understand the role that homeowners' preferences, such as risk tolerance and preferences for the aesthetic and privacy benefits of landscaping, play in fire-safe investment decisions. Creating adequate defensible space is the cumulative outcome of several individual fire-safe actions and investments. This information will provide whether individual landscaping preferences are preventing homeowners from creating adequate defensible space even when they are generally engaged in performing fire-safe actions and investments on their property.

This thesis develops an econometric model to better understand the underlying motivations behind a homeowner's decision to make fire-safe investments. We consider the decision of a homeowner who has the option to invest in defensible space, where the net benefit of investment to the homeowner is the difference between expected utility with and without defensible space. We use Compensating Variation (CV) to identify the welfare change for the homeowner from having defensible space. Compensating Variation is defined as the compensating payment required to make an individual indifferent between the original situation (not having defensible space) and the new situation (having defensible space) (Freeman III, 2003). When Compensating Variation is positive, it would define the amount of money an individual is willing to pay (WTP) for defensible space. However, investing in defensible space could also result in a welfare loss, especially for homeowners who incur high utility losses, in terms of loss of privacy or aesthetic value, from investing in defensible space. When Compensating Variation is negative, it identifies the compensation the homeowner is willing to accept (WTA) for investing in defensible space in order for the homeowner to maintain their initial level of utility. It is completely rational for a homeowner to choose not to invest in defensible space if their compensating variation is negative. For example, homeowners could be choosing to live into WUI communities due to their aesthetic utility, and investing in defensible space would significantly reduce that aesthetic utility to the point where they have a negative CV.

We develop a probit model to identify the choice probability of homeowner investing in defensible space or some individual fire-safe action. Specifically, we look at how the interaction between the homeowners' decision problem and the homeowners' subjective knowledge of wildfire affects their propensity to make fire-safe investments. We include controls on objective fire risk, wildland policy characteristics, vegetation types, and other non-monetary restrictions to investment to better improve our estimates on the components of the decision problem and subjective beliefs about wildfire. We impute values for some of the missing data via Multiple Imputation by Chained Equations (MICE) to increase our sample size and improve the precision of our estimates. The econometric model and the methods used to impute values are described in further detail in Chapter 4.

1.2 Contributions

This article provides four contributions to the previous literature. First, we use a unique data set that combines on-site hazard assessments and mail survey data of the same population. The assessments provide us with information on whether homeowners have adequate defensible space, as well as information on the biophysical determinants of their wildfire risk (i.e. the predominant vegetation in their community, the average fuel load, the slope of their property, etc.). The survey provides information on homeowners' subjective beliefs about their wildfire risk, their risk tolerance, their concerns for aesthetic and privacy utility loss by making fire-safe investments, and other factors. Previous studies that look into homeowners' investment in defensible space have either relied on survey data or in-person interviews (Brenkert-Smith, Champ, and Flores 2012; Bright and Burtz 2006; Talberth et al. 2006) or on-the-ground assessments (Shafran 2008), but have only a few have combined data from the two sources. Previous studies that have used on-the-ground assessment information with homeowner survey data assess the relationship between homeowners' perceived and actual wildfire risk. The evidence from these studies is mixed, with some studies finding a close correspondence between perceived and actual risk (Kaval 2009) and other studies not (Schulte and Miller 2010). Combining these two sources allows us to analyze the extent the homeowners' decision is affected by the components of the decision problem versus the homeowners' subjective beliefs about wildfire. Furthermore, using on-the-ground assessments allows us study the role of the homeowners' decision problem and subjective attitudes towards wildfire play on observable fire safe investments (rather than their self-reported actions), while controlling for objective wildfire risk.

Second, our sample provides us with a gradient of wildfire risk across 35 WUI communities based on predominant vegetation type, average fuel loads, slope, wind speed, probability of ignition due to lightning, and other factors. Most previous studies have used data from a small number communities and do not have this variation in predominant vegetation and other determinant of wildfire risk (Graham 2003; Monroe and Nelson 2004; Syphard et al 2014; Brenkert-Smith et al 2006). This variation in wildfire risk across communities helps us to evaluate the role that homeowners' subjective beliefs about their wildfire risk and their trust in fire-safe investments at reducing this risk play in their investment decisions while controlling for each homeowners' objective wildfire risk.

Third, our data includes home value, years of homeowner ownership, and insurance status for each homeowner. This information allows us to analyze the extent value at risk drives their fire-safe investment decision. There is likely to be a fair amount of variation between WUI homeowners regarding their value at risk. Homeowners' value at risk can differ depending on whether they carry homeowners' insurance and their net equity position (their property value minus their outstanding mortgage balance)[2]. If we find evidence that homeowners' value at risk impacts their fire-safe investment decisions, this would suggest that wildland fire policy should focus on the financial aspects of homeowners' investment decisions.

Fourth, the majority of homeowners in our survey do not have recent experience with wildfire. Previous studies have surveyed homeowners who recently experienced a wildfire (Graham 2003; Davis et al 2014; Chas-Amil et al 2015). That our study focuses on homeowners in fire-prone WUI communities but have not recently experienced a fire allows us to draw conclusions about the components driving fire-safe investment decisions that are unaffected by a cognitive bias related to recent wildfire experience (Zeckhammer 1996). This feature of our data implies that our findings about fire-safe investments are more likely to generalize to other natural disasters. For most other natural disasters such as hurricanes, earthquakes, and tornados, the majority of at-risk homeowners are unlikely to have had recent, direct experience with the disaster.

1.3 Organization

The remainder of this thesis is organized as follows. The second chapter provides a detailed description of the data. The third chapter describes the econometric model and other methodological issues. The fourth chapter will report the results and discuss their implications. The fifth chapter provides conclusions and directions for further research. The sixth chapter comprises the appendix.

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[2] Homeowners without a mortgage can choose to not carry insurance

Chapter 2: Data

2.1 Introduction

The data used in this thesis was collected as part of a previous project conducted at the University of Nevada, Reno. This chapter summarizes the subset of data from that project used in this thesis. This chapter describes the defensible space assessment process, the tax assessor data obtained for each property, and the specific survey data used for this thesis. The descriptive statistics below compare the property characteristics from the subsample of survey respondents with the full sample of every property assessed in order to establish that the survey respondents are representative of homeowners in the 35 WUI communities in Nevada included in this study.

In 2011, University of Nevada, Reno, researchers, through a grant funded by the Nevada Agricultural Experiment Station (Rollins and Evans 2010), conducted a study of 35 WUI communities in Nevada that would represent variation in wildfire risk, fuel types, and fuel accumulation in fire prone communities throughout the state. The study includes an assessment of private residential properties to document the existence of adequate defensible space around housing structures. A survey was distributed to a subsample of these properties to gather information from the homeowners regarding what motivated their decisions to take fire-safe actions on their property. These 35 communities were chosen to meet the following selection criteria:

- The community contained at least 50 private properties
- Was rated as at least a *"moderate"* risk in a 2005 *assessment* (RCI 2005*)*
- Be within Nevada

- Vegetation type was not predominantly cheatgrass
- Predominantly brush, alpine forest, and pinyon-juniper pine vegetation types
- A variety of community types with lots and roads interspersed with wildlands versus newer development patterns
- A variety of community ages (newer developments versus established areas)

The communities were selected on information provided by the 2004 fuels and risk assessment of the 239 WUI communities in Nevada commissioned by the US Forest Service contracted to Resource Concepts, INC (RCI) (RCI 2005)[3]. The 2011 assessments included a re-assessment of fire risk for the chosen 35 communities to take into account changes in fuel loadings and the creation of defensible space between 2004 and 2011. The Forest Service fuels assessment specialist, who led the initial 2004 assessment, was contracted to train UNR researchers and students to perform the follow-up assessments based on observable property variables using the same methods used in 2004. The re-assessment assessed each private residential property in the community and defined WUI area for adequate defensible space (*DEFSP*). A total of 8,867 homes in the 35 communities were assessed. Latitude and longitude recorded for each property was used to match each property with 2011 County Tax Assessor Data.

The survey portion of the research was based on an earlier pilot survey (Rollins and Evans, 2006) that was designed to capture homeowner attitudes towards defensible space, their perceived wildfire risk and general risk attitudes, and willingness to pay to

[3] Data collected by RCI for the Forest Service included an assessment of wildfire risk, biophysical traits of communities, and information about community fire suppression resources.

reduce wildfire risk and property damage. The 2011 survey was distributed to 2,379 homes chosen to represent the 35 WUI communities, with a total of 736 completed responses.

2.2 Survey Sample Representativeness

The final dataset contains the 2011 hazard assessment data for each residential property, 2011 county tax assessor data for each property (matched via the longitude and latitude coordinates taken during the assessment), and the survey data of the 736 survey respondents. Table 2.1 provides the summary statistics on the distribution of defensible space and other characteristics from the 8,867 homes assessed in 2011, the 2,379 homes who received surveys, and the 736 homes who responded to the survey. Table 2.2 provides the summary statistics on the distribution of biophysical determinants of wildfire risk between the three groups. Table 2.3 provides summary statistics on the distribution of wildland policy variables between the three groups. Tables 2.1, 2.2, and 2.3 establish that based on observable variables, the subsample of survey respondents are representative of homeowners in the 35 WUI communities in our study.

Table 2.1 Property Characteristics

Name	Description	Mean	Std. Dev.	Min.	Max.
Hazard Assessment (N = 8,867)					
DEFSP	=1 if 30ft of Defensible Space	0.36	0.48	0	1
HHV	Home Value ($)	$179,086	$296,507	$40	$9,999,927
HHVL	Log of Home Value	11.37	1.39	3.69	16.12
LOT	Size of Property (Acres)	3.03	7.99	0.001	205.90
Received Survey (N = 2,379)					
DEFSP	=1 if 30ft of Defensible Space	0.39	0.49	0	1
HHV	Home Value ($)	$144,126	$306,324	$468	$9,999,927
HHVL	Log of Home Value	11.10	1.34	6.15	16.12
LOT	Size of Property (Acres)	4.10	10.93	0.001	205.90
Returned Survey (N = 736)					
DEFSP	=1 if 30ft of Defensible Space	0.37	0.48	0	1
HHV	Home Value ($)	$152,984	$404,214	$526	$9,999,927
HHVL	Log of Home Value	11.18	1.33	6.27	6.12
LOT	Size of Property (Acres)	5.06	13.45	0.001	205.90

Table 2.2 Biophysical Variables

Name	Description	Mean	Std. Dev.	Min.	Max.
Hazard Assessment (N = 8,867)					
WIND	Avg. Max. Daily Wind Speed (MPH)	30.69	9.06	14	46
ASPECT	=1 if Property is South Facing	0.14	0.35	0	1
SLOPE	Slope of Property (%)	6.12	5.16	0	37.56
ELEVDIFF	Difference between the Elevation of a Residence and the Avg. Elevation in Community	0.00	158.74	-661.94	789.88
LGHTN	Number of Lightning Strikes within 10 Miles	937.3	508.57	306	2491
Received Survey (N = 2,379)					
WIND	Avg. Max. Daily Wind Speed (MPH)	31.47	7.38	14	46
ASPECT	=1 if Property is South Facing	0.19	0.39	0	1
SLOPE	Slope of Property (%)	5.84	5.50	0	35.49
ELEVDIFF	Difference between the Elevation of a Residence and the Avg. Elevation in Community	2.66	131.1	-582.14	710.87
LGHTN	Number of Lightning Strikes within 10 Miles	1047.3	519.89	316	2487
Returned Survey (N = 736)					
WIND	Avg. Max. Daily Wind Speed (MPH)	31.11	7.57	14	46
ASPECT	=1 if Property is South Facing	0.20	0.40	0	1
SLOPE	Slope of Property (%)	6.43	5.81	0	31.74
ELEVDIFF	Difference between the Elevation of a Residence and the Avg. Elevation in Community	14.92	131.97	-577.55	697.24
LGHTN	Number of Lightning Strikes within 10 Miles	973.5	489.2	317	2468

Table 2.3: Sample Representation: Wildland Fire Policy Variables

Name	Description	Mean	Std. Dev.	Min.	Max.
Hazard Assessment (N = 8,867)					
ROAD_MORE_24ft	=1 if Roads > 24ft wide	0.806	0.395	0	1
RES_PC	Number of Residences Within 10 miles, Per Capita	0.005	0.007	0	0.057
RX_PC	Number of Fuel Treatments on Public Lands Within 10 miles in Previous 5 Years, Per Capita	0.008	0.029	0	0.151
Received Survey (N = 2,379)					
ROAD_MORE_24ft	=1 if Roads > 24ft wide	0.804	0.397	0	1
RES_PC	Number of Residences Within 10 miles, Per Capita	0.007	0.011	0	0.057
RX_PC	Number of Fuel Treatments on Public Lands Within 10 miles in Previous 5 Years, Per Capita	0.012	0.036	0	0.151
Returned Survey (N = 736)					
ROAD_MORE_24ft	=1 if Roads > 24ft wide	0.813	0.391	0	1
RES_PC	Number of Residences Within 10 miles, Per Capita	0.008	0.011	0	0.057
RX_PC	Number of Fuel Treatments on Public Lands Within 10 miles in Previous 5 Years, Per Capita	0.014	0.040	0	0.151

2.3 Description of Variables used in Regressions

In this section, we describe the variables included in our econometric model. Table 2.12 describes all variables used in the study. Variables taken from the survey (sixteen in total) have missing values. We expect these variables to reduce the sample size of our model and will take this into account in our next chapter.

2.3.1 Defensible Space

Our data contains a binary indicator for assessed adequate defensible space (*DEFSP*), which we use as our dependent variable in our probit model. *DEFSP* is set to 1 if the homeowner has observed defensible space according to the assessment standards within 30 feet from the residence and 0 if it does not. Table 2.4 reports response rates, average home values, and percent defensible space by vegetation type.

Table 2.4: Defensible Space by Vegetation Type

Vegetation Type	**Response Rate %**	**Avg. Home Value ($)**	**Defensible Space %**
Sagebrush Communities	30%	$104,799	47%
Alpine Forest Communities	36%	$322,403	19%
PJ Communities*	29%	$127,431	39%
Grassland Communities	28%	$90,185	40%

*PJ = Pinyon-Juniper Communities

2.3.2 Individual Fire-Safe Investments

Our data includes six self-reported variables indicating whether a homeowner has spent time or money reducing fire risk on their housing structure, inner zone of their property, and outer zone of their property: *HH_SPEND, HH_WORK, IZ_SPEND,* *IZ_WORK, OZ_SPEND,* and *OZ_WORK*. Each variable is coded as a binary indicator of whether or not a homeowner has spent money (*_SPEND*) or spent time (*_WORK*) to reduce fire risk on a particular zone of their property[4]. Table 2.5 reports the means of each of these variables, along with the percentage of homeowners who have defensible space given that they have made a fire-safe investment on their property. Missing observations were given a "0" value to increase our sample size and improve the precision of our estimates[5].

Table 2.5: Individual Fire-Safe Investments

Variable		**Obs**	**Mean**	**St. Dev.**	**Defensible Space Mean**
Household	*Spend*	736	0.232	0.423	0.310
	Work	736	0.518	0.500	0.339
Inner Zone	*Spend*	736	0.299	0.458	0.305
	Work	736	0.586	0.493	0.350
Outer Zone	*Spend*	736	0.239	0.427	0.347
	Work	736	0.489	0.500	0.369

2.3.2 Value at Risk

We include three variables that are correlated with homeowners' expected monetary loss should a wildfire occur: home value (*HHVL*), years of home ownership (*OWN_YRS*), and Homeowner Insurance (*INSURANCE*). Home Value (*HHVL*) is the homes' assessed values in United States Dollars ($) obtained from the State of Nevada County Tax Assessor data. Our model uses log of assessed home value to reduce the

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[4] *HH* = Household, *IZ* = Inner Zone, *OZ* = Outer Zone

[5] This thesis is concerned with what drives homeowners to make a fire-safe investment. We impute "0" for missing observations to increase our sample size, and we maintain the number of homeowners who made at least one fire-safe investment on their property.

weight given to expensive homes in the regressions. Years of home ownership (*OWN_YRS*) is the number of years the homeowner has owned the property as self-reported in the survey. The number of years the homeowner has owned the property is included because, all else equal, it is likely to be positively correlated with a homeowners net equity position (their property value less their outstanding mortgage balance). Homeowner Insurance (*INSURANCE*), also self-reported, is a binary variable that indicates whether the homeowner has insurance that covers wildfire loss or not. *INSURANCE* is included because homeowners can choose to invest in defensible space, purchase homeowners insurance, or both to protect the financial value of their home in the case of a wildfire. The decision to purchase insurance and the decision to invest and maintain defensible space may be endogenous for homeowners who do not have mortgages (mortgage lenders generally require that homeowners with mortgages carry insurance). However, our dataset contains only 30 observations (4.63%) that report being uninsured. Summary statistics for these three variables are reported in Table 2.6.

Table 2.6: Value at Risk Summary Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
HHVL	736	11.19	1.33	6.27	16.12
OWN_YRS	652	16.25	11.86	0.33	145.00
INSURANCE	648	0.95	0.21	0.00	1.00

2.3.3. Wealth

Wealthier homeowners have both a greater ability to pay for defensible space and to absorb the financial loss associated with wildfire. We do not capture homeowner wealth directly, but include several variables correlated with homeowner wealth. These variables include home value and years of home ownership (described above), homeowner self-reported income (*INCOME*), homeowners' age (*AGE*), and whether the homeowner owns another property (*OWN_MORE*). Income (*INCOME*) is self-reported from the survey, where homeowners could select their total household income for 2011 in United States Dollars from nine income brackets ranging from "Under $15,000" to "$200,000 or more". We recoded the income survey data to be the median value of each individual income bracket provided in the survey. For example, for the income bracket "$50,000 to $74,999" the recoded median value used in our final dataset was "$62,499.50", while "Under $15,000" was set to "$10,000" and "Over $200,000" to "$250,000". Age (*AGE*) is also self-reported from survey respondents and is included because we expect it to be correlated with financial wealth, and we consider investment in defensible space a financial decision. We include a dummy variable for whether or not a homeowner owns another property (*OWN_MORE*) and is self-reported from survey respondents. Table 2.7 reports the summary statistics of the variables correlated with wealth.

Table 2.7: Wealth Summary Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
INCOME	548	102458.10	68627.64	10000	250000
AGE	603	62.24	11.25	20	91
OWN_MORE	653	0.44	0.50	0	1

2.3.4. Cost of Investment

We include four variables associated with the cost of fire-safe investments. Fire-safe investments can potentially reduce a homeowner's privacy from their neighbors and the perceived attractiveness of their landscaping. We include whether homeowners believe that fire-safe investments reduces their privacy (*PRIVATE*) and an index designed to capture the homeowners' concern that fire-safe investments reduces their property's aesthetic value (*AESTHETICS*)[6]. *PRIVATE* and *AESTHETICS* are coded from 0 to 100, where 100 means that homeowners feel strongly that fire-safe investments reduces their privacy/landscape aesthetic. *AESTHETICS* is an index created to capture the variation between two variables: concern for loss of housing attractiveness as a barrier to making fire-safe investments (*HOUSE_ATTR*) and concern for loss of landscaping attractiveness as a barrier to making fire-safe investments (*LAND_ATTR*). *HOUSE_ATTR* and *LAND_ATTR* were derived from 5-point Likert question blocks, where each Likert point was recoded in increments of 25 from 0 to 100, where 100 indicates that homeowners feel strongly that fire-safe investments reduces the attractiveness of their property. The creation of the index *AESTHETICS* is described in further detail in Chapter 3. We also include the age of the home (*AGEHOME*) and lot size (*LOT*). Age of the home is

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[6] We use factor analysis on specific question blocks to reduce the dimension of data into underlying unobservable factors (Indexes). These factors are intended to capture a broad idea contained by the question blocks. Factor analysis was performed in R to capture which variables within the question block are correlated with each factor. Once *n* correlated variables were identified, the factor was created by summing the correlated variables and dividing by *n*. *PRIVACY* is an index variable created to capture the variability in the response "Changes to landscaping may reduce my privacy". It is coded on a Likert scale from 1-5 with 1 being *No!!* and 5 being *Yes!!*. *AESTHETICS* is an index variable created via factor analysis to capture the variability between two variables on homeowner preference towards housing structure and housing landscaping attraction in response to defensible space. Both variables are coded on a Likert scale from 1-5 with 1 being *No!!* and 5 being *Yes!!*.

self-reported from survey respondents and is included because, on average, older homes have more matured landscaping. Fire-safe investments would require building around the older features of the house, which could invoke higher financial costs, and require the removal of matured landscaping, which is valued by homeowners. Lot size the acreage of the property, is taken from the 2011 State of Nevada County Tax Assessor data.

Table 2.8 reports the summary statistics for cost of investment variables.

Table 2.8: Cost of Investment Summary Statistics

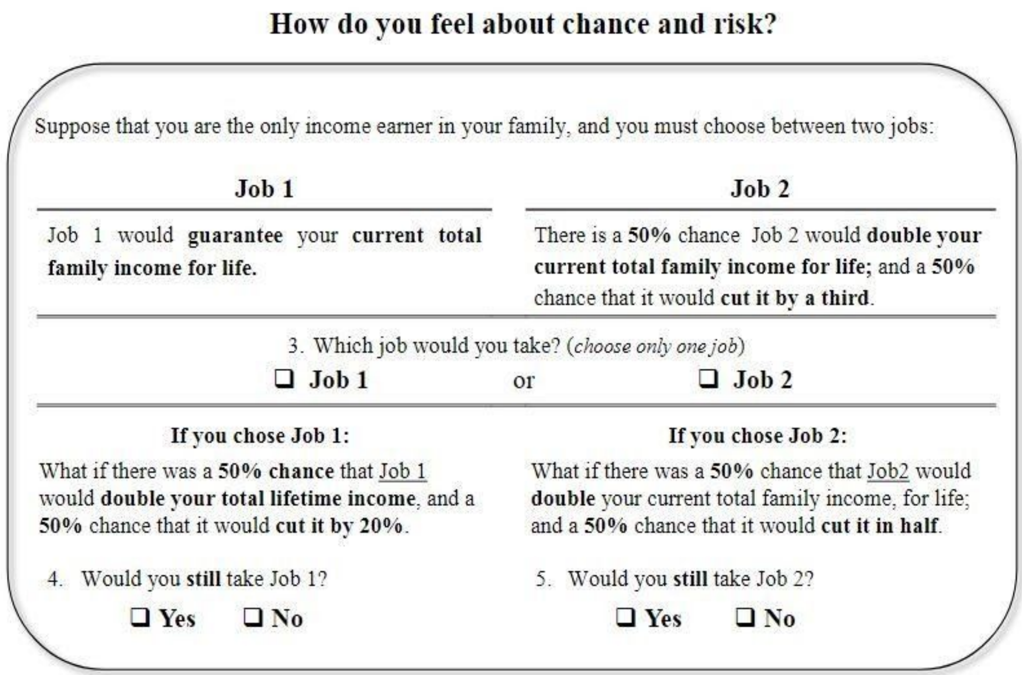
Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
PRIVATE	618	31.11	23.82	0	100
AESTHETICS	612	30.58	22.15	0	100
HOUSE_ATTR	619	30.49	22.67	0	100
LAND_ATTR	616	30.72	23.18	0	100
LOT	736	5.06	13.45	0.001	205.90
AGEHOME	651	22.33	9.22	1	30

2.3.5. Risk Preference

We include a single measure of financial risk (*LRTOL*) as each homeowners' log coefficient of relative risk tolerance. We calculate each homeowners' coefficient of risk tolerance based on homeowners' responses to a hypothetical decision gamble over lifetime income (see Figure 1), assuming that constant relative risk aversion (CRRA) approximates homeowners' utility over lifetime income (Pratt 1964), and using the methodology developed by Kimball, Sahm, and Shapiro (2008). While our survey does not directly measure homeowners' coefficients of relative risk tolerance, homeowners' responses to hypothetical gambles over lifetime income establish boundaries for each homeowners' coefficient of relative risk tolerance parameter. Kimball, Sham, and

Shapiro (2008) find that these hypothetical gambles over lifetime income, which have been included in numerous survey instruments, including the Health and Retirement Survey, the Panel Survey on Income Dynamics, and the National Longitudinal Survey, are subject to measurement error. For this reason, we elect to use Kimball, Sham, and Shapiro (2008)'s response error-corrected estimates of each homeowners' coefficient of relative risk tolerance based on the bounds established by their survey responses. Table 2.9 displays our respondents by group along with their associated risk tolerance.

Figure 2.1: Lifetime Decision Gambles



How do you feel about chance and risk?

Suppose that you are the only income earner in your family, and you must choose between two jobs:

Job 1	Job 2
Job 1 would **guarantee** your **current total family income for life.**	There is a **50%** chance Job 2 would **double your current total family income for life;** and a **50%** chance that it would **cut it by a third**.

3. Which job would you take? (*choose only one job*)

❑ **Job 1** or ❑ **Job 2**

If you chose Job 1:
What if there was a **50% chance** that Job 1 would **double your total lifetime income**, and a **50%** chance that it would **cut it by 20%**.

4. Would you **still** take Job 1?

❑ **Yes** ❑ **No**

If you chose Job 2:
What if there was a **50%** chance that Job2 would **double** your current total family income, for life; and a **50%** chance that it would **cut it in half**.

5. Would you **still** take Job 2?

❑ **Yes** ❑ **No**

Table 2.9: Survey Respondent Financial Risk Distribution

Risk Tolerance in WUI Communities in Nevada				
		Imputations (Taken from Kimball 2008)		
Response Category	Percent of Respondents	Log Risk Tolerance	Risk Tolerance	Risk Aversion
1	51.3	-1.811	0.203	7.6
2	10.1	-1.693	0.228	6.7
3	7.5	-1.575	0.257	6
4	10.1	-1.419	0.301	5.1

2.3.6. Perceived Wildfire Risk

There may be a fair amount of noise in subjective assessments of the risk of a natural disaster. Media reports may update residents of WUI communities on wildfires in their area, but may tend to focus on the instances of events rather than the true associated risk (Singer and Endreny, 1994). Furthermore, previous literature has suggested that homeowners vary in what they consider effective risk reducing measures. We therefore include variables correlated with perceived wildfire risk (*PERCEIVED_RISK*) and the homeowners trust in defensible space to defend against a wildfire (*TRUST*). Perceived Wildfire Risk (*PERCEIVED_RISK*) is an index created from a Likert question block in the survey (Figure 2.2) and is a continuous variable bounded [0,1]. We recode each selection choice for the 9 point Likert scale in 0.111 increments in the [0,1] range to represent a probability. As the choice "A wildfire in your community will reach your property" is conditional on "A wildfire will occur in your community", we multiply the self-reported results for both Likert scales from this question block for each individual homeowner to generate an index that represents the perceived conditional probability a wildfire reaches a property given it occurs in a community.

Figure 2.2: Perceived Wildfire Risk Likert Question Block

2. What is your best guess about the chances of these happening in the next **5 years**?…	Certain to happen								Will not happen
A wildfire will occur in your community.	❑	❑	❑	❑	❑	❑	❑	❑	❑
A wildfire in your community will reach your property.	❑	❑	❑	❑	❑	❑	❑	❑	❑

Previous literature has stressed the efficacy of defensible space in reducing homeowner wildfire risk, many homeowners in WUI communities do not invest in defensible space (Cohen 2000, Brenkert-Smith et al 2012). It is possible that some homeowners fail to invest in defensible space because they are uninformed about its efficacy at reducing wildfire risk. Trust in defensible space (*TRUST*) is an index created from self-reported responses to a Likert scale in the survey (Figure 2.3) and is a categorical variable bounded [0,1]. We code each selection choice for the Likert scale in 0.111 increments in the [0,1] range. The index is coded to represent the percentage of trust a homeowner has from taking all defensible space actions in preventing a wildfire on their property from reaching their home.

Figure 2.3: Trust in Defensible Space Question Block

2. If you took **<u>all</u> possible** defensible space actions and home modifications that you could on this property …	Certain to happen								Will not happen
Would a wildfire on your property spread to your house?	❑	❑	❑	❑	❑	❑	❑	❑	❑

Table 2.10 summarizes variables correlated with perceived wildfire risk.

Table 2.10: Perceived Wildfire Risk Summary Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
COM_CHANCE	636	0.33	0.26	0	1
TRUST	625	0.49	0.27	0	1

2.3.8. Objective Wildfire Risk

The 35 communities have four dominant vegetation types (grassland, sagebrush rangeland, pinyon-juniper woodlands, and alpine forest) each with a different wildfire risk rating. We include six variables indicative of the homeowner's objective wildfire risk: three topographical variables (*ASPECT, ELEVDIFF, SLOPE*), two explanatory variables that affect wildfire hazard (*LGHTN, WIND*), and one variable affecting the homeowners experience with wildfire (*NEARFIRE*). *ASPECT* is a dummy variable equal to 1 if the property is on a southern exposure. Southern exposure is included because vegetation on a southern exposure generally has a lower moisture content and is exposed to higher average wind speeds. We include the slope of the property (*SLOPE*) as fire tends to move uphill and faster in steeper areas. Third, we include the difference in elevation between the property and the average elevation of the community (*ELEVDIFF*) in feet. As fire moves uphill, higher properties will, on average, have a higher wildfire risk. To control for the role of wind in affecting wildfire risk, we include the average maximum wind speed (mph) in each community for May 1 to September 30 of 2010. As lightning strikes affect ignition, we include the number of lightning strikes within 10 miles of each property for 2005 – 2010 (*LGHTN*).

It is possible some homeowners are more likely to invest in defensible space or other fire safe investments because they noticed an increase in fires near their property while other homeowners have not. We include a self-reported measure of the closest distance a fire has come to a homeowner's property since owning it. The proximity of the nearest fire since the homeowner has owned the home (*NEARFIRE*) is a categorical variable that measures distance in miles. Figure 2.4 shows how the question was structured and potential categories. We recoded the variable to be in mileage terms by setting the mileage to the median of each potential answer[7].

Figure 2.4: Nearest Fire Question Block

[7] "On the property" was set to 0.005, "Up to the property line" was set to 0.02, "More than 10 miles away" was set to 15, and "Not Sure" was set to 50. The rest were set to the median of the provided ranges for each potential answer.

4. Since owning this house, what is the closest a fire has come to it?

❑ On the property ❑ Up to the property line ❑ Within 1 mile ❑ Between 1 and 5 miles

❑ Between 5 and 10 miles ❑ More than 10 miles away ❑ Not sure

We use these variables to control for differences in defensible space and other fire-safe investments driven by differences in objective wildfire risk.

2.3.9 Wildland Policy Variables

Wildland policy at the community level affects the suppression and prevention of wildfire in the WUI. We include three explanatory variables related to wildland policy. We include the per capita number of fire protection resources within 10 miles for the years 2006-2010 (*RES_PC*) to control for the effectiveness of wildfire protection resources in a community. We also include the per capita number of hazardous fuel reduction treatments performed on public lands within 10 miles of each property for the years 2006-2010 (*RX_PC*) as fuel treatment, on average, will reduce objective wildfire risk. We use *per capita* for these measures to control for larger communities that may have more residences or more fuel treatments. Finally, we include a dummy variable equal to 1 if the primary road of a community is larger than 24 feet (*ROAD_MORE24*) as wider roads may increase the ability of fire suppression resources in responding to wildfire. We include these variables to control for differences in defensible space investments and other fire-safe investments driven by differences in community wildland policy characteristics.

2.3.10 Barriers to Defensible Space

Other non-pecuniary restrictions may influence homeowners' decisions to invest in defensible space. Defensible space is the cumulative outcome of man fire risk reducing actions and requires continual maintenance, which can be physically demanding and time consuming, and possibly be restricted by zoning regulations designed to protect community aesthetics. We therefore include several variables that capture non-pecuniary restrictions that may influence homeowners' decisions to invest in defensible space and other fire-safe investments. Zoning restrictions (*ZONING*) is a self-reported binary variable from survey respondents indicating whether zoning restrictions prevent them from doing more to improve their defensible space. Time restrictions (*TIME*) is a self-reported binary variable from survey respondents indicating whether a lack of time affects their defensible space. Health restrictions (*HEALTH*) is a self-reported binary variable from survey respondents indicating their level of health. *HEALTH* was taken from a question in the survey where homeowners could identify their level of health on a Likert scale from "Poor" to "Excellent". We recoded the survey data to a (0,1) binary indicator of health by setting *HEALTH* = 1 if homeowners chose "Fair" or "Poor" and = 0 if homeowners chose "Excellent", "Very Good", or "Good". Table 2.11 reports the summary statistics for variables identified to be barriers to investment.

Table 2.11: Barriers to defensible space summary statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
ZONING	627	0.17	0.37	0	1
TIME	626	0.23	0.42	0	1
UNHEALTHY	615	0.08	0.28	0	1

2.4 Missing Observations

We acknowledge that our data contains missing observations for some of the variables used in this thesis. As a result, this can significantly reduce the sample size of the data used when performing analysis. We use Multiple Imputation by Chained Equations (MICE) to impute values for some of the variables with missing observations. The MICE process is described in further detail in Chapter 3. Table 2.12 reports each dependent variable used in this thesis with its description, variable type, and number of observations. Table 2.13 reports each explanatory variable used in this thesis with its description, variable type, and number of observations.

Table 2.12: Dependent Variable Descriptions

Variable	Description	Type	Obs
DEFSP	=1 if Property Contains Adequate Defensible Space	Binary	736
HH_SPEND	= 1 if Homeowner spent money on reducing fire risk on Housing Structure	Binary	736
HH_WORK	= 1 if Homeowner spent time on reducing fire risk on Housing Structure	Binary	736
IZ_SPEND	= 1 if Homeowner spent money on reducing fire risk on the Inner Zone of their property	Binary	736
IZ_WORK	= 1 if Homeowner spent time on reducing fire risk on the Inner Zone of their property	Binary	736
OZ_SPEND	=1 if Homeowner spent money on reducing fire risk on the Outer Zone of their property	Binary	736
OZ_WORK	=1 if Homeowner spent time on reducing fire risk on the Outer Zone of their property	Binary	736

Table 2.13: Explanatory Variable Descriptions

Variable	Description	Type	Obs
HHVL	Log of Home Value ($)	Continuous	736
OWN_YRS	Length of Home Ownership (Years)	Continuous	652
INCOME	Median Tax Bracket	Categorical	548
AGE	Age of Homeowner (Years)	Continuous	603
OWN_MORE	Ownership of Other Property	Binary	654
INSURANCE	Insurance Status	Binary	648
LRTOL	Log of Risk Tolerance	Categorical	581
RTOL	Risk Tolerance	Categorical	581
AESTHETICS	Index of Landscaping Aesthetic as a Barrier to Investment	Index	612
HOUSE_ATTR	Concern for loss of housing attractiveness as a barrier to making fire-safe investments	Categorical	619
LAND_ATTR	Concern for loss of landscaping attractiveness as a barrier to making fire-safe investments	Categorical	616
PRIVATE	Index of Privacy as a Barrier to Investment	Index	618
AGEHOME	Age of Home (Median Range)	Categorical	651
LOT	Size of Property (Acres)	Continuous	736
COM_CHANCE	Index of Subjective Probability of Fire Reaching Property (%)	Index	636
NEARFIRE	Proximity of Nearest Fire Since Owning Property	Categorical	652
TRUST	Index of Trust in Defensible Space (%)	Index	625
BRUSH	=1 if Predominantly Sagebrush Grassland	Binary	736
GRS	=1 if Predominately Cheatgrass	Binary	736
PJ	=1 if Predominately Pinyon-Juniper Pine	Binary	736
TMBR	=1 if Predominately Alpine Forest	Binary	736
FUEL	Average Fuel Loading in Community (ton/ac)	Categorical	736
ASPECT	=1 if Property Facing South	Binary	736
SLOPE	Slope of Property	Continuous	736
ELEVDIFF	Slope of Property	Continuous	736
LGHTN	Lightning Count Within 10 Miles	Integer	736
WIND	Average Maximum Windspeed (MPH)	Categorical	736
ROAD_MORE24FT	=1 if Roads are more than 24ft	Binary	736

RES_PC	Number of Residence within 10 Miles, Per Capita	Continuous	736
RX_PC	Number of Fuel Treatments on Public Land Within 10 Miles in Previous 5 Years, Per Capita	Continuous	736
ZONING	=1 if Zoning is a Barrier to Investment	Binary	627
TIME	=1 if Time is a Barrier to Investment	Binary	626
HEALTH	=1 if Health is a Barrier to Investment	Binary	615

Chapter 3: Methods

3.1. Introduction

The purpose of this chapter is to describe the methods used in this thesis. The first section describes how the indices introduced in Chapter 2 were created. The second section introduces the econometric model used to estimate choice probability of investing in defensible space and other individual fire-safe investments. The third section discusses the probit model and how to interpret it. The final section describes the Multiple Imputation by Chained Equations (MICE) procedure used to impute some of our variables with missing data and discusses the re-estimation of the probit model using all imputed datasets.

3.2 Index Creation

We created indices from survey variables correlated with one another to capture a single underlying concept unobserved by survey responses. Creation of these indices followed a three-step process. First, we identified question blocks in the survey related to some feature we expected to influence the homeowners' decision problem to invest in defensible space or take some individual fire-safe action. For example, homeowners were asked which items were restricting their decision to do more to reduce fire-risk on their property (Figure 3.1). We expected these variables could be reduced to a smaller number of indices that captured individual features not directly observed by the question block.

Figure 3.1: Question Block on Restrictions to Reducing Fire-Risk

4. Do these affect your choice to do more to reduce fire risk on your property?	Yes!!	yes	maybe	no	No!!
Zoning, homeowner's association rules, local regulations	❑	❑	❑	❑	❑
Expense	❑	❑	❑	❑	❑
Too little time	❑	❑	❑	❑	❑
Don't tend to think about the risk of wildfire damage very much	❑	❑	❑	❑	❑
Don't want to make my house less attractive	❑	❑	❑	❑	❑
Don't want to make my landscaping less attractive	❑	❑	❑	❑	❑
Changes to landscaping may reduce my privacy	❑	❑	❑	❑	❑
Concern about wildlife habitat	❑	❑	❑	❑	❑

Second, we used factor analysis to identify which variables were correlated with one another. Factor analysis identifies the smallest number of underlying factors that the data can be reduced to and which variables are correlated with each factor. Using the example above, we found that survey responses for "Don't want to make my house less attractive" and "Don't want to make my landscaping less attractive" were highly correlated (0.86 and 0.87, respectively) with the first factor capturing the majority of the variation in the question block.

Third, we used the evidence from the factor loadings to justify the creation of our indices. We recoded the variables highly correlated with a single factor to the 0-100 range. We then generated the indices as the average of the correlated variables. In the example above, each response option for "Don't want to make my house less attractive" and "Don't want to make my landscaping less attractive" was recoded to 0-100 in increments of 25, where 0 indicated a "No!!" response and 100 indicated a "Yes!!" response. Both variables were then added to one another, and the average was taken by dividing by two. In this example, we created the index "*AESTHETICS*" to capture the underlying concept of aesthetic preference as a restriction to fire-risk reducing actions indirectly observed by the question block. However, while this index was created, it was found to be more effective if “Don’t want to make my house less attractive” and “Don’t want to make my landscaping less attractive” as separate aesthetic variables.

This process was repeated with slight alterations for *PERCEIVED_RISK*. Factor analysis was used to identify which variables in the question block were correlated with one another. However, as reported in Chapter 3, the correlated variables were multiplied with one another, rather than averaged, to represent the homeowners’ perceived conditional probability a wildfire reaches their property given it occurs in their community.

3.3 The Econometric Model

We are considering the decision of a homeowner who has the option to invest in defensible space, and use Compensating Variation (CV) to identify the difference in expected utility to the homeowner from investment. We acknowledge that some homeowners would have a positive CV, where they would be willing to pay for defensible space because it provides a net welfare benefit to the homeowner, and other homeowners would have a negative CV, where they would require compensation to maintain their initial level of utility prior to investing because defensible space would incur a welfare loss to the homeowner.

We can express homeowner i’s net benefit from investing in defensible space as $y_i^* = WTP_i^*$ and the homeowner i’s expected utility is expressed as:

$$EU^{NoDS}(w_i - CV,\ DS = 0,\ I,\ X) = EU^{DS}(w_i - C_i^d,\ DS = 1,\ I,\ X)$$

Where

$$CV = f(w_i, C_i^I,\ C_i^d,\ I,\ X)$$

And compensating variation is a function of homeowner i's wealth, cost of insurance, cost of defensible space, insurance status, and other exogenous features affecting the homeowners' decision problem. From the expected utility and compensating variation function, we define the empirical model as:

$$\Pr Pr\ (y = 1)\ = \Pr Pr\ (CV \geq 0)\ = Pr(CV + \varepsilon \geq 0)$$

Defensible space is the cumulative outcome of many individual fire-safe investments, and a homeowner either has or does not have adequate defensible space. We use an econometric model with variables we believe to be directly affecting the homeowners' utility function and compensating variation to determine what is driving the decision to invest in defensible space. We define our econometric model as

$$DEFSP = \beta_0 + \beta_1 HHVL + \beta_2 OWNYRS + \beta_3 INCOME + \beta_4 AGE + \beta_5 OWNMORE + \beta_6 INSURAN$$

Where Objective Wildfire Risk, Wildfire Policy, and Barriers to Defensible Space are the control blocks defined in Chapter 2. Our analysis begins with a probit on the base componenets directly affecting the homeowners' utility function in the decision to invest in defensible space (*HHVL – TRUST*). We sequentially add each control block to discover how each factor affecting the decision problem interacts among one another, while controlling for differences in investment driven by differences in objective wildfire risk, wildfire policy, and non-pecuniary barriers to investment.

We repeat this process for individual fire-safe actions to check if there is a difference between full investment in defensible space and taking an individual fire-safe action. The survey data contains dummy variables indicating whether or not homeowner's spent any time or money to reduce fire risk on either their housing structure, inner zone of their property, or outer zone of their property. These variables are described in Section 2.3.2 of Chapter 2. We use the same explanatory variables defined by our econometric model to predict the choice probability of taking a fire-safe action (either through time spent or money spent) in a specific zone of the homeowner's property.

3.4 The Probit Model

The dependent variables in our analysis are dummy variables indicating whether or not a homeowner has assessed adequate defensible space or has a taken an individual fire-safe action. The nature of the dummy dependent variable requires the use of a binary choice model. We use a nonlinear probit model to estimate the choice probability of investing in defensible space or other fire-safe investments. The probit model keeps the choice probability bounded in the range [0,1] and allows for a nonlinear S-shaped relationship between the explanatory variables and the probability of investment in defensible space or other fire-safe actions (Hill 2007). The slope of the nonlinear relationship defines the change in probability of investment in defensible space or other fire-safe actions given by a unit change in an explanatory variable. The probit model is defined by the standard normal probability density function. Consequently, the probit cumulative distribution function is defined as:

$$\varnothing(Z) = P\,[Z \leq z] = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2}\,du$$

And the statistical probit model defining the probability of defensible space or other fire-safe investments equaling 1 is $p = P\left[Z \leq \beta_0 + \beta X\right] = \varnothing(\beta_0 + \beta X)$ where X is a vector of known explanatory variables and β is the unknown parameter used to derive the change in choice probability as a result of a unit change in X. The unknown β coefficients must be estimated through Maximum Likelihood Estimation (MLE).

We use the probit model to estimate the β coefficients through the likelihood function $P\left[y_i = K\right] = \prod_{i=1}^{n} \varnothing(\beta_0 + \beta X)$ where K is 0 or 1 depending on homeowner *i*'s defensible space status and *n* is the total number of homeowners in the sample (736 in our data). The likelihood function derives the probability of observing investments in defensible space or other fire-safe actions, and the probit model chooses β coefficients for each explanatory variable that maximizes the probability of matching our data. The probit model iteratively chooses MLE estimates for each coefficient until the log likelihood function is maximized. We report the iteration history for each model we run in Chapter 5.

The MLE procedure provides MLE estimates for the unknown parameter β, but does not provide the change in probability as a result of a unit change in *X*. To provide an economic interpretation for our explanatory variables, the derivative with respect to each explanatory variable in the estimated statistical probit model must be derived. We take the derivatives with respect to the vector of explanatory variables in our model, taken at the mean of each explanatory variable. These marginal effects allow us to identify the change in probability for investing in fire-safe actions at the average value of each explanatory variable and are reported in Chapter 5.

3.5 Multiple Imputation by Chained Equations (MICE)

As described by Table 2.13, a few of our variables contain missing values as a result of using survey data, and these missing values can reduce the sample size of our model and decrease the precision of our estimates. Multiple Imputation (MI) and its derivations are commonly used by government agencies, political science, and other social sciences as a method to impute missing values in data (Zhong, Hu, and Penn 2018). We use a particular form of MI called multiple imputation by chained equations (MICE), developed by van Buuren and Oudshoorn (1999), to impute select variables with missing data in our dataset, while dealing with different variable types (such as categorical or continuous) and bounded variable ranges. The underlying assumption of Multiple Imputation is that the missing data can be explained by observable information. To test if this assumption holds, we identify if our variables with missing observations fall under three types of missing data: Missing at Random (MAR), Missing Completely at Random (MCAR), or Missing Not At Random (MNAR). MAR implies that some of the missing data can be explained by the some values of other observable data; MCAR implies that the missing data is completely unrelated to observable data; MNAR implies the data depends on unobserved data, conditional on observed data (MAR is indistinguishable from MNAR from observed data alone) (Royston and White 2011). MICE assumes that the data is MAR, and imputing missing values when the variables are MCAR can add noise to the model and create biased estimates (Azur et al 2011).

Multiple Imputation by Chained Equations is an iterative method used to impute multiple variables by univariate imputation chained equations. In practice, MICE is a three-step process: Imputation, Analysis, and Pooling (UCLA 2018). First, the Imputation Phase can be defined as letting $X = (X_1, X_2, \ldots, X_k)$ as a set of *k* random variables, where any X_i can be observed or missing, and X_1 to X_k is sorted from most missing data to least. The process continues by iteratively imputing a sequence of univariate imputations based on observable values in the full dataset. This process begins where X_1^{t+1} has imputations drawn from $P(X_1|X_2^t \ldots X_k^t)$, X_2^{t+1} has imputations drawn from $P(X_2|X_1^{t+1}, X_3^t, \ldots X_k^t)$, and so on for all *k* variables MAR, where *t* is an iteration (van Buuren and Oudshoorn 1999). Each missing value is imputed based on the distribution of the variable (binary, continuous, bounded continuous, etc) and in the order of magnitude of missing data (from the variable with the most amount of missing data to the variable with the least). The variable with the most amount of missing data (X_1) is regressed on values from the full dataset, the next variable with the second most amount of missing data (X_2) is then imputed by regressing on values of the full dataset and the imputed values of the first variable (X_1^{t+1}), and so on. Generally, this process occurs a defined amount of times (generally 10-20, but can be more if trying to reduce variation explained by missing data) to produce a single imputed dataset, and then repeated *m* times to produce *m* datasets (Royston and White 2011). Second, the Analysis phase occurs by running the econometric model on all *m* datasets to acquire coefficient and standard error estimations for each imputed dataset. Finally, the Pooling stage, pools the coefficient and standard error estimates of each imputed dataset to create one set of MI estimated coefficients.

Some of the variables with missing values contained in our data are included as controls to improve our estimates while others directly affect the decision making process. We choose to impute the variables used as controls and allow for missing observations in the variables directly affecting the decision problem. We test the variables with missing observations for type of missing data[8]. We find that *OWN_YRS, OWN_MORE, AGEHOME, ZONING,* and *HEALTH* are MAR and justified for MICE. We find that *INCOME, AGE,* and *TIME* are MCAR and could result in biased estimates if imputed. We elect to impute these MCAR variables because they do not directly influence the decision problem and were included as controls for financial characteristics and non-monetary barriers. We impute these variables using the STATA 14 MICE command and create 30 dataset imputations to account for the amount of variation explained by missing data. Table 3.1 presents the results of the Imputation Phase of the MICE process[9].

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[8] Table 6.3 in the Appendix reports the results of this analysis

[9] Section 6.1 in the Appendix provides the distribution of each variable before and after MICE. While the Appendix contains post-MICE distributions for all variables, the analysis in this thesis only uses imputations for *OWN_YRS, OWN_MORE, AGEHOME, INCOME, AGE, ZONING, TIME,* and *HEALTH*.

Table 3.1: Multivariate imputations by chained equation results

Observations per m		
	Imputations	30
	Added	30
	Burn-In	10
	Iterations	300

Variable	Method	Complete	Incomplete	Imputed	Total
ZONING	Logit	627	109	109	736
TIME	Logit	626	110	110	736
UNHEALTHY	Logit	615	121	121	736
OWN_MORE	Logit	653	83	83	736
OWN_YRS	Truncated Regression	652	84	84	736
AGEHOME	Truncated Regression	651	85	85	736
AGE	Truncated Regression	603	133	133	736
INCOME	Truncated Regression	548	188	188	736

During the Analysis phase, we estimated our analytical model (probit) for all 30 datasets. We pool the coefficients and standard errors of each dataset to create one set of estimated coefficients. Chapter 4 presents the results of this analysis along with an interpretation of each variables marginal effects[10].

[10] In STATA, the *margins* command (an r-class command) does not work for *mi estimate* (an e-class command). We use the *mimrgns* command to transfer coefficient estimates contained in the ereturn list (e-class) to the information contained in the *margins* return list (r-class)

Chapter 4: Results and Discussion

4.1. Introduction

This chapter presents the results of the econometric model described in Chapter 4. We use the model to investigate the drivers of homeowner fire-safe actions and investments. We compare the importance of financial considerations, risk tolerance, aesthetic and privacy preferences, and property constraints relative to homeowners' subjective beliefs about wildfire. We examine the homeowners' propensity to take any individual fire-safe action on their property to reduce their wildfire risk.

4.2. Results

Table 4.1 and 4.2 reports the results of the Multiple Imputation (MI) estimated probit models. Table 4.1 reports the marginal effects at the mean and associated p-Values for each sequential model in the decision to invest in defensible space. We use the complete set of controls in Model (5) of Table4.1 for the regressions on individual fire-safe actions on the property. Table 4.2 reports the MI estimated probit marginal effects and associated p-Values for the regressions on individual fire-safe actions on the housing structure, inner zone of the property, or outer zone of the property.

4.2.1. Financial Variables

Table 4.1 and 4.2 show that our variables correlated with financial status (*HHVL, OWN_YRS, INCOME, AGE, OWN_MORE, INSURANCE*) are all insignificant in our regressions, with the exception of *INSURANCE* in the interaction reported in Table 4.2

and the Housing-Spend regression in Table 4.2. We would expect our value at risk variables (*HHVL* and *OWN_YRS*) to be positively associated with the decision to invest in defensible or take any fire-safe action, as home value has a greater value at risk and income has a greater ability to pay for defensible space. Furthermore, we would expect our wealth variables (*INCOME*, *AGE, OWN_MORE*) to at least affect the decision to invest in defensible space or other fire-safe investments through an increased ability to pay (a positive relationship) or an increased ability to absorb the loss associated with wildfire damage (a negative relationship).

These results suggest that financial considerations are not a primary driver of the decision to invest in defensible space and other fire-safe investments for homeowners in our sample. It is possible that the insignificance of our financial variables is due to the nature of the data. Since our financial variables came from demographic questions in the survey and Nevada County Tax Assessor data, we were unable to directly capture homeowners' value at risk or wealth, and we instead had to use variables correlated with their financial position. Future work could improve the precision of financial data by asking more direct questions related to financial status such as the net equity position of the home, specific information on insurance status and why it was acquired, and more direct measures of homeowner' wealth other than age or income.

4.2.2. Risk Tolerance

Our measure for financial risk tolerance (*LRTOL*) has been a significant proxy for risk preferences in other settings such as asset allocation or stock holdings, and its construction was intended for use in behavioral settings involving risk preferences

(Kimball, Sahm, and Shapiro 2008). We would expect, holding all else equal, homeowners with a higher financial risk tolerance would be less likely to reduce their wildfire risk by taking fire-safe actions or investing in defensible space. Tables 4.1 and 4.2, however, report insignificant marginal effects at the 5% level for financial risk tolerance. Our findings suggest that financial risk preferences are not a primary driver in the decision to take fire-safe actions on private property.

There are three possible explanations for why financial risk tolerance is insignificant in our models. First, previous literature has found risk preferences are inconsistent among different domains (Einav et al 2012; Schoemaker 1990). Our risk tolerance parameter, *LRTOL*, is a measure of financial risk tolerance, and it is possible risk preferences change between the financial risk context and wildfire risk context for homeowners in our sample. Our survey used lifetime decision gambles to acquire homeowner' risk preferences, and since we have no other measure of risk tolerance, we cannot further address this issue in this thesis.

Second, risk-tolerant homeowners may be choosing to live in areas with higher wildfire risk, and then invest in defensible space or take individual fire-safe actions to mitigate this risk. The probability of wildfire is low for most WUI communities, so it is possible we are unable to see the marginal effects of risk preferences in responding to wildfire risk. While we control for many factors influencing the homeowners' decision-problem, we test this hypothesis by allowing the coefficient on *LRTOL* to vary between high wildfire risk and low wildfire risk communities. We create dummy variables out of each objective wildfire risk variable (*ASPECT, SLOPE, WIND, LGHTN,* *ELEVDIFF*), where 1 indicates an observation above the mean and 0 indicates an observation below the mean, and interact these dummy variables with *LRTOL*. We would expect the homeowners living in high fire risk communities to have significant marginal effects for financial risk tolerance in the decision to take fire-safe actions because they are responding to that higher wildfire risk. Tables 6.1 and 6.2 in the Appendix report the results from these regressions. We find no significance in these interacted models. This suggests the insignificance *LRTOL* in the decision to make fire-safe investments is not due to homeowners choosing to live in higher wildfire risk communities.

Finally, the insignificance of *LRTOL* could be a result of risk averse homeowners being more likely to purchase insurance. Homeowners who are financially risk averse could purchase insurance to protect the financial value of their home and, by having homeowner's insurance, feel sufficiently protected from wildfire damage and choose to not invest in defensible space. We explore this option further in section 4.2.5.

4.2.3. Perceived Wildfire Risk

Tables 4.1 and 4.2 show subjective beliefs towards wildfire is a dominant driver for homeowners' propensity to take individual fire-safe actions while controlling for financial characteristics and objective wildfire risk. This result suggests it is important to understand how these subjective beliefs are formed if policy wants to encourage homeowners to invest in defensible space. Defensible space is the cumulative outcome of several individual fire-safe investments, and homeowners can care significantly about wildfire and take several actions to reduce their wildfire risk, but may not meet the adequate defensible space threshold due to components related to the cost of investment such as loss of aesthetic utility and privacy utility offered by landscaping.

That fire-safe actions and investments of homeowners in our sample are driven by subjective beliefs about wildfire suggests it is important to understand homeowners develop these beliefs. Previous literature has stressed the role of communication and media in how individuals are informed and respond to natural disaster risk (Singer and Endreny 2006; Karanikola et al 2015). There can be two types of inefficiencies as a result of subjective wildfire risk driving the decision to make fire-safe investments: 1. homeowners' may not be concerned enough about wildfire to make fire-safe investments and put an excess burden on the public sector to protect their home; and 2. homeowners' may be more concerned about wildfire than is warranted and, as a consequence, are inefficiently allocating resources at the household level. For efficient resource allocation, homeowners' subjective beliefs towards wildfire should match their true wildfire risk.

Current wildfire policy in the WUI focuses on community outreach efforts to educate homeowners on their wildfire risk to encourage defensible space investment. This policy may only increase homeowner propensity to take an individual fire-safe action, but some other factors are restricting homeowners from meeting the threshold of individual actions that cumulatively account for defensible space. Subjective beliefs towards wildfire is a dominant driver in taking some action to reduce fire risk, but is outweighed by components related to the cost of investment when homeowners' consider the decision to fully invest in defensible space.

4.2.4. Cost of Investment

We include four variables associated with the cost of fire-safe investments: concerns about loss of privacy as preventative factor to making fire-safe investments (*PRIVACY*), concerns about loss of aesthetic value offered by their landscaping or home as preventative factor to making fire-safe investments (*AESTHETICS*), age of home (*AGEHOME*), and lot size (*LOT*). We expect concerns about loss of privacy (*PRIVACY*) and loss of aesthetic value (*AESTHETICS*) to be correlated with the utility cost of fire-safe investments and, holding all else equal, homeowners with higher concerns about the loss or privacy or loss of aesthetic value to be less likely to make fire-safe investments. We expect age of home (*AGEHOME*) to be correlated with both the financial cost of investment and utility cost of investment. Older homes have more matured landscaping and older features, and by making fire-safe investments, homeowners have to bear the cost of removing larger tress and building around the older features of their home. Homeowners with older homes also face the opportunity cost between removing tress to reduce the probability of a wildfire destroying their home and the utility value of matured landscaping. All else equal, we expect homeowners with older homes to be less likely to make fire-safe investments. We expect lot size (*LOT*) to reduce the utility cost of fire-safe investment associated with privacy, as larger lots could still meet the 30ft defensible space requirement and have the landscaping within the property line that maintains the homeowners' desired privacy. We expect, all else equal, homeowners with larger lots to be more likely to make fire-safe investments.

Tables 4.1 and 4.2 show that the cost of investment influences the decision to make individual fire-safe investments and the decision to fully invest in defensible space differently. Table 4.1 reports negative and significant marginal effects for *PRIVATE* and *AGEHOME* for homeowners in our sample. This suggests that concerns about loss of privacy by making fire-safe investments is a restricting factor in homeowner defensible space compliance, and homeowners who value the privacy offered by their landscaping are less likely to invest in defensible space. Homeowners with older homes are also less likely to invest in defensible space, either due to the financial cost of investment by removing larger trees and building around the older features of their home or the opportunity cost between reducing the probability their home will be destroyed by a wildfire fire and the utility value offered by their matured landscaping. Both concerns about loss of privacy, age of the home, and lot size are insignificant in the regressions concerning individual fire-safe investments.

Table 4.2 reports negative and significant marginal effects for *AESTHETICS* for spending time to reduce wildfire risk on the housing structure and outer zone of the property. The *AESTHETICS* index was created out of two survey questions regarding concerns about the loss of aesthetic value from fire-safe investments: 1. Concerns about loss of aesthetic value on the housing structure, and 2. Concerns about the loss of aesthetic value offered by the landscaping. These results suggest that concerns about landscaping aesthetics and housing aesthetics directly impact the homeowners' decision to make fire-safe investments. Both concerns about loss of aesthetic value and lot size are insignificant in the regressions concerning defensible space compliance.

Our results indicate that concerns about the loss of aesthetic value directly reduce the propensity of homeowners to make individual fire-safe investments, while concerns about the loss of privacy and the age of the home directly reduce the propensity of homeowners to invest in defensible space. These results indicate that defensible space compliance is driven by preferences unrelated to wildfire concern or awareness. That lot size is insignificant for both defensible space compliance and individual fire-safe investments for homeowners in our sample only indicates that the reduced utility cost of a larger lot is not a major determinant in the homeowners' decision problem. Current WUI policy that focuses on increasing homeowner awareness of wildfire may increase their propensity to take individual fire-safe investments driven by their perceived wildfire risk, but meeting the threshold of fire-safe actions that result in defensible space is restricted by the costs of investment.

4.2.5. Insurance

Homeowners can reduce their expected financial loss from wildfire by purchasing homeowners insurance. However, homeowners insurance does not cover non-monetary losses, such as keepsakes or photos, or protect against the emotional damage of losing a home to a wildfire. As some homeowners are required to carry insurance as a part of their mortgage agreement, our data is limited in that it does not contain information on homeowner mortgage status. As a result, of the 95% of our sample with insurance, we cannot distinguish between homeowners that are required to hold insurance from homeowners that choose to purchase insurance to reduce their expected financial loss from a wildfire. We acknowledge that the decision to purchase insurance and invest in defensible space may be endogenous for homeowners who are not required to hold insurance via their mortgage agreement. However, we are unable to address the endogeneity issue in this thesis because our data does not contain a strong IV to instrument insurance status.

Table 4.3 reports summary statistics of defensible space compliance, fire-safe actions, risk tolerance, and measures of wildfire awareness to better understand the differences between insured and uninsured homeowners. Table 4.3 differs from the analysis reported in Tables 4.1 and 5.2 by not looking into how insurance status influences the decision problem to make fire-safe investments, but by looking into how, on average, homeowners with different insurance statuses think about wildfire and make fire-safe investments. Table 4.3 shows that insured homeowners have lower levels of defensible space, despite having a lower risk tolerance, believing they are at greater risk of wildfire, and being more likely to be thinking about wildfire when purchasing their home. We expand this analysis by looking into differences between insured and uninsured homeowners on individual actions to reduce fire risk in different areas of their property. We find that insured homeowners, on average, spend more time to reduce fire risk on their housing structure, inner zone of their property, and outer zone of their property when compared to uninsured homeowners. Our findings suggest that insured and uninsured homeowners are statistically different from each other in their beliefs towards wildfire and actions taken to reduce their wildfire risk.

As homeowners can reduce their expected financial loss from a wildfire by purchasing homeowners insurance, a question to address is whether or not homeowners insurance is reducing the level of private fire-safe actions or investments taken by homeowners. Mandatory insurance for homeowners with mortgages may reduce the homeowners' propensity to take fire-safe actions or investments, leading to socially-inefficient underinvestment that could amplify risk externalities associated with a lack of fire-safe investments or impose external costs on public agencies tasked with fire suppression. We face an empirical problem when trying address this issue, as the decision to purchase homeowners insurance and the decision to make fire-safe investments are endogenous, and a homeowner may choose to not carry insurance if they are making private fire-safe investments, or vice-versa. However, we are able to provide some analysis on this issue.

Table 4.2 reports a negative and significant marginal effect for *INSURANCE* in the decision to spend money to reduce fire risk on the housing structure. This finding suggests what we would expect, that, holding all else equal, homeowners with insurance are less likely to spend money to reduce fire risk on their housing structure, as the housing structure is financially protected by homeowners insurance. When looking at the unconditional means reported in Table 4.3, we find that insured homeowners have statistically lower levels of defensible space compliance. Furthermore, uninsured homeowners are more risk tolerant and have lower levels of perceived wildfire risk. This suggests that the homeowners who would likely drop insurance if given the choice would also be the homeowners least likely to invest in defensible space. However, while we cannot answer this question definitively, Tables 4.1 and 4.2 report no evidence to suggest that insurance status is a primary driver of defensible space compliance or fire-safe investments. Since other financial considerations were not primary drivers of defensible space compliance or fire-safe investments, it is not surprising that insurance status is not either. To better address this issue, future work should focus on identifying which homeowners are required to hold insurance due to their mortgage status from those who choose to purchase insurance to reduce their expected financial loss from wildfire.

4.3. Tables

Table 4.1: Investment in Defensible Space Model Development

	Model (1)		**Model (2)**		**Model (3)**		**Model (4)**		**Model (5)**	
	Marginal Effects	**P>t**	**Marginal Effects**	**P>t**	**Marginal Effects**	**P>t**	**Marginal Effects**	**P>t**	**Marginal Effects**	**P>**
HHVL	-0.023	0.208	0.008	0.710	0.020	0.319	0.006	0.772	0.022	0.2
OWN_YRS	0.000	0.857	0.000	0.983	0.000	0.993	0.000	0.928	0.000	0.9
INCOME	0.000	0.491	0.000	0.750	0.000	0.429	0.000	0.614	0.000	0.3
AGE	-0.001	0.688	0.001	0.734	0.001	0.689	0.000	0.868	0.001	0.6
OWN_MORE	-0.042	0.406	-0.017	0.734	-0.044	0.393	-0.017	0.743	-0.040	0.4
INSURANCE	-0.200*	0.074	-0.163	0.143	-0.148	0.192	-0.142	0.205	-0.123	0.2
LRTOL	0.161	0.315	0.192	0.237	0.221	0.176	0.201	0.216	0.236	0.1
AESTHETICS_1	0.002	0.374	0.002	0.473	0.002	0.510	0.002	0.451	0.001	0.5
AESTHETICS_2	-0.002	0.458	-0.001	0.668	-0.001	0.619	-0.001	0.652	-0.001	0.6
PRIVATE	-0.003**	0.034	-0.003**	0.025	-0.003**	0.037	-0.003**	0.021	-0.003**	0.0
AGEHOME	-0.013***	0.000	-0.012***	0.000	-0.012***	0.000	-0.012***	0.000	-0.012***	0.0
LOT	-0.001	0.504	-0.002	0.304	-0.002	0.220	-0.002	0.261	-0.002	0.2
PERCEIVED_RISK	-0.165*	0.089	-0.174*	0.078	-0.178*	0.070	-0.185*	0.059	-0.179*	0.0
TRUST	0.164*	0.063	0.099	0.268	0.114	0.209	0.113	0.213	0.130	0.1
Wildland Policy			x	x					x	x
Objective Wildfire Risk					x	x			x	x
Barriers to Defensible Space							x	x	x	x
Imputations	30		30		30		30		30	
Observations	502		502		502		502		502	
Average RVI	0.024		0.017		0.015		0.022		0.016	
Largest FMI	0.152		0.164		0.154		0.165		0.170	

*** p<0.01, ** p<0.05, * p<0.10

Table 4.2: Individual Fire-Safe Investments

	Housing Structure				Inner Zone				Outer Zone		
	Spend		Work		Spend		Work		Spend		Work
	Margina l Effects	P>t	Margina l Effects	P>t	Marginal Effects	P>t	Marginal Effects	P>t	Marginal Effects	P>t	Marginal Effects
HHVL	0.019	0.335	-0.018	0.416	0.026	0.211	0.006	0.782	0.001	0.941	-0.009
OWN_YRS	0.002	0.481	-0.001	0.741	-0.005*	0.078	-0.001	0.587	-0.001	0.842	-0.001
INCOME	0.000	0.234	0.000	0.370	0.000	0.590	0.000	0.609	0.000	0.247	0.000
AGE	0.001	0.694	-0.002	0.398	0.003	0.267	0.001	0.685	0.001	0.520	0.002
OWN_MORE	-0.075*	0.093	-0.075	0.158	0.021	0.674	0.015	0.760	0.016	0.709	-0.043
INSURANCE	-0.212**	0.037	0.109	0.374	0.005	0.969	0.132	0.219	0.264*	0.086	-0.008
LRTOL	0.127	0.367	-0.092	0.597	0.214	0.177	-0.149	0.345	-0.053	0.718	-0.304*
AESTHETICS_1	0.002	0.333	-0.002	0.368	-0.001	0.580	-0.001	0.591	-0.003	0.148	-0.002
AESTHETICS_2	-0.003*	0.060	-0.001	0.568	0.001	0.579	-0.001	0.748	0.002	0.259	0.000
PRIVATE	0.002	0.152	0.001	0.361	0.001	0.319	0.001	0.317	0.000	0.867	0.002
AGEHOME	-0.001	0.754	0.004	0.178	0.003	0.379	0.002	0.415	-0.001	0.779	0.000
LOT	0.001	0.548	0.002	0.429	0.001	0.470	0.004	0.113	0.002	0.201	0.004*
PERCEIVED_RISK	0.106	0.212	0.380***	0.000	0.107	0.263	0.391***	0.000	0.121	0.155	0.331***
TRUST	-0.016	0.843	0.080	0.399	0.030	0.733	0.080	0.369	0.088	0.266	0.038
Imputations	30		30		30		30		30		30
Observations	502		502		502		502		502		502
Average RVI	0.015		0.013		0.015		0.011		0.018		0.013
Largest FMI	0.126		0.130		0.178		0.086		0.151		0.127

*** p<0.01, ** p<0.05, * p<0.10

Table 4.3: Differences Between Insured and Uninsured

Name	Description	Mean Insured	Mean Uninsured	t Statistic	p-Value
RTOL	Risk Tolerance with Insurance	0.223	0.235	1.804	0.036
PERCEIVED_RISK	Subjective Fire Risk with Insurance	0.339	0.252	-1.785	0.037
DEFSP	Defensible Space Status	0.356	0.467	1.232	0.218
FEXP	Noticed increase in nearby fires	2.285	2.278	-0.032	0.487
CONCERN	Thinking about fire when purchasing home	2.161	1.850	-1.649	0.050
Individual Fire-Safe Investments					
Housing Structure	Money	0.257	0.233	-0.293	0.385
	Time	0.586	0.400	-2.015	0.022
Inner Zone	Money	0.332	0.267	-0.740	0.230
	Time	0.659	0.467	-2.156	0.016
Outer Zone	Money	0.273	0.067	-2.518	0.006
	Time	0.550	0.400	-1.613	0.054

Chapter 5: Conclusions

5.1. Background

In this thesis, we used a unique data set collected from 35 WUI communities in Nevada containing information on the components of the homeowners' decision problem to take fire-safe actions and include variables related to the homeowners' subjective beliefs about their wildfire risk and their trust of fire-safe investments in reducing that risk. We use this data set to analyze the extent the homeowners' decisions are affected by the components of their decision-problem versus their subjective beliefs about wildfire by developing a probit model to identify the choice probability of homeowner investment in defensible space or some individual fire-safe action. We include controls on objective wildfire risk, wildland policy characteristics, and other non-monetary barriers to investment to improve our estimates. As some our variables contain missing observation, we impute missing data for the variables used as controls in our analysis by Multiple Imputation by Chained Equations (MICE) to increase our sample size and further improve the precision of our estimates.

5.2. Major Conclusions

Our analysis comes to two major conclusions about the underlying motivations to invest in defensible space or take some individual fire-safe action on the property, while identifying potential shortcomings. First, we find that subjective wildfire beliefs are driving the propensity to take individual fire-safe actions on the property, but, when considering the decision to fully invest in defensible space, is outweighed by components related to the cost of investment. Second, we identify concerns about loss of privacy and age of the home are the dominate drivers preventing homeowner' defensible space compliance. We find that many of our variables are insignificant in our regressions, but this could be a result of imprecise measures of certain features affecting the decision problem.

We find that including subjective beliefs about wildfire in the model drives the propensity to take some individual fire-safe action on the housing structure, inner zone of the property, and outer zone of the property. That subjective beliefs drive the propensity to take some individual fire-safe action can lead to two potential inefficiencies in the homeowners' individual allocation of resources. Homeowners perceived wildfire risk may be less than their true wildfire risk and, as a result, may not be making enough fire-safe investments on their property to sufficiently protect themselves from a wildfire. Conversely, homeowners may believe their wildfire risk is higher than their true wildfire risk and could be inefficiently allocating their resources. Individually inefficient underinvestment in defensible space could result in a socially-inefficient outcome. Defensible space provides external benefits by reducing wildfire risk for neighbors, and individually inefficient underinvestment could exacerbate this risk externality. Future work should focus on how these beliefs are formed, whether they match the homeowners' true wildfire risk, and whether they lead to individually efficient fire-safe investments.

We find that privacy and age of the home act as restricting factors in defensible space compliance. Defensible space is the cumulative outcome of several individual fire-safe investments. Homeowners can make many individual fire-safe investments on their property, but the utility cost of investment in the form of lost aesthetic value from matured landscaping or concerns about loss of privacy prevent them from being defensible space compliant. For these homeowners, the cost of investment outweighs the benefits from investment. Defensible space compliance would incur a high aesthetic utility loss where the homeowner would experience a negative compensating variation and a welfare loss from investment. Current wildland policy aims to increase homeowner fire-safe investments on private property. We find evidence that suggests homeowners are making decisions driven by preferences unrelated to wildfire concern or awareness, and policy that aims to educate homeowners about their wildfire risk may be ineffective. Policy should consider homeowner utility preferences when discussing fire-safe investments.

5.3. Thesis Limitations

We find limitations in our data. First, financial characteristics were added to the model because we expected them to affect the ability to pay for defensible space or the ability to absorb the loss due to a wildfire. That our financial characteristics were insignificant suggests that a homeowners' financial position is not a major driver to their decision problem or that our variables were insufficient in capturing the homeowners' financial characteristics. Future work should incorporate more precise measures of homeowners' financial position by asking more direct questions related to financial status such as the net equity of the home or more direct measures of homeowner wealth to determine if they are significant in affecting the homeowners' decision problem. Second, we were unable to deal with the endogeneity issue of insurance and defensible space investment. We expect the decision to purchase insurance and the decision to invest in defensible space to occur simultaneously, as both reduce the expected loss as a result of wildfire damage. However, many mortgage lenders require homeowners to hold homeowners' insurance to protect the financial value of the home. Our data contained limited variability in insurance status, with 95% of homeowners holding insurance, and we were unable to separate who was required to hold insurance per mortgage agreement and who chose to purchase insurance to protect the financial value of their home in the case of a wildfire. We were able to find evidence to suggest that homeowners with insurance, on average, had lower levels of defensible space, and homeowners who were likely to drop insurance if given the choice were less likely to invest in defensible space. However, we were unable to definitively answer if insurance status is a dominate driver in the decision to invest in defensible space. Future work should attempt to distinguish these two types of homeowners in the survey and incorporate a strong IV to instrument insurance to determine if insurance is reducing the level of private investment.

Chapter 6. Appendix

6.1. Multiple Imputation by Chained Equation Distribution Change

6.1.1. Years of Home Ownership (*OWN_YRS*)

Figure 6.1: Density of *OWN_YRS* Pre-Imputation

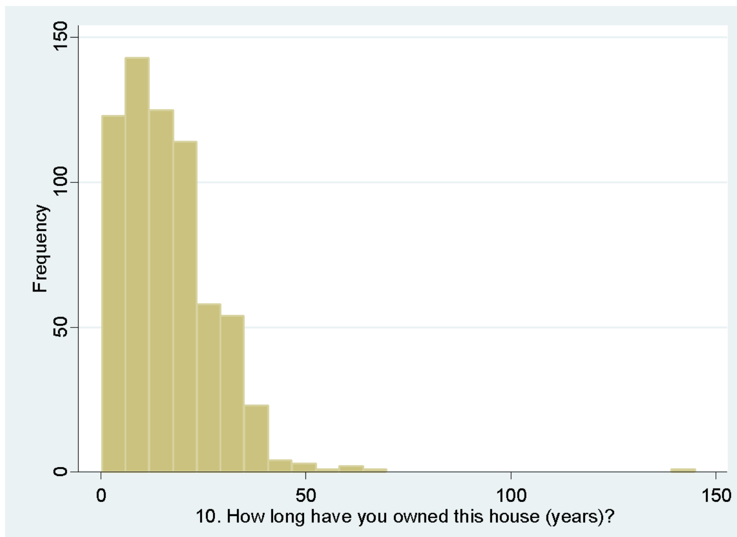
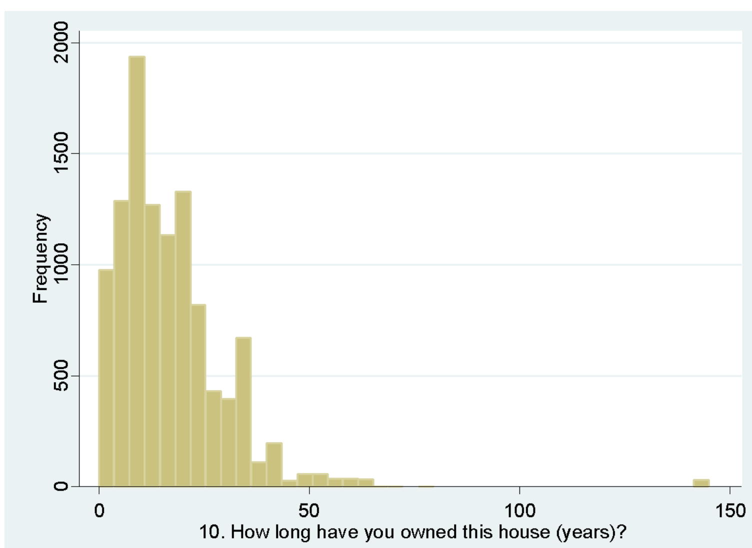


Figure 6.2: Density of *OWN_YRS* Post-Imputation



6.1.2. Income of Homeowner (*INCOME*)

Figure 6.3: Density of *INCOME* Pre-Imputation

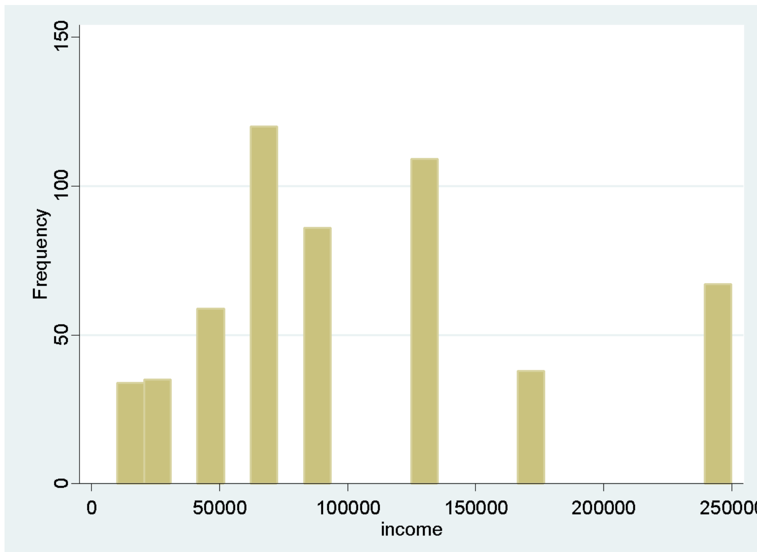
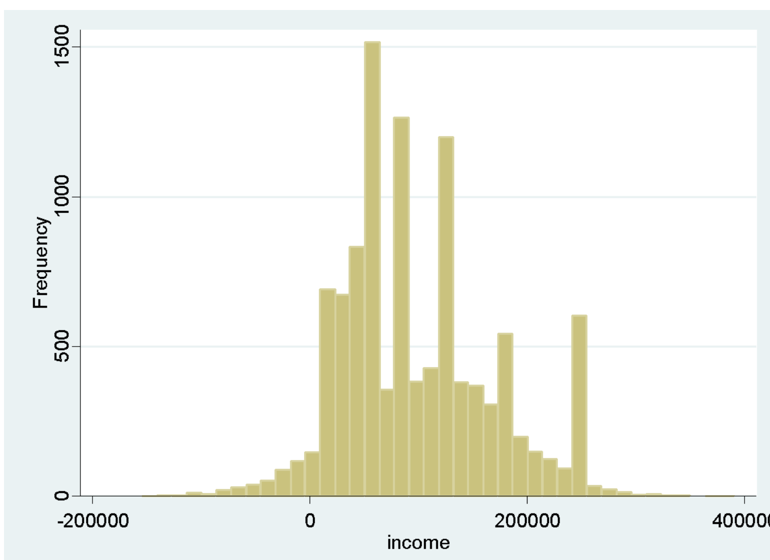


Figure 6.4: Density of *INCOME* Post-Imputation



6.1.3. Age of Homeowner (AGE)

Figure 6.5: Density of *AGE* Pre-Imputation

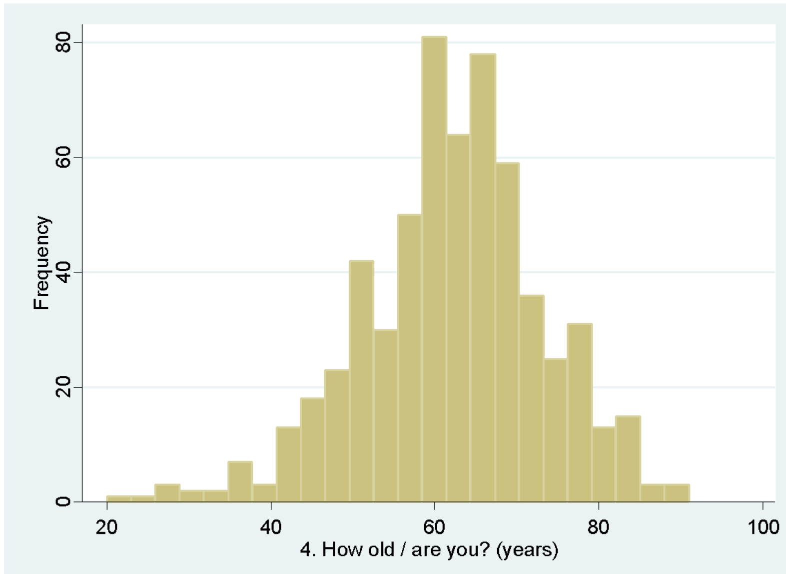
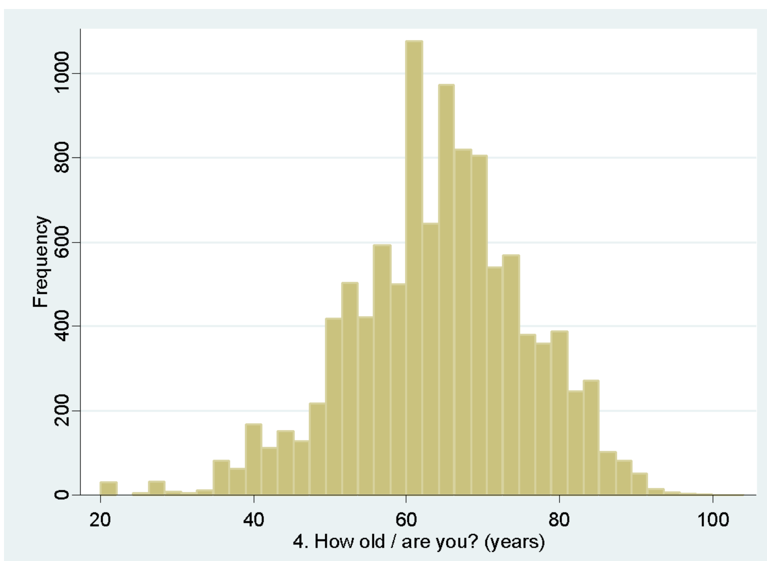


Figure 6.6: Density of *AGE* Post-Imputation



6.1.4. Ownership of another property (*OWN_MORE*)

Figure 6.7: Density of *OWN_MORE* Pre-Imputation

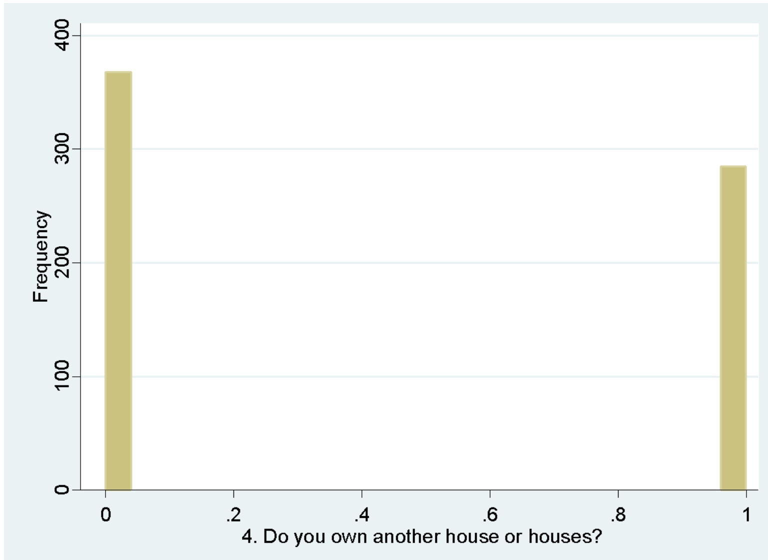
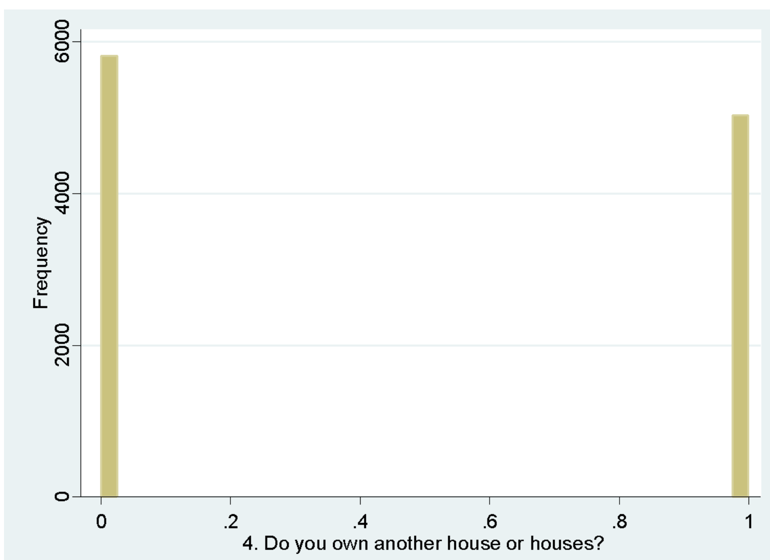


Figure 6.8: Density of *OWN_MORE* Post-Imputation



6.1.5. Insurance Status (*INSURANCE*)

Figure 6.9: Density of *INSURANCE* Pre-Imputation

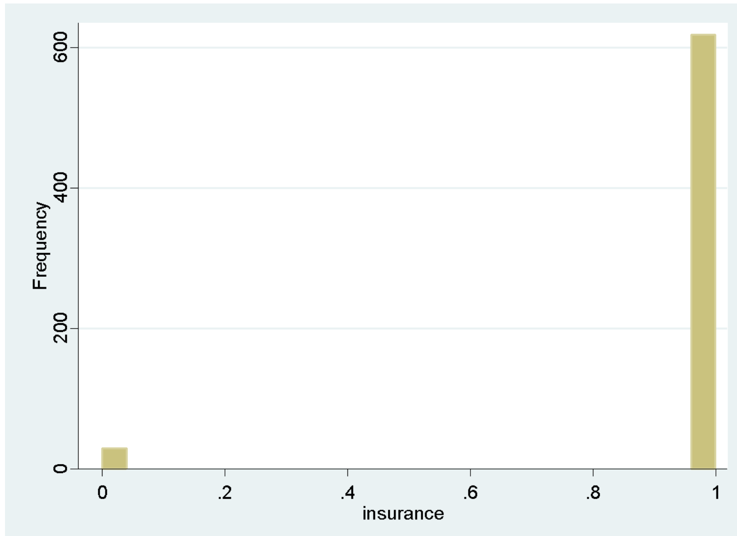
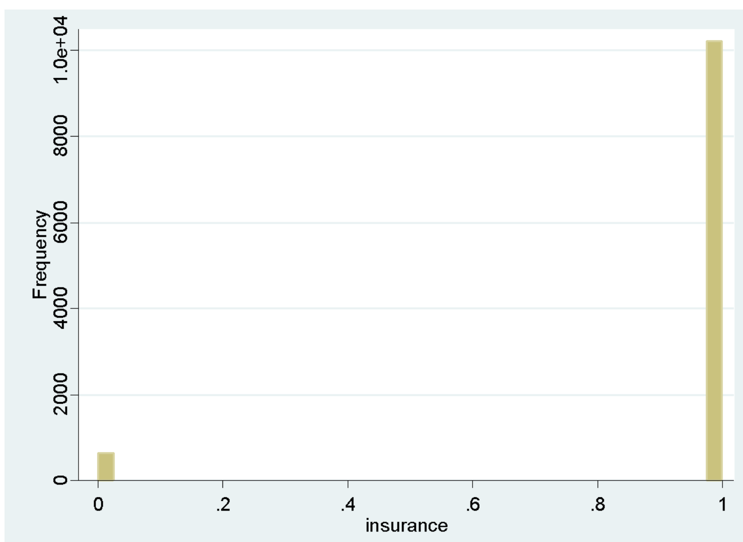


Figure 6.10: Density of *INSURANCE* Post-Imputation



6.1.6. Log of Risk Tolerance (*LRTOL*)

Figure 6.11: Density of *LRTOL* Pre-Imputation

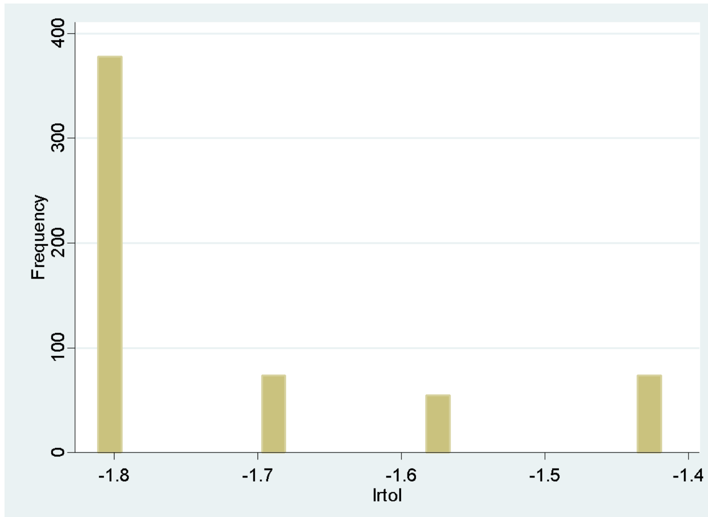
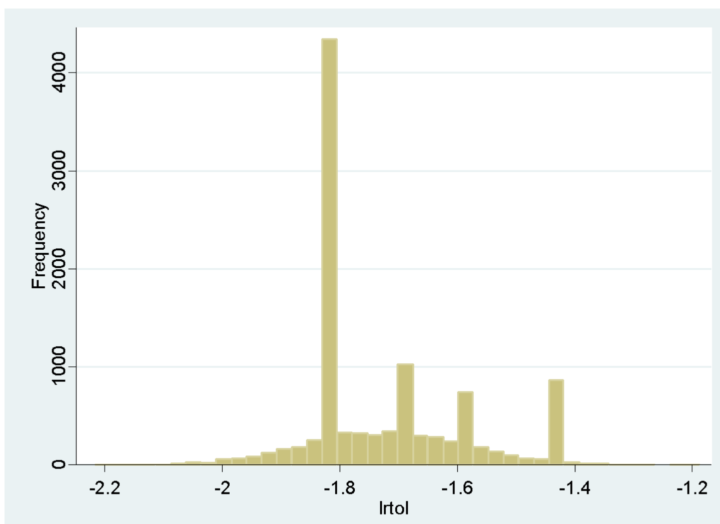


Figure 6.12: Density of *LRTOL* Post-Imputation



6.1.7. Aesthetics as a Barrier to Fire-Safe Investments (*AESTHETICS*)

Figure 6.13: Density of *AESTHETICS* Pre-Imputation

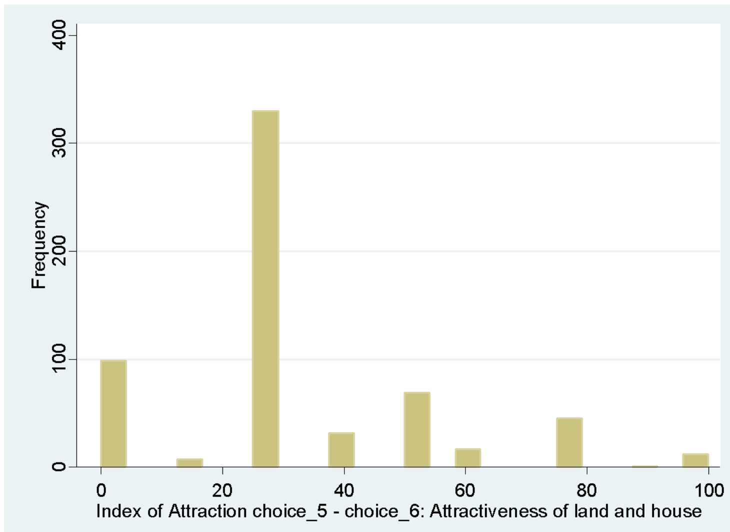
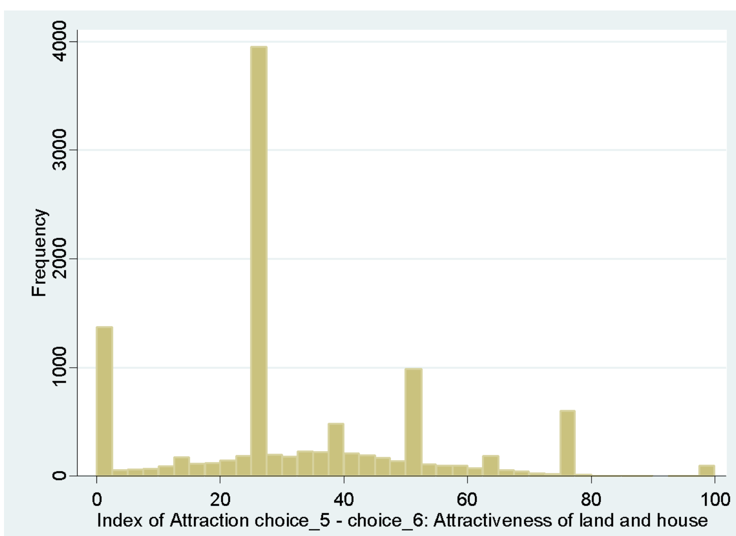


Figure 6.14: Density of *AESTHETICS* Post-Imputation



6.1.8. Privacy as a Barrier to Fire-Safe Investments (*PRIVACY*)

Figure 6.15: Density of *PRIVACY* Pre-Imputation

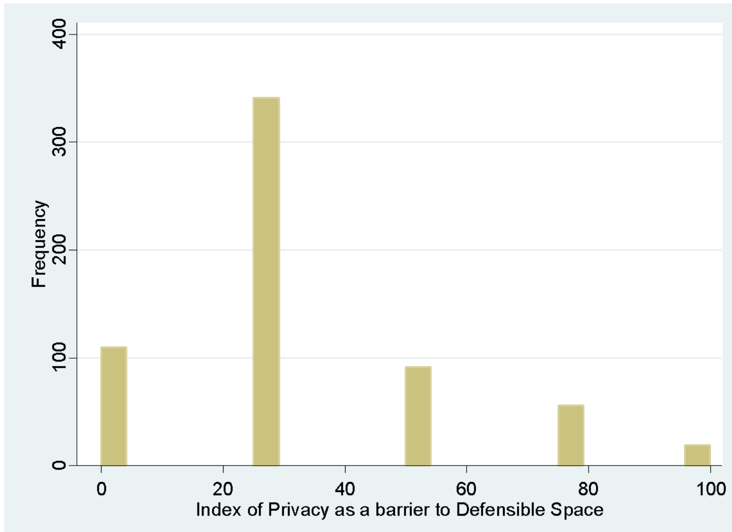
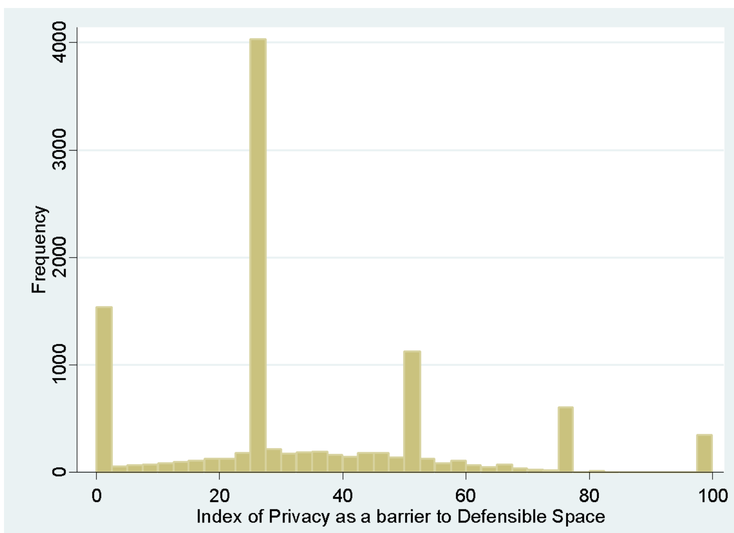


Figure 6.16: Density of *PRIVACY* Post-Imputation



6.1.9. Age of Home (*AGEHOME*)

Figure 6.17: Density of *AGEHOME* Pre-Imputation

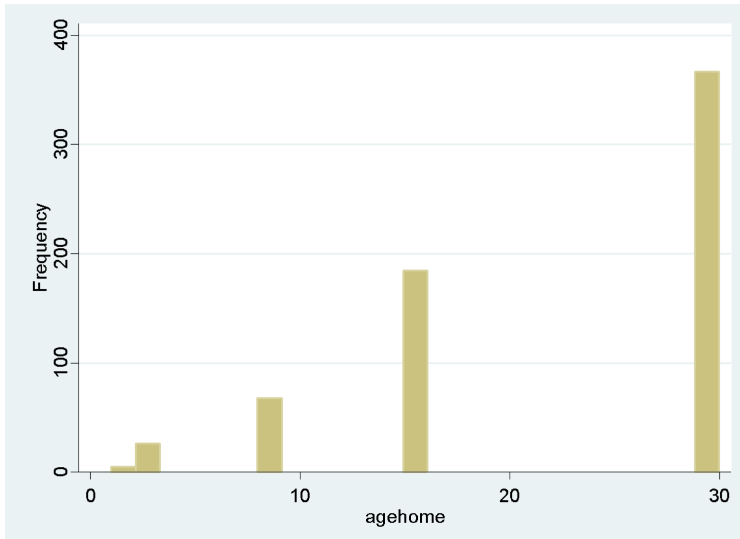
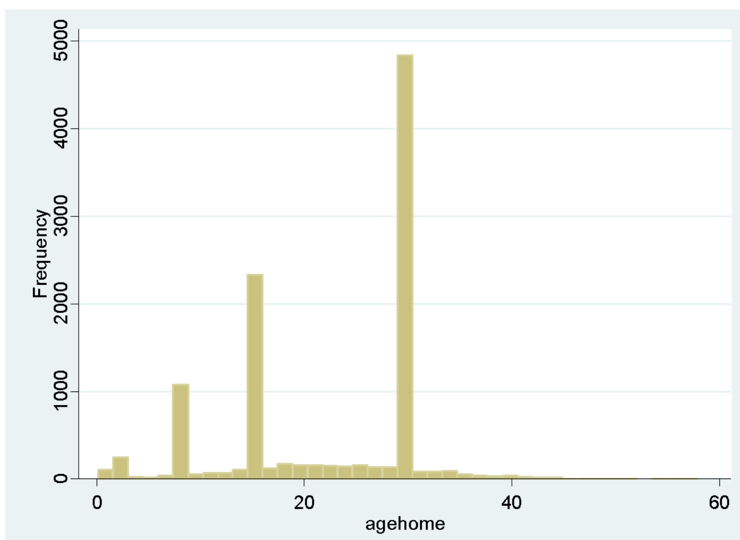


Figure 6.18: Density of *AGEHOME* Post-Imputation



6.1.10. Subjective Beliefs of Wildfire (*COM_CHANCE*)

Figure 6.19: Density of *COM_CHANCE* Pre-Imputation

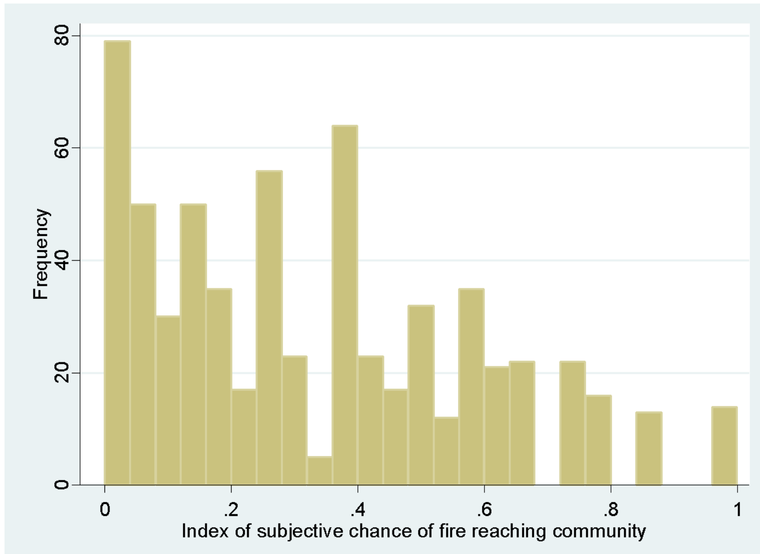
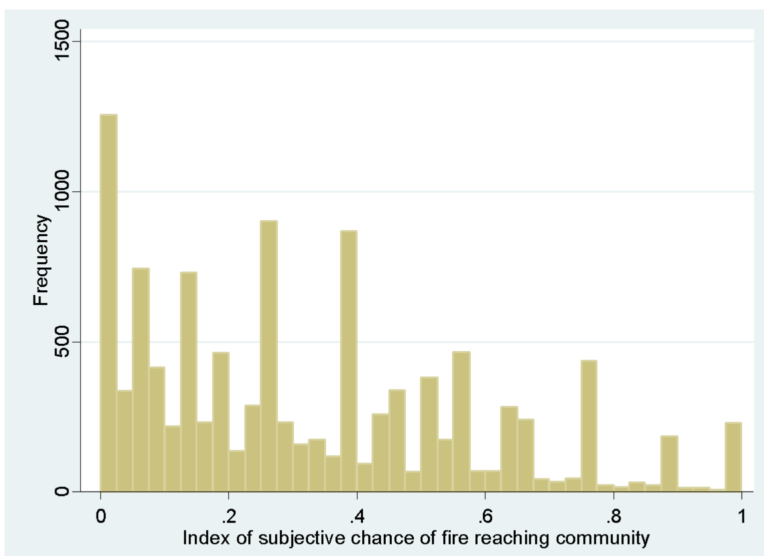


Figure 6.20: Density of *COM_CHANCE* Pre-Imputation



6.1.11. Proximity of Nearest Fire (*NEARFIRE*)

Figure 6.21: Density of *NEARFIRE* Pre-Imputation

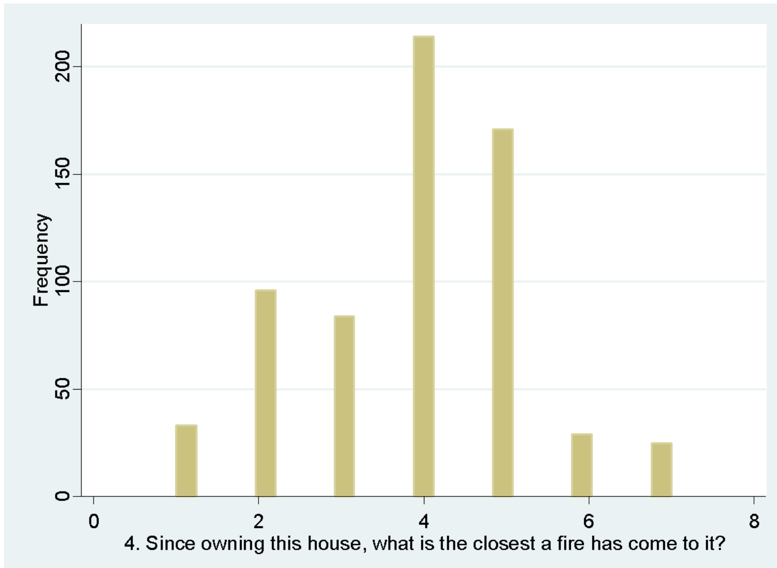
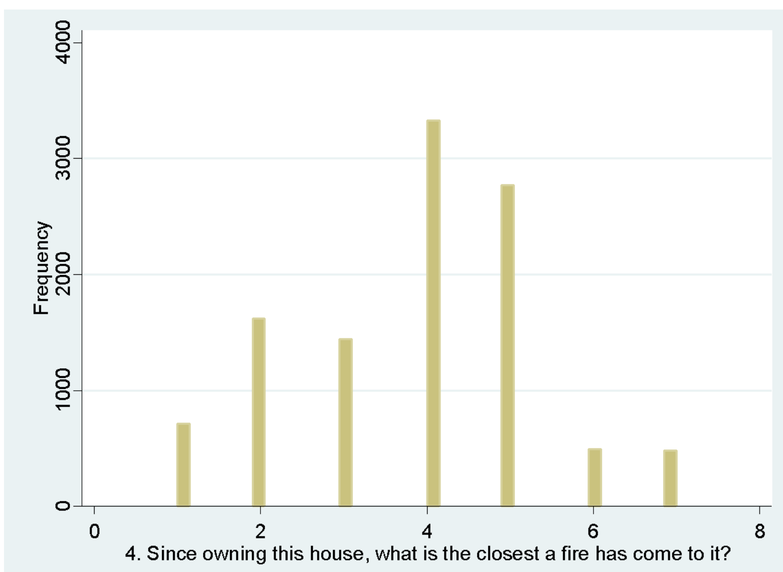


Figure 6.22: Density of *NEARFIRE* Post-Imputation



6.1.12. Trust in Defensible Space (*TRUST*)

Figure 6.23: Density of *TRUST* Pre-Imputation

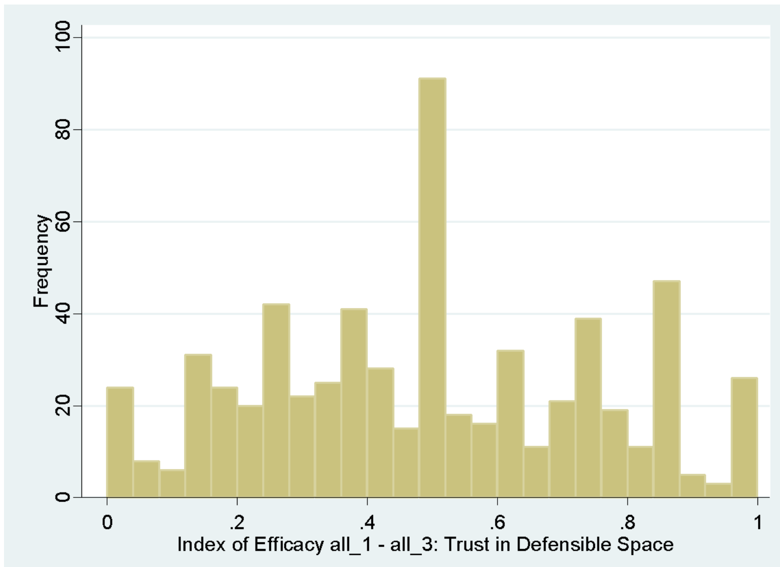
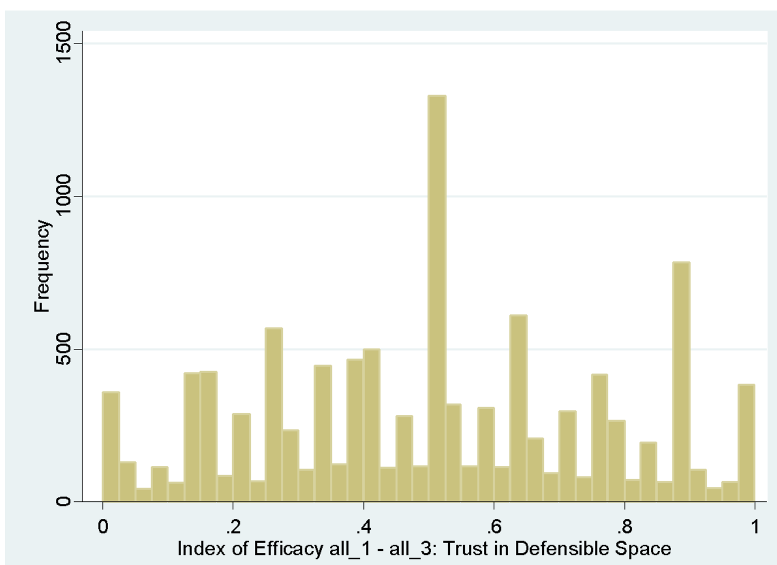


Figure 6.24: Density of *TRUST* Post-Imputation



6.1.13. Zoning Restrictions as a Barrier to Fire-Safe Investments (*ZONING*)

Figure 6.25: Density of *ZONING* Pre-Imputation

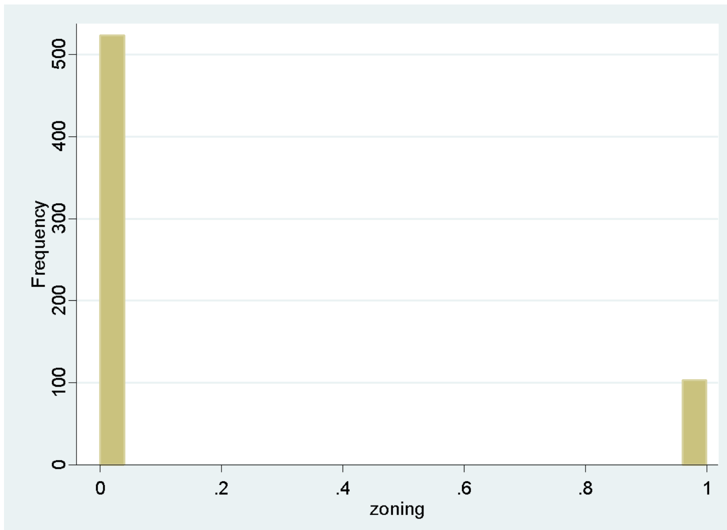
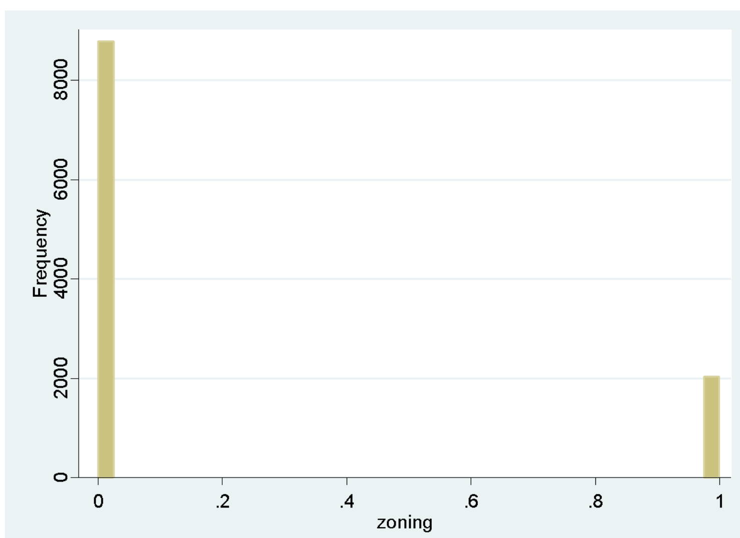


Figure 6.26: Density of *ZONING* Post-Imputation



6.1.14. Time as a Barrier to Fire-Safe Investments (*TIME*)

Figure 6.27: Density of *TIME* Pre-Imputation

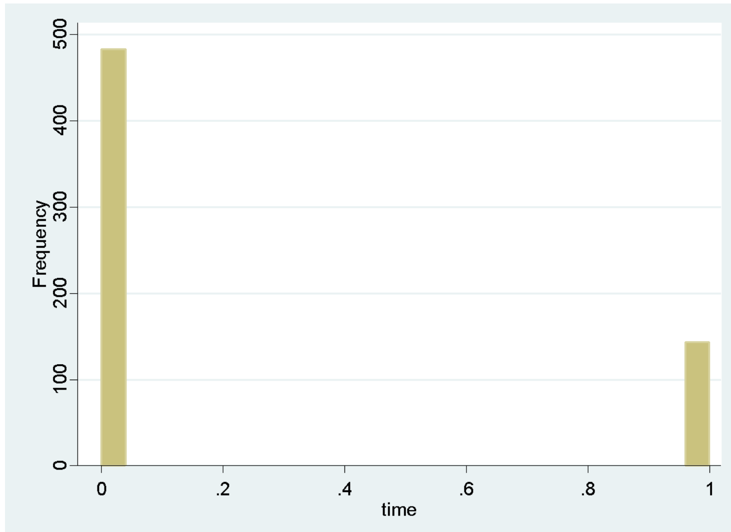
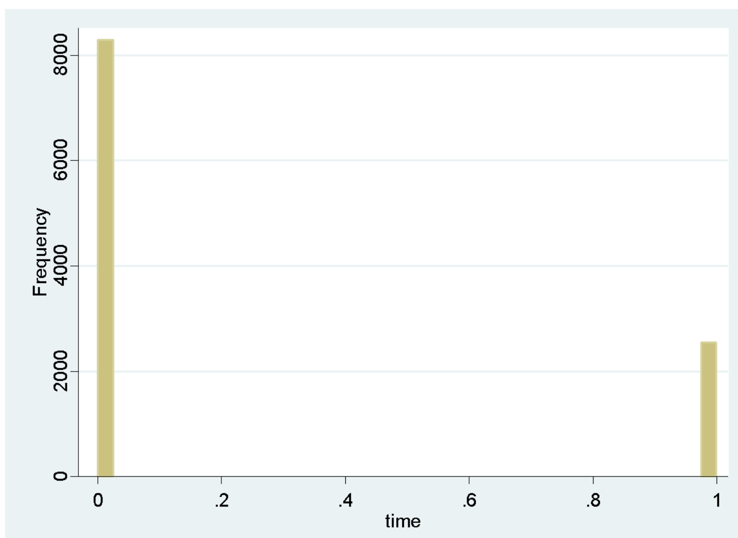


Figure 6.28: Density of *TIME* Post-Imputation



6.1.15. Health as a Barrier to Fire-Safe Investments (*UNHEALTHY*)

Figure 6.29: Density of *UNHEALTHY* Pre-Imputation

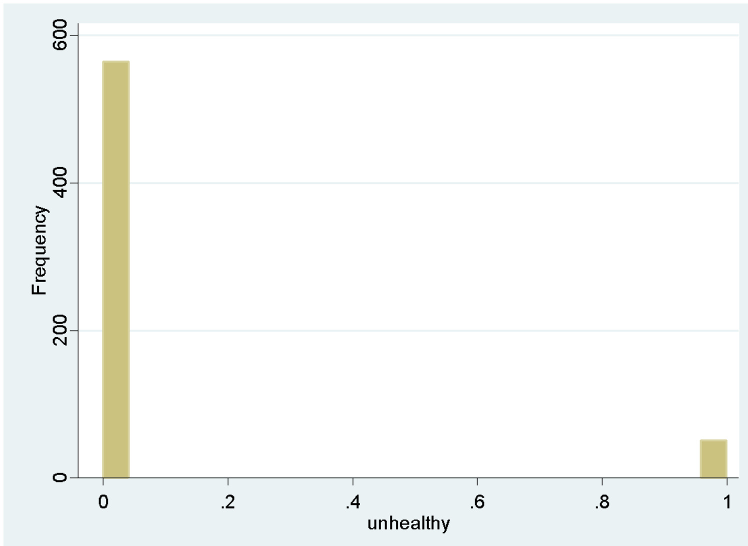
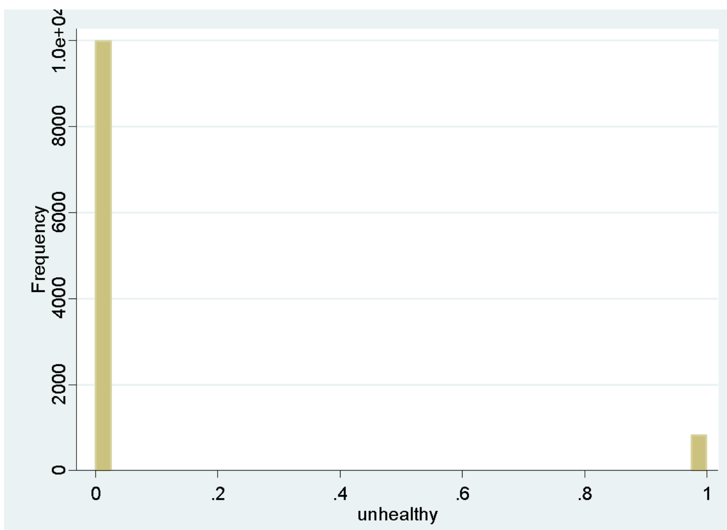


Figure 6.30: Density of *UNHEALTHY* Post-Imputation



6.2. Self-Sorting into High-Fire Risk Interaction Models

Table 6.1: Interaction Models of High-Risk and Low-Risk WUI Communities (*ASPECT, SLOPE, ELEV*

Variable	dy/dx	P>t	Variable	dy/dx	P>t	Variable	dy/
HHVL	0.021	0.315	*HHVL*	0.013	0.715	*HHVL*	0.0
OWN_YRS	0.000	0.960	*OWN_YRS*	0.000	0.923	*OWN_YRS*	0.0
INCOME	0.000	0.307	*INCOME*	0.000	0.325	*INCOME*	0.0
AGE	0.001	0.670	*AGE*	0.001	0.859	*AGE*	0.0
	-0.04			-0.06			-0
OWN_MORE	6	0.380	*OWN_MORE*	5	0.472	*OWN_MORE*	
	-0.11						-0
INSURANCE	6	0.307	*INSURANCE*	0.089	0.603	*INSURANCE*	
LRTOL	0.264	0.154	*LRTOL*	0.265	0.366	*LRTOL*	0.3
							-0
ASP_LRTOL	0.021	0.958	*SLOPE_LRTOL*	0.000		*ELEV_LRTOL*	
							-0
ASPECT	0.001	0.999	*SLOPE*	0.000		*ELEVDIFF*	
AESTHETICS	0.001	0.682	*AESTHETICS*	0.003	0.332	*AESTHETICS*	0.0
	-0.41			-0.76			-0
PRIVATE	9	0.001	*PRIVATE*	5	0.001	*PRIVATE*	
	-0.01			-0.00			-0
AGEHOME	2	0.000	*AGEHOME*	8	0.155	*AGEHOME*	
	-0.00			-0.00			-0
LOT	2	0.252	*LOT*	1	0.695	*LOT*	
PERCEIVED_RIS	-0.17		*PERCEIVED_RIS*	-0.06		*PERCEIVED_RIS*	-0
K	8	0.077	*K*	8	0.671	*K*	
TRUST	0.105	0.252	*TRUST*	0.356	0.024	*TRUST*	0.1

Table 6.2: Interaction Models of High-Risk and Low-Risk WUI Communities (*LGHTN, WIND*)

Variable	dy/dx	P>t	Variable	dy/dx
HHVL	0.022	0.303	*HHVL*	0.01
OWN_YRS	0.000	0.977	*OWN_YRS*	0.00
INCOME	0.000	0.308	*INCOME*	0.00
AGE	0.001	0.677	*AGE*	0.00
OWN_MORE	-0.046	0.374	*OWN_MORE*	-0.04
INSURANCE	-0.121	0.289	*INSURANCE*	-0.12
LRTOL	0.255	0.269	*LRTOL*	0.37
LGHTN_LRTOL	0.022	0.947	*WIND_LRTOL*	-0.20
LGHTN	0.100	0.861	*WIND*	-0.26
AESTHETICS	0.001	0.691	*AESTHETICS*	0.00
PRIVATE	-0.421	0.001	*PRIVATE*	-0.42
AGEHOME	-0.012	0.000	*AGEHOME*	-0.01
LOT	-0.002	0.219	*LOT*	-0.00
PERCEIVED_RISK	-0.173	0.085	*PERCEIVED_RISK*	-0.18
TRUST	0.113	0.219	*TRUST*	0.09

6.3. Multiple Imputation Indicator Test

As defined in Chapter 3, missing variables can be defined under three types: Missing at Random (MAR), Missing at Completely Random (MCAR), and Missing Not at Random (MNAR). We test for what type our variables with missing data fall under. We recreate each variable with missing data as a binary variable, where the binary variable equals 1 if it contained a missing observation in the original variable and equals 0 if it contained data. We regress the new binary variable on all observed variables. Variables with significant p-Values are identified as Missing at Random (MAR) and justified for Multiple Imputation by Chained Equations (MICE). Variables with insignificant p-Values are identified as Missing at Completely Random (MCAR), and if included in MICE, can result in biased estimates. Table A-3 reports the results of the indicator test.

Table 6.3: Multiple Imputation Indicator Test

Variables	**Prob > Chi2**
OWN_YRS	0.067
INCOME	0.541
AGE	0.226
OWN_MORE	0.063
INSURANCE	0.023
LRTOL	0.260
AESTHETICS	0.168
PRIVATE	0.116
AGEHOME	0.004
PERCEIVED_RISK	0.284
NEARFIRE	0.025
TRUST	0.036
ZONING	0.036
TIME	0.174
HEALTH	0.056

We find that *OWN_YRS, OWN_MORE, AGEHOME, ZONING,* and *HEALTH* are MAR and justified for MICE. We elect to impute *INCOME, AGE,* and *TIME* although they are MCAR because they do not directly influence the decision-problem and were included to control for financial characteristics and non-monetary barriers.