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# Wildfire Risk and the Residential Housing Market: A Spatial Hedonic Analysis

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**Abstract**

This paper analyzes the effect of wildfire risk on residential housing prices in Colorado Springs, Colorado. As a recent hotbed for large-scale wildfires, the state of Colorado has suffered significant damage from uncontrolled burns in high-risk "red zone" development areas. At the same time, the hedonic literature on natural disasters has focused primarily on flood and earthquake risk, with little written about wildfires. I expand the literature by including additional locational attributes in my regression analysis, utilizing GIS software that has only recently been used in conjunction with hedonic research. Contrary to my initial hypothesis, wildfire risk does not appear to negatively impact residential housing prices. I propose two potential explanations, including positive amenities in wildfire-prone areas and market participants underestimating the risk a property may face.

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## 4.1 Introduction

A hotbed for large-scale wildfires in recent years, the state of Colorado has suffered significant damage from uncontrolled burns in high-risk "red zone" development areas. Highlighted by the Waldo Canyon and Black Forest conflagrations, the 2012 through 2014 summers have marked the most destructive wildfire seasons in Colorado's history. As an increasing number of homes are developed in the wildland-urban interface, the potential for property damage has risen dramatically.

The goal of this paper is to analyze the effect of wildfire risk on residential housing prices in Colorado Springs, Colorado. How does the risk of wildfire impact transaction values, and do buyers and sellers in the residential housing market accurately capitalize their perception of low probability events such as wildfires into the price of a house? Working within the hedonic property model framework, I conducted a spatial analysis of the Colorado Springs housing market. This paper employs regression analysis to better understand how the spatial and structural characteristics of a house, along with an objective wildfire risk rating, jointly determine market value.

I narrowed my research to the wildland-urban interface of Colorado Springs in El Paso County, examining the geographical intersection between high-risk fire areas and significant residential development. According to a recent report by the U.S. Department of Agriculture and U.S. Forest Service, 32% of U.S. homes are currently in the wildland-urban interface, and a Colorado State University study projects that the state's growth of development in this area will increase from 715,500 acres in 2000 to 2,161,400 acres by 2030 (van Heuven et al., 2013). Unfortunately, ongoing drought conditions and past suppression efforts have created areas highly vulnerable to wildfire destruction in Colorado Springs. In fact, a 2013 wildfire report by data analytics firm, CoreLogic, ranked Colorado first as the state with the largest number of "very high" risk property parcels.

The issue of wildfire risk and its effect on the housing market has not been extensively researched. The hedonic literature on natural disasters focuses primarily on flood and earthquake risk, with little written about wildfires. I expand the literature by including additional locational attributes in my regression analysis, utilizing GIS software that has only recently been used in conjunction with hedonic research.

## 4.2 Literature Review

The modern hedonic literature begins with Frederick Waugh (1928) in the original application of a hedonic model to the study of vegetable prices. Waugh worked to understand how the physical characteristics of various vegetables such as asparagus, tomatoes, and cucumbers affect the price of those vegetables. By estimating a hedonic price function, Waugh unbundled the quality factors that comprise a differentiated product, placing a marginal value on each vegetable attribute.

Following Waugh, A.T. Court (1939) coined the term "hedonics" in his application of the model to automobiles. Court focused on qualities such as horsepower, breaking distance, window size, and seat width to define a price index for different automobiles. Ridker and Henning (1967) further expanded hedonic theory to the real estate market in order to value non-market environmental amenities. Backed by the Division of Air Pollution in the U.S. Public Health Service, Ridker analyzed the cost of air pollution to reveal the unobserved value that individuals place on clean air.

By 1974, labor economist Sherwin Rosen had formalized the theory of hedonic pricing, more fully developing the hedonic property model. Rosen empirically demonstrated that differentiated products could be valued based on their underlying characteristics; each good is a package of inherent attributes that provides utility for the consumer. The observed product prices and specific amounts of certain attributes define a set of implicit, marginal "hedonic" prices (Rosen, 1974). Rosen's model has since been adapted to studies of noise pollution, air quality, and most importantly, natural disaster risk. The following literature review details the evolution of hedonic theory as it has been used to value the impact of natural disaster risk on the residential housing market. The hedonic literature first focuses on hurricane flooding, earthquakes, and finally, wildfires.

In 1976, Damianos and Shabman sought to evaluate the impact of government flood policies by looking at housing prices. Location in a flood-prone area may result in future costs from flood damage, which negatively affects the eventual sale value of the property. Building off of Rosen's framework, the authors considered each property as a "bundle of rights," and worked to quantify the utility that a homeowner gains due to the environmental risks and amenities of the property, accessibility to economic activities, proximity to schools and places of worship, and the general neighborhood quality. They recognized that the price of a house is not determined solely by physical characteristics, but also by the unobservable benefits that the owner receives from the location. Because modern GIS software was not developed in 1976, the authors instead selectively sampled transactions to enhance homogeneity among the housing observations on all dimensions except flood risk. They then used regression analysis to compare the differences in transaction prices while only having to control for the flood hazard disamenity and differences in structural characteristics. Ultimately, Damianos and Shabman found it difficult to generate a strong explanatory regression for housing market sales in the flood plain areas of Alexandria, VA, indicating a significant amount of unexplained variation in sales prices which could result from home buyers' ignorance of flood risk.

Brookshire et al. (1985) expanded the hedonic literature on natural hazards to low-probability, high-loss earthquakes in California. The authors developed an expected utility model of self-insurance in which individuals can self-insure by buying homes in lower-risk areas. Incorporating a hedonic price function into their analysis, Brookshire et al. found that earthquake zones demarcated by the 1974 Alquist-Priolo Act lowered market values of properties in the Los Angeles and

San Francisco areas.[1] The 1974 California state act provided consumers with information to more accurately assess the hazard risk, effectively creating a market for house safety in earthquake prone locations. Beron (1997) also considered the effect of earthquake risk on the housing market. Beron estimated the hedonic price of earthquake risk before and after the destructive Loma Prieta earthquake of 1989. Interestingly, the author found that the implicit price of the risk actually fell after the earthquake; the differential in house prices due to location in an earthquake zone decreases from 4% before the Loma-Prieta earthquake to 3.4% after the disaster. Beron thus concluded that prior to the earthquake individuals overestimated the potential damage from such a natural disaster, as reflected in the small rise in average housing prices in the San Francisco Bay area 8 months after the earthquake.

More recently, the hedonic literature has returned to focus on the impact of floodplain risk on the housing market. For example, Shultz (2002) analyzes the housing market in North Dakota and Minnesota, empirically concluding that location in a 100-yr floodplain lowers home values by $8,990. As well, required flood insurance premiums accounted for 81% of the price depreciation. Similarly, Chivers and Flores (2002) use a HPM to find evidence of a decrease in sale prices only in the years directly after the flood event in question (i.e. a diminishing effect exists). Chivers and Flores also come to a similar conclusion as Damianos and Shabman (1976) in highlighting the fact that a lack of information about the natural hazard risk can cause a difference in the perceived versus objective risk assessment that results in a market failure.

Bin and Polasky (2004) attempt to overcome the problem of imperfect information in their hedonic flood analysis by observing a housing market that has experienced significant recent exposure to flood damage. The authors study the effect of flood destruction on 8,000 single-family residential homes between 1992 and 2002 in Pitt County, NC. The target market experienced recent flood damage from Hurricane Floyd in September of 1999, serving to increase the perceived risk of living within a floodplain. Hurricane Floyd resulted in the largest peacetime evacuation in U.S. history, according to Bin and Polasky, increasing awareness of the flood risk, decreasing home values, and overall improving information in the housing market. While a house located in a floodplain had a lower market value compared to a comparable house outside of the risk zone prior to Hurricane Floyd, the price discount was even larger after Floyd. Bin and Landry (2011) re-examine Bin and Polasky's (2004) findings using a difference-in-difference framework for two major flooding events (Hurricanes Fran and Floyd) to understand the variability in the flood risk premiums. Following hedonic theory, risk factors are capitalized in a house's transaction price, and lower risk properties sell at a premium. Consistent with the earlier 2002 study, Bin and Landry find that the price differential is greater after each storm; the risk premium increase to 5.7% after Hurricane Fran and

[1] The Alquist-Priolo Earthquake Fault Zoning Act provides a means of reducing damage from surface faults by prohibiting the construction of most structures across traces of active fault lines.

8.8% after Hurricane Floyd. While Chivers and Flores (2002) find that the hazard effect decreased quickly after only a few months, Bin and Landry (2011) conclude that the price differential effect diminishes more slowly over 5-6 years as the disaster fades from the public's recent memory.

In comparison to the previous research on hurricanes and flooding, the hedonic literature in the area of wildfire risk is relatively rare. Prior to Huggett (2003), discussed below, no study had directly estimated the impact of wildfire risk on housing prices using a hedonic property model. In 2001, following the Cerro Grande Fire of early June 2000 that burned 17,400 hectares and 230 structures near Los Alamos, New Mexico, the Office of Cerro Grande Fire Claims commissioned a report by Price Waterhouse Coopers to determine if the fire had caused a decline in property values not physically damaged by the fire. The authors use separate regressions to compare the Los Alamos pre-fire price trend to its post-fire price trend and to compare Los Alamos's post-fire sales price trend to a community similar to Los Alamos. The report estimates that the countywide average transaction price for single-family homes declined 3-11% after the fire. Although the study relies on regression analysis without a foundation in hedonic theory, the Price Waterhouse Coopers report lays the groundwork for more current hedonic studies and embodies some of the early literature on understanding the impact of wildfire risk on real estate.

In his dissertation at North Carolina State, Huggett (2003) first applies the hedonic property model to the study of wildfires and the housing market. Using residential housing sales data from 1992 to 1996 in Chelan County, Washington, Huggett seeks to observe how the market responds to fires in the Wenatchee National Forest that burned over 180,000 acres. The author finds a decrease in willingness to pay to live near a burned area for 6 months after the fires. As well, the hedonic price for fire resistant roofs increases slowly for 18 months before dropping to pre-fire levels in the second half of 1996. This drop reflects either a general lack of awareness of the fire risk, or an increased risk threshold over time. In 2008, Huggett, Murphy, and Holmes further examine the 1994 Chelan County wildfires and find that the price reduction due to the wildfires amounts to a 13-14% drop in the mean price. They cite the fact that this result is between the upper bound of 11% in the Price Waterhouse Coopers (2001) report and the 15% decrease found in Loomis (2004).

Loomis (2004) similarly applies a HPM to the residential housing market. Loomis focuses on how forest fires effect the demand for houses in high amenity, high hazard natural areas, and whether people update their perception of risk after low probability events such as wildfires or floods actually occur. Loomis follows the previous natural disaster literature (including Damianos et al. 1976; Brookshire et al., 1985; Shultz, 2002; Bin and Polasky, 2004; Huggett, et al., 2008) in comparing property values before and after a disaster event. Loomis studies the town of Pine, Colorado, which is located 2 miles from Buffalo Creek and was a "near miss." The town of Pine also has similar vegetation and topography (and thus potential wildfire exposure) to Buffalo Creek. What happens when the wildfire does not directly damage structures or property yet is close enough that it poses a serious threat? Loomis' approach helps control for value loss due to direct damage to the property. Employing log and semi-log hedonic specifications, the author accounts for differences in house characteristics and other exogenous trends during the period under review. As in Murdoch's earthquake study and Shultz's flood analysis, Loomis uses a pre-post fire dummy variable, yet he does not follow Huggett (2008) in including environmental amenities in his model. Theoretically consistent with Bin and Polasky's (2002) finding on hurricane flooding, Loomis reports that house prices in the unburned town of Pine decreased 15% due to the increased perception of risk and the lower net benefit to living in the forested area. Although the town of Pine was not directly damaged by the wildfire, amenity levels may have been reduced by burning in areas that Pine residents commute through or recreate in. Thus, both the increased risk perception and the reduced amenities may have influenced the housing market. Overall, Loomis' (2004) conclusion has government policy implications; if housing prices decrease in unburned areas after a recent fire, then the market may be efficient at signaling the presence of wildfire risk, making new government zoning or building policy in the wildland-urban interface unnecessary.

An accurate perception of wildfire risk is necessary for the market to efficiently capitalize the environmental disamenity in the value of a house. In past hedonic literature, authors have studied the impact of the actual occurrence of wildfires, observing prices before and after the event. Donovan, Champ, and Butry (2007) take a different approach in validating the assumption of near perfect market information. In their case study of Colorado Springs, Donovan et al. study the effect of a wildfire education campaign on home prices. The authors seek to understand whether the public release of risk assessment ratings for individual parcels improves the subjective perception of risk and thus affect housing values. As Donovan et al. explain, it is unclear whether homeowners in the wildland-urban interface understand the true risk that they face. Wildfire risk ratings are often aggregated on a large geographic scale, making it difficult for homeowners to understand the specific risk posed to their home. In response, the Colorado Springs Fire Department rated the wildfire risk of 35,000 housing parcels in the wildland-urban interface, and made the information public online in 2000. Twenty-five variables were used to evaluate the wildfire risk as low, medium, high, very high, or extreme. The authors then conducted a spatially corrected hedonic analysis (four different specifications) to compare the relationship between home prices and wildfire risk before and after the risk assessment information was published online. The study finds that before the release, the risk ratings were positively related to housing price, indicating that the positive amenity value from living in high risk areas (more secluded wooded areas, ridge views, etc.) outweigh the increased risk. Post-fire, however, risk ratings and home prices were not positively correlated, although the effects of the online information release appear to diminish over time.

Champ, Donovan, and Barth (2010) attempt to validate the results of Donovan et al. (2007) by comparing the results of a market level analysis and a household survey. As Donovan et al.

(2007) argue, homebuyers prefer to live near dangerous topography yet also in houses constructed with less flammable materials (although most individuals are unaware of the wildfire risk when they decided to purchase the house). Champ et al. find that only 27% of homebuyers in the study realized the house was in an at-risk area before submitting their purchase offer. The authors note that this percentage is significantly more than the 8% of homeowners in the Chivers and Flores (2002) study, yet hardly indicates perfect information in the housing market. Individuals have a poor understanding of the true objective risk of wildfires, and only 14% of respondents to the Champ et al. survey had accessed the Colorado Springs Fire Department FireWise program website to view the parcel risk ratings, the fundamental assumption for the Donovan et al. analysis.

Mueller, Loomis, and Gonzalez-Caban (2007) contribute to the hedonic literature by seeking to answer whether first wildfires have a different effect than subsequent wildfires on the demand for housing in a high-risk area. Rather than analyzing the effect of a one-time disaster event, Mueller et al. (2007) consider repeat forest fires several years apart in a small geographic area. The authors test and reject the hypothesis that the price reduction from the first fire is equal to the reduction from the second fire; the first fire results in a 10% decrease while the second fire causes a 23% decrease. Theoretically, a second fire pushes individuals to reevaluate their perceived risk if the first fire is not enough. After the first wildfire, house prices continue to decrease due to landscape damage, while the second fire results in an initial decrease followed by an eventual increase. Mueller et al. (2007) concludes that it could take between 5 and 7 years for prices to fully recover after the second fire as vegetation regenerates and people forget about the immediate risk.

Mueller and Loomis (2008) further develop the hedonic property model by investigating the impact of spatial dependence. British real estate tycoon Harold Samuel is credited with popularizing the common mantra "location, location, location," highlighting the reality that the market value of a house is significantly impacted by the price and quality of the houses surrounding it. Unfortunately, most of the previous hedonic literature utilizes OLS specifications that overlook spatial dependence that may result in biased coefficient estimates. Thus, Muller and Loomis (2008) consider spatial error and spatial lag effects by using weighting matrices. The authors find, however, that the spatially corrected estimates of the implicit hedonic prices are nearly the same as the OLS estimates, indicating that the biased nature of the OLS estimates may not actually be economically significant. Mueller and Loomis thus confirm the utility of non-spatial models. In a subsequent study, Mueller and Loomis (2013) take a quantile regression approach to the effect of wildfire risk on housing prices. The impact of wildfire risk has significant variation over the distribution of housing prices (i.e. there is not a constant marginal price found with an OLS regression).

The majority of the hedonic literature has emerged from researchers located in and focused on the state of Colorado. Stetler, Venn, and Calkin (2010), however, widen the geographical scope of wildfire risk research to Montana. Stetler et al. examine 256 wildfires in 4 million hectare of the northern Rockies in Montana between 1996 and 2007. Unsurprisingly, while proximity to lakes, national forests, Glacier National Park, and golf courses has a positive effect on property values, proximity to and view of burned areas depress values. However, if the burned area is not visible to the homeowner, then there is no significant impact on prices as the risk is “out of sight, out of mind.” Furthermore, the distance from a wildfire significantly affects the homebuyer’s willingness to pay, as does the size of the fire. Specifically, houses five kilometers from a burned area sold for 13.7% lower than equivalent homes at least twenty kilometers from the fire. The large, persistent, and negative effect on property values in the study area is consistent with Loomis’ (2004) findings in Colorado. Stetler et al. also echo Loomis (2004) in noting that it is difficult to determine the relative magnitude of the price loss attributed to degradation in environmental amenities versus an increase in perceived risk. Like Bin and Polasky (2004) found regarding floodplains, homebuyers correlated a view of and closer proximity to a burned area with increased risk.

## 4.3 Economic Theory

Originally proposed by Rosen (1974), the hedonic framework is based on a theory of consumer behavior in markets for differentiated products. The hedonic property model has been used to estimate the effect of environmental amenities on property prices, allowing econometricians to estimate the marginal, implicit “prices” of the underlying attributes of a residential property. Consumers gain utility from housing and all other goods, and each house is considered as a bundle of structural and spatial characteristics. Homeowner utility is a function of the structural characteristics of the house, the non-environmental characteristics of the neighborhood, and location specific amenities and risks. The homeowner then maximizes his or her utility subject to a budget constraint, which is defined over income and housing prices. Using a hedonic regression a price can be estimated for each attribute, with the sum representing the total property value. After estimating the hedonic price function, a prospective homebuyer’s willingness to pay is then found by taking first order conditions for utility maximization subject to the budget constraint.

Following Donovan et al. (2007), household utility is thus expressed as

$$U = U(X, Y, \alpha)$$

where utility is a function of $X$ (a vector of property characteristics), $Y$ (a vector of neighborhood characteristics), and $\alpha$ (the wildfire risk). Utility is increasing in desirable characteristics and decreasing in wildfire risk.

Housing attributes are classified into two main groups: structural characteristics and spatial attributes. Structural characteristics include physical features such as floor square footage, age, number of bedrooms, bathrooms, lot size, existence of basement, garage, patio, water heating system, and fireplaces. Not all of these items are significant drivers of value; however, and they are often not recorded in public assessment records.[2] Spatial attributes, meanwhile, consist of both the quality of the surrounding neighborhood (e.g. median income, crime rate, traffic noise, quality of schools) and location (e.g. distance to hospitals, airports, central business districts, golf courses, etc.).

Additionally, the hedonic model requires a series of assumptions. For example, the sampled houses are assumed to be drawn from a single market. The geographic sample space of the Colorado Springs wildland-urban interface has a sufficiently homogenous housing market that this premise reasonably holds. Additional assumptions in applying the hedonic framework include perfect competition with lots of buyers and sellers, freedom to enter and exit the market, and perfect information concerning the housing product and price. If individuals do not understand the danger of wildfires and the potential for property loss, then the risk will not be reflected in the house price. Further complicating the issue is the fact that proximity to dangerous topography can have both negative and positive value. For example, homes that are located on ridges or surrounded by dense vegetation face greater risk from fire. At the same time, however, living on a ridge provides better views and people enjoy having trees and other vegetation around their houses. Thus, the problem of perception bias - the divergence between the objective risk probability and an individual's perception of the risk -may be exacerbated by the correlation between disaster risk and positive natural amenities (Daniel, 2009).

## 4.4 Data

The hedonic regression analysis in this paper requires three distinct data sets: (1) housing price data, (2) a wildfire risk metric, and (3) the structural characteristics and spatial attribute data for each land parcel.

### 4.4.1 Geographic Sample and Transaction Prices

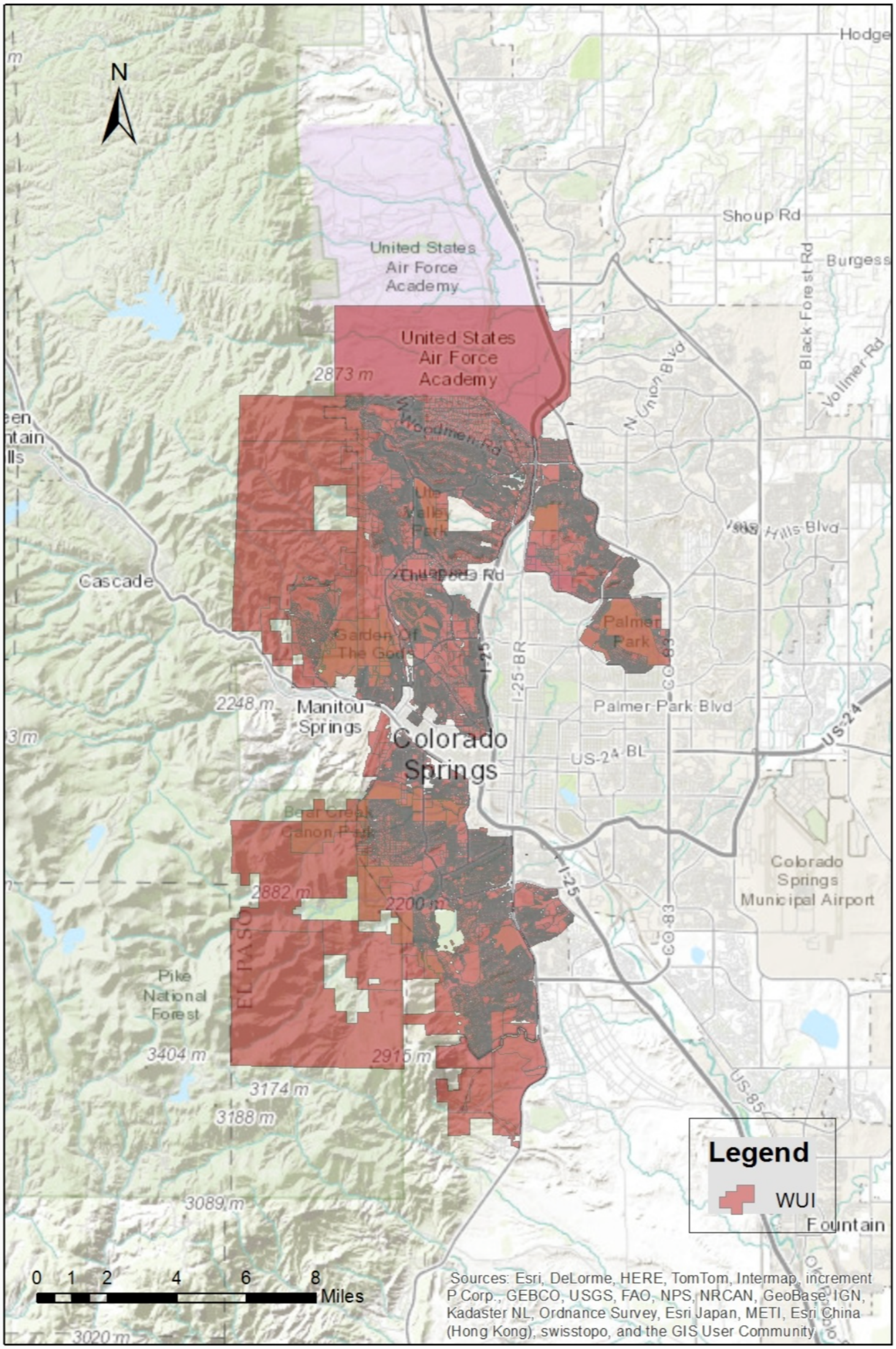
The dependant variable of interest is transaction price data for residential properties in Colorado Springs, CO. Located 60 miles south of Denver in El Paso County, Colorado Springs has a residential population of 414,358 (Lacey, 2011). I sampled housing parcels from the wildland-urban interface area in the western part of the city bordering the Pike National Forest and the United States Air Force Academy to the north. Figure 1 below provides a visual representation of the sample area.

[2] In this paper, structural characteristics are chosen based on availability of data, guidance from past hedonic literature, and a general understanding of the value drivers for real estate.

The wildland-urban interface (WUI) constitutes the geographical area where man-made developments intersect with wildland fuel and topography. The Colorado Springs wildland-urban interface covers approximately 28,800 acres and nearly a quarter of the city's population lives within this area (Lacey, 2011). Due to factors such as dense vegetation and fuel, topographical slope and elevation, as well as local weather and climate conditions, the wildland-urban interface area is a "red zone" that is highly susceptible to large-scale wildfires.

As noted previously, the hedonic property model assumes that there is near perfect information in the housing market. Homebuyers understand the objective risk of wildfires. Without near perfect information, wildfire hazard is not capitalized in a property's value. Thus, I selected the wildland-urban interface as the sample space where wildfires are most prevalent and homeowners are more likely to be aware of the risk. It is important to note, however, that despite the historical geographic clustering of wildfires in Colorado Springs, houses in the sample still exhibit sufficient variation in risk ratings. Specifically, a property may be rated "low" risk, while an adjacent property may have a "very high" rating.

**Figure 1** Colorado Springs wildland-urban interface map



The housing price data set is cross sectional data from 2013 and includes all houses sold in the Colorado Springs wildland-urban interface.[3] I obtained the data from the El Paso County Assessor's Office.[4] As Table 1 reports below, 1,205 houses were sold with transaction values ranging from \$25,000 to \$1.8 million. The average transaction value for the sample is \$308,481. As well, the median sample sale price of \$265,000 is very close to what is expected based on a 2011 median property price for Colorado Springs of \$275,000.[5] The distribution of housing prices is positively skewed, with few properties in the right tail greater than \$750,000. Figure 2 presents the full distribution of transaction values.

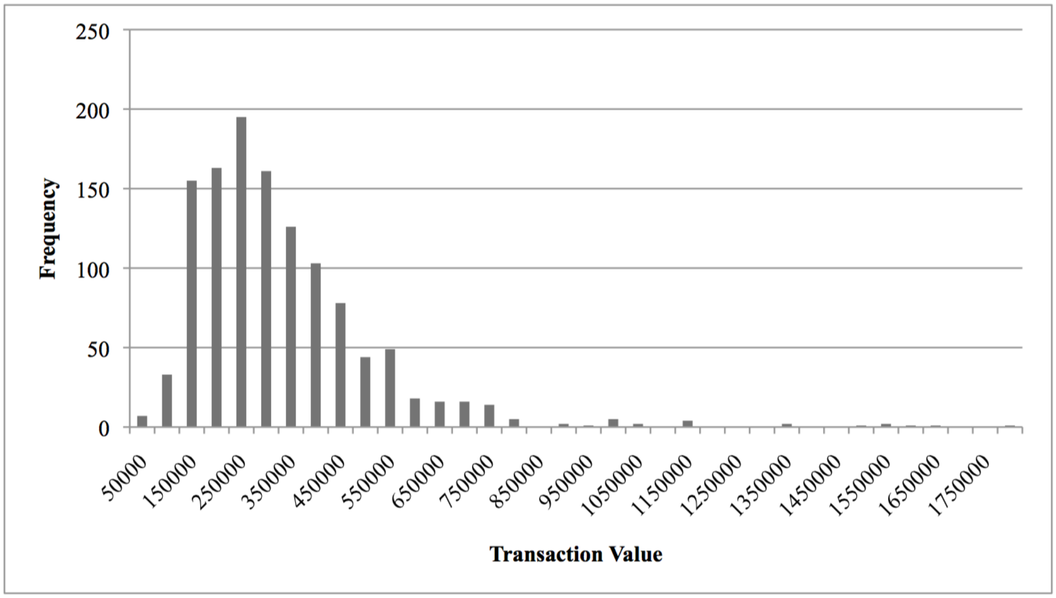
**Table 1** Summary statistics of 2013 housing transactions in the Colorado Springs wildland-urban interface

| | Mean | Median | Standard Dev. | Maximum | Minimum |
|---|---|---|---|---|---|
| Sale Price | \$308,481 | \$265,000 | \$193,157 | \$1,800,000 | \$25,000 |
| Age | 31 | 29 | 21 | 125 | 0 |
| Number of Bedrooms | 3.40 | 3.00 | 1.06 | 7.00 | 1.00 |
| Number of Bathrooms | 2.41 | 2.50 | 0.84 | 7.00 | 1.00 |
| Total Square Footage | 1907 | 1710 | 841 | 9236 | 367 |
| Lot Size (thousands of square feet) | 71.70 | 11.45 | 329.93 | 3682.47 | 0.25 |
| Finished Basement | 60% yes, 40% no | n/a | n/a | n/a | n/a |
| Median household income | \$79,329 | \$73,545 | \$29,319 | \$141,912 | \$24,065 |
| Distance to nearest public airport | 5.85 | 6.05 | 1.88 | 9.82 | 2.08 |
| Distance to nearest hospital | 2.22 | 2.06 | 1.32 | 6.17 | 0.09 |
| Distance to nearest public library | 1.53 | 1.42 | 0.84 | 4.33 | 0.01 |
| Distance to nearest school | 0.56 | 0.53 | 0.30 | 2.02 | 0.05 |
| Distance to centroid of city or town | 1.93 | 1.98 | 0.74 | 4.42 | 0.13 |
| Distance to nearest major highway | 1.10 | 0.92 | 0.86 | 4.15 | 0.00 |
| Distance to nearest church | 6.11 | 5.94 | 3.63 | 13.17 | 0.32 |
| Distance to nearest golf course | 3.42 | 3.18 | 1.65 | 7.00 | 0.24 |

Notes: There are 1,205 observations in the Colorado Springs WUI sample.

[3] The WUI is defined by the Colorado Springs Fire Department.
[4] Thanks to El Paso County GIS analyst Steve Fischer for his help in compiling the data set.
[5] Source: Realator.com

**Figure 2** Histogram of 2013 transaction prices in Colorado Springs WUI




Broken down by risk rating category, the properties sold in 2013 demonstrate a consistent increase in average value from the "low" risk rating ($179,256) to "extreme" risk ($449,150). As Table 2 below demonstrates, value increases with risk. The median price exhibits a similar trend. While I hypothesize that higher risk has a negative impact on property value, those houses that have highest risk from dangerous topography (e.g. location on an exposed ridge or surrounded by dense vegetation) also benefit from the positive amenity values.

**Table 2** Summary statistics of 2013 transaction values by wildfire risk category

| | Mean | Median | Standard Dev. | Maximum | Minimum |
|---|---|---|---|---|---|
| Extreme | $449,150 | $415,950 | $242,060 | $1,325,000 | $137,000 |
| Very High | $381,002 | $352,500 | $198,994 | $1,350,000 | $87,500 |
| High | $331,163 | $307,500 | $180,550 | $1,150,000 | $25,000 |
| Moderate | $283,191 | $243,000 | $194,483 | $1,800,000 | $33,000 |
| Low | $179,256 | $145,000 | $95,025 | $535,000 | $85,000 |

### 4.4.2 Wildfire Risk Rating

I next adjoined a wildfire risk rating to each housing parcel in the sample space. A wildfire risk map with the geocoded houses is presented in Figure 4. The risk ratings are from the Colorado Springs Fire Department Wildfire Mitigation program.[6] In 2001, the Colorado Springs Fire Department

[6] Thanks to the Colorado Springs GIS Division and Senior Analyst Steve Vigil for providing me the wildfire hazard rating data set.

undertook a risk assessment project, rating the wildfire susceptibility of 35,000 property parcels in the wildland-urban interface. Prior to the initiative, little public information existed on the parcel-level risk that each individual homeowner faced. Using 25 different variables to calculate the risk rating, the Wildfire Hazard Information Extraction model categorizes parcel-level risk on a 5-tier scale from "low" to "moderate," "high," "very high," and "extreme." The most significant factors are the roof and siding construction material, the parcel's proximity to dangerous topography, the vegetation density surrounding the house, and the average land slope. Since the 2001 study, the Colorado Springs Fire Department has worked to continually reassess the risk of all houses in the WUI. Currently, 30,131 individual parcels are identified as at-risk. In the present sample, 3% houses are rated as low risk, 52% moderate risk, 35% high risk, 9% very high risk, and 1% extreme risk.[7] This distribution of risk across the 2013 housing sample very closely matches the risk distribution for all rated properties. Table 3 compares the sample risk distribution with the population risk distribution, revealing a maximum variation of 2%. The histogram in Figure 3 then presents a more visual representation of the risk distribution.

**Table 3** Summary statistics of wildfire risk ratings

| Risk Rating | Properties Sold[1] | % Properties Sold | Total Properties[2] | % Total Properties |
|---|---|---|---|---|
| Extreme | 18 | 1% | 611 | 2% |
| Very High | 107 | 9% | 2867 | 10% |
| High | 422 | 35% | 9811 | 33% |
| Moderate | 627 | 52% | 16038 | 53% |
| Low | 31 | 3% | 804 | 3% |

Notes: [1]Observations include all houses in the Colorado Springs WUI sold in 2013. [2]All rated properties in the WUI (30,131 houses).

[7]The wildfire risk ratings used in this paper represent the most current assessments available from the Colorado Springs Fire Department.

**Figure 3** Distribution of 2103 wildfire risk ratings in the Colorado Springs WUI

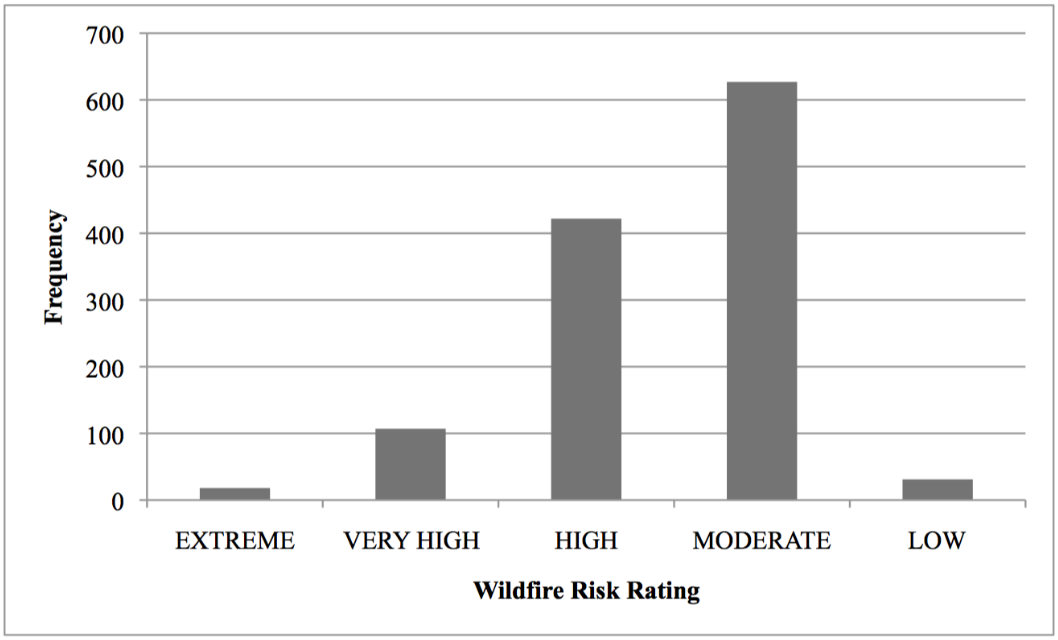
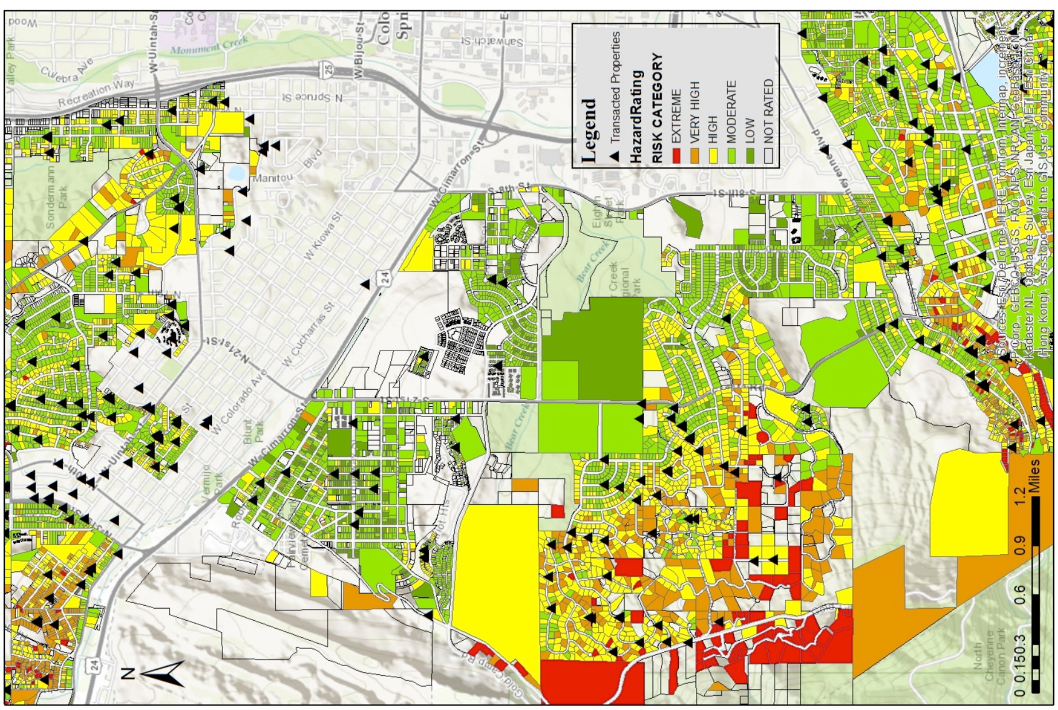



**Figure 4** Geocoded houses overlaid on wildfire risk map



### 4.4.3 Structural Attributes

Appended to the housing price data set are the structural characteristics for each house. These are features that significantly drive a property's value; for example, the number of bedrooms and bathrooms, floor area square footage, age of the building, and whether or not it has a finished basement.[8] Table 1 details the complete set of summary statistics. The average residential house in 2013 is 31 years old, has 2,907 square feet of living space, 3.4 bedrooms, and 2.4 bathrooms. Sixty percent of the transacted houses have a finished basement, while 40% do not.[9] Based on estimates from Realtor.com, the median number of bedrooms in the Colorado Springs housing market is 3, and the median number of bathrooms is 2.5, nearly exactly matching our sample of 2013 housing transactions. Spatial Attributes

### 4.4.4 Special Attributes

The value of a house is implicitly a function of its location. Consequently, locational and neighborhood attributes are commonly used in hedonic models. The spatial hedonic analysis in this paper requires independent variables that help quantify the value stemming from proximity to entities such as airports, schools, and hospitals. Additionally, a house's value is related to such neighborhood characteristics as the median income of the residents in the immediate area. Thus, I used the geographical information system vector data to create spatial attribute variables. The GIS data are drawn from a variety of sources including the U.S. Census Bureau's TIGER data files, the El Paso County GIS data catalogue, the Baruch College Geoportal, the Colorado Web Development Center, SimplyMap, Natural Earth database, and the Colorado Department of Transportation Online Transportation Information System.[10]

## 4.5 Empirical Analysis

### 4.5.1 Geocoding and Spatial Analysis

The first step in my analysis was to geocode each land parcel within the wildland-urban interface sample.[11] Geocoding is the process of converting street addresses to geographic coordinates (i.e. latitude and longitude). The original housing parcel data set included all houses in El Paso County

[8] The finished basement variable is coded as a dummy variable due to the fact that the presence of a finished basement is more important to the value of a house than the actual number of square feet.

[9] All structural data was compiled by the El Paso County Assessor's Office in conjunction with the transaction data.

[10] See Table 4 in the appendix for specific data sources for each geographical feature.

[11] I use ESRI ArcGIS mapping software for all geographic mapping and spatial data analysis.

sold in either 2011 or 2013. Once the properties were geocoded and mapped according to their street addresses, I sampled only those houses located within the wildland-urban interface boundary.

I next conducted network analysis to generate the spatial attribute data for each house. This entails calculating the distance from each property to landmarks such as schools, hospitals, libraries, major highways, and airports.[12] Theoretically, the closer a property is to services and amenities, the higher the value. I next joined the wildfire risk rating data to the geocoded housing parcels. The merged data set comprising the wildfire risk rating, transaction price, structural characteristics, and spatial characteristics constitutes the complete data set.

### 4.5.2 Independent Variables

The structural variables that I chose to include are: $BEDROOMS$ for the number of bedrooms in each house; $BATHROOMS$ for the number of bathrooms; $AGE$ which equals the year the house was built subtracted from 2013; $SQUAREFOOTAGE$ which is the total square footage available for living; $LOTSIZE$ for the total parcel square footage; and $BASEMENT$ which is a dummy variable representing whether or not the house has a finished basement. The other categorical independent variables are also re-coded as dummy variables. $GOLFCOURSE$ is a dummy variable for whether the property is located within a 30 mile buffer zone of a golf course, and the excluded variable is the category designating that the parcel is located greater than 30 miles from a golf course. There are four wildfire risk rating dummies: $EXTREME$, $VERYHIGH$, $HIGH$, $MODERATE$, and “low” which I omit. $INCOME$ denotes the median income of the census block group in which the property falls. The remaining variables are spatial attributes that represent the straight-line distance from each feature to the home. These variables are $AIRPORT$, $HOSPITAL$, $LIBRARY$, $SCHOOL$, $HIGHWAYS$, $CITYCENTER$, and $CHURCH$. Table 5 fully describes the attribute data found for each house.

[12] Straight-line distances are used rather than street distances due to limitations on software processing power.

**Table 5** Definition of independent variables

| Variable | Description |
|---|---|
| AIRPORT | Distance to nearest public airport |
| GOLFCOURSE | Dummy variable for if within 30 miles of a golf course (1 if yes, 0 if no) |
| HOSPITAL | Distance to nearest hospital |
| LIBRARY | Distance to nearest public library |
| SCHOOL | Distance to nearest school |
| INCOME | Median household income |
| HIGHWAYS | Distance to nearest major highway |
| CITYCENTER | Distance to centroid of city or town |
| CHURCH | Distance to nearest church |
| BEDROOMS | Number of bedrooms |
| BATHROOMS | Number of bathrooms |
| AGE | Year house was built subtracted from 2013 |
| BASEMENT | Dummy variable for finished basement (1 if yes, 0 no) |
| LOTSIZE | Total parcel lot square footage |
| SQUAREFOOTAGE | Total above ground square footage |
| EXTREME | Dummy variable for fire risk rating (1 if extreme, 0 otherwise) |
| VERY_HIGH | Dummy variable for fire risk rating (1 if very high, 0 otherwise) |
| HIGH | Dummy variable for fire risk rating (1 if high, 0 otherwise) |
| MEDIUM | Dummy variable for fire risk rating (1 if medium, 0 otherwise) |

### 4.5.3 Regression Specification

I regressed the log of housing prices on the wildfire risk rating in addition to the structural and spatial characteristics of each house. Following the hedonic literature, I chose a log-linear specification, although the results prove to be largely insensitive to functional form.[13] After further analysis, I also removed household income from the regression equation due to potential endogeneity.[14]

In my analysis I work to more accurately understand the interaction between wildfire risk and the amenity value from living in a risky location. While wildfire risk should negatively affect the price of a house, risk is also correlated with amenities that positively influence house value (Donovan et al. 2007). The model that the Colorado Springs Fire Department used to determine parcel risk ratings includes factors such as the density of vegetation around the house, the distance to dangerous topography, the slope of the land that the house is situated on, and the roofing and siding material used in construction.[15] Each of these variables provides positive amenity value; homeowners gain utility from living in densely forested areas with trees and shrubs around their house, they enjoy the views from living on ridges and land with steeper slopes, and wooden construction materials are preferred to vinyl and plastic siding. Unfortunately, the data on these amenity characteristics are either unavailable or unobservable. The amenity factors are potentially omitted variables that

[13] Linearity cannot be assumed in the hedonic property model because parts of a house cannot be "unbundled" and sold off individually.

[14] Most people are only able to buy an expensive house if they have a high income.

[15] Wildfires spread faster and with greater intensity as the slope of land increases, and houses with wooden shingles and siding face a higher susceptibly to burning.

both help determine the dependant variable and are correlated with independent variables (the risk rating dummies). The result is a violation of OLS assumptions and potentially biased estimates.

The $LOTSIZE$ variable may act as a proxy and help to control for the positive amenity variables. Based on an analysis of the Colorado Springs area, bigger houses and mansions on larger land parcels tend to be closer to the western edge of the city in more secluded areas. They also tend to be situated on or near hills with better views. Likewise, houses on smaller lots are often in more densely developed urban areas with less surrounding vegetation and more level terrain. The goal here is to determine what effect wildfire risk has on house value, and whether the counteracting amenities influence how homeowners capitalize risk. Thus, I estimate a hedonic regression of the following form:

$$\begin{aligned}\ln SalePrice = \alpha + \beta_0 AIRPORT + \beta_1 GOLFCOURSE + \beta_2 HOSPITAL + \beta_3 LIBRARY \\ + \beta_4 SCHOOL + \beta_5 CITYCENTER + \beta_6 CHURCH + \beta_7 HIGHWAY + \beta_8 AGE \\ + \beta_9 BASEMENT + \beta_{10} SQUAREFOOTAGE + \beta_{11} LOTSIZE + \beta_{12} EXTREME + \\ \beta_{13} VERYHIGH + \beta_{14} HIGH + \beta_{15} MODERATE + \epsilon\end{aligned}$$

### 4.5.4 Spatial Dependence

The hedonic specification must also account for spatial dependence. Spatial dependence indicates that the dependent variable is spatially autocorrelated; essentially, the price of a home is partially a function of the value of all other homes in the nearby area. Failing to account for spatial dependence can result in underestimating standard errors. In order to account for this spatial clustering of similar values I use robust standard errors.[16]

[16]Further analysis of spatial dependence might include conducting a Moran Test and observing the semi-variogram, which plots the distance between two observations versus the semivariance between them.

## 4.6 Results

**Table 6** Regression outputs for log-linear specification

| | *Specification 1* | | *Specification 2* | |
|---|---|---|---|---|
| **Variable** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** |
| C | 11.018* | 0.148 | 11.004* | 0.145 |
| AIRPORT | 0.073* | 0.013 | 0.073* | 0.013 |
| GOLFCOURSE | 0.046 | 0.024 | 0.048* | 0.024 |
| HOSPITAL | -0.086* | 0.024 | -0.086* | 0.023 |
| LIBRARY | 0.007 | 0.020 | 0.007 | 0.019 |
| SCHOOL | -0.042 | 0.032 | -0.040 | 0.032 |
| HIGHWAYS | 0.135* | 0.022 | 0.134* | 0.022 |
| CITYCENTER | -0.069* | 0.025 | -0.069* | 0.025 |
| CHURCH | -0.010 | 0.007 | -0.010 | 0.007 |
| BEDROOMS | 0.029* | 0.011 | 0.029* | 0.011 |
| BATHROOMS | 0.048* | 0.018 | 0.048* | 0.018 |
| AGE | -0.002* | 0.001 | -0.002* | 0.001 |
| BASEMENT | 0.270* | 0.022 | 0.270* | 0.022 |
| SQUAREFOOTAGE | 4.23E-04* | 1.59E-05 | 0.000424* | 1.56E-05 |
| LOTSIZE | -7.72E-08* | 3.20E-08 | -7.69E-08* | 3.20E-08 |
| EXTREME | 0.136 | 0.098 | 0.134 | 0.097 |
| VERY_HIGH | 0.031 | 0.072 | | |
| HIGH | 0.031 | 0.066 | | |
| MODERATE | 0.021 | 0.066 | | |
| OTHER_RISK | | | 0.025 | 0.065 |

* denotes P-value < .05

Based on visual inspection of the first specification, the dummy variables for "very high," "high," and "moderate" risk appear to be very close. Thus, I conduct a Wald Test to test the linear restriction that they are equal, with the results presented in Table 7. Based on a $p$-value of 0.874, I fail to reject the null hypothesis that the dummies are equal. Consequently, I combine the three dummy variables into a new $OTHERRISK$ dummy, and run the regression a second time. The results of the second regression are presented in the second specification in Table 6.

**Table 7** Wald test for equality of variables

| **Test Statistic** | **Value** | **P-value** |
|---|---|---|
| F-statistic | 0.135 | 0.874 |
| Chi-square | 0.270 | 0.874 |

The coefficients in the regression output are semi-elasticities, representing the percentage increase in sale price due to a unit increase in the independent variable. Additionally, the magnitude and sign of the coefficients on the dummy risk variables are largely insensitive to which variables are included in the regression, with the exception of the lot size variable. Overall, the specification fits the data well, with an adjusted $R^2$ of 0.70 and a $F$-statistic $p$-value of 0.00, indicating that the regressors jointly have strong explanatory power.

As anticipated, each of the structural attributes is statistically significant at the 5% level, with the expected sign on the coefficient. The existence of a finished basement has a large impact on house value, increasing value by 27%. House value also increases with the number of bedrooms and bathrooms, albeit to a lesser extent. Each additional bedroom increases sale price by 2.9% and each additional bathroom by 4.8%. Square footage also has a small, but significant effect. For every marginal square foot, the sale price increases 0.04%. This is very close to the unconditional sample average price of $161.72/square foot, which equates to a 0.05% increase per square foot. Additionally, the lot size variable is significant but has almost no practical effect on the sale price. I initially included a lot size squared variable in order to determine if there was a non-linear effect, but the quadratic term was not significant and the specification had a higher AIC and SIC. Finally, the age of a house has a negative effect on value with a significant p-value of 0.00. As a house increase in age by one year, it loses 0.2% in value.

The statistical significance of the spatial characteristics is more mixed. $AIRPORT$ is statistically significant, but the coefficient has a negative sign. Upon initial inspection the negative sign is somewhat counterintuitive; location closer to an airport should have a positive impact on house price because of improved access. However, the positive coefficient may be due to the fact that airports generate high levels of noise pollution. Few people want to live close to an airstrip where planes are constantly landing and taking off. Similarly, the variable for distance from a major highway has a positive coefficient and is significant at the 5% level. Although proximity to a highway allows for ease of travel and decreases commute time, the automobile traffic on highways is a major source of air and noise pollution. Neighborhoods abutting highways are less attractive and prospective homebuyers often shy away from areas that are directly off of major exits.

The $HOSPITAL$ and $CITYCENTER$ variables are significant and have the expected negative sign. The nearer one lives to the downtown district of a city the better the access to malls, transportation hubs, grocery stores, shops, city hall, and public services such as fire stations, police coverage, and postal offices. Living a shorter distance to the epicenter of the city often also decreases commute time to work and improves proximity to the central business district. Every mile closer to the city center, increases sale price by 6.9%. While living in a less densely populated area is certainly attractive, the development pattern in Colorado Springs is such that a house may be located close to the center of a city yet simultaneously be in a secluded area. Similarly, the closer a house is to a hospital, the higher the value. $HOSPITAL$ has a highly significant $p$-value of 0.00, and a coefficient of $-0.086$. The marginal effect of living a mile farther from a hospital is an 8.6% decrease in home value. This marginal effect seems high, although the coefficient may be biased if proximity to hospitals is correlated with other omitted variables that account for similar amenities.

The only other spatial characteristic that has a significant regression coefficient is the distance to the nearest golf course variable. However, this variable has a positive sign, the opposite from what would be expected, with little plausible explanation.

Perhaps unsurprisingly, the variables denoting proximity to libraries and churches are not statistically significant ($p$-values of 0.703 and 0.192 respectively). Libraries and churches are certainly amenities that homeowners enjoy having easy access to, but they are not main value drivers of a property's sale price. Few buyers realistically factor the distance to the nearest church or library into their calculation on how much to bid for a house. Furthermore, while proximity to a school appears to increase a house's value, the effect is not statistically significant.

Interestingly, none of the coefficients on the wildfire risk dummy variables are significant. Higher risk should negatively impact price, yet the coefficients are positive. An extreme risk rating actually causes a 13.4% increase in sale price, although the coefficient is not significant. This result could be explained by the fact that houses rated as extremely risky have high positive amenities that dominate the negative effect of the wildfire risk. If you remove lot size, which acts as a proxy for some amenity variables, then the $EXTREME$ variable becomes significant and larger. For the other three risk ratings ("very high," "high," and "moderate") the positive amenity value may not be as large, and thus would be counterbalanced by the wildfire risk, causing the coefficients to be insignificant. The omitted amenity variables that are correlated with risk and help determine the sale price cause the coefficient on the risk variables to be over-estimated.

Under-specification may cause biased coefficients. Thus, it is important to aim for parsimony, yet to include all necessary variables. This has proved especially difficult in the present analysis due to issues in obtaining and manipulating geospatial data accurately. The result is an omitted variable bias if the lot size parameter is not included (the extreme risk dummy is over-weighted). Overall, it has proven difficult to generate a strong explanatory regression equation for transaction prices demonstrating that wildfire risk negatively and significantly impacts house values. As Damianos and Shabman (1976) explain in their analysis of hurricane risk, the results may be due to the fact that homebuyers are legitimately ignorant of the true risk of natural disasters. Previous research shows that a lack of information on natural disasters can cause failures in the housing market. As Donovan (2007) explains, it is not clear that homeowners in the wildland-urban interface understand the risk that wildfire poses to their homes, although the Black Forest Fire (2013) and Waldo Canyon Fire (2012) were the most destructive wildfires in state history and resulted in major "red zone" insurance claims. Furthermore, because homeowners living in at-risk areas consider wildfires to be random and inherently uncontrollable, they are less likely to make an effort to protect their own property (Winter and Fried, 2000). This is the reality despite continual efforts by the Colorado Springs Fire Department to educate the public.

## 4.7 Conclusion

Contrary to my initial hypothesis, wildfire risk cannot be shown to negatively impact residential housing prices. This may be the result for two main reasons. First, living in dangerous, wildfire-prone areas comes bundled with positive amenities that may dominate the negative risk effect. Secondly, actors in the market often underestimate the objective wildfire risk attached to a house. Market information inefficiency coupled with positive amenity effects make it difficult to discern what the true impact of risk is on the residential housing market. The market failure also has important policy implications. If transaction values had been negatively correlated with risk after the recent wildfire devastation in Colorado, then the housing market might have been efficient at signaling risk, reducing the need for zoning policy changes. However, homebuyers clearly do not understand the true extent of the risk.

Why has development in dangerous "red zones" continued if the objective risk is so high? One issue is a misalignment of incentives. Local town governments and real estate developers enjoy larger tax bases and increased business from expanding construction. However, the majority of the costs of large-scale wildfires are borne by county, state, and federal emergency response teams. Zoning laws and construction restrictions should thus be standardized and legislated at the county or state level. Whether or not homebuyers become more aware of the objective wildfire risk, it will become increasingly expensive to build structures in dangerous areas. Counties and local municipalities will ultimately begin to regulate what building materials and methods may be used in construction and where developers can build, all leading to higher building costs. Colorado Springs has already started such initiatives. With a city ordinance passed in December 2012, the city adopted wildfire mitigation measures for new construction in the high-risk "hillside overlay zone" characterized by slope, vegetation, drainage, and rock outcroppings that require special attention during development. The ordinance focuses on fuel management and creating a safety clearance zone free of vegetation around each house. The Colorado Springs Fire Department has further created a chipping program in over 100 neighborhoods to help residents remove and dispose of branches, brush, and other vegetation that could fuel a wildfire. Thus, wildfire risk will become inherently embedded in the opportunity cost of new development. On the whole, wildland-urban interface development, climate change, and years of past suppression policies have set the table for wildfire prevention and suppression to continue to grow as a major policy issue facing the United States today.

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# Appendix A

**Table 4** Geographical features used for spatial network analysis

| Feature | Data Source |
|---|---|
| Airports | Colorado Dept. of Transportation |
| Golf courses | Baruch College Geoportal (ESRI 2008) |
| Hospitals | Baruch College Geoportal (ESRI 2008) |
| Libraries | Colorado Web Development Center |
| Parks | El Paso County GIS Office |
| Schools | Baruch College Geoportal (ESRI 2008) |
| Ski areas | Simply Map |
| City center | Baruch College Geoportal (ESRI 2008) |
| Median household income | Simply Map |
| Churches | Baruch College Geoportal (ESRI 2008) |
| Major highways | Baruch College Geoportal (ESRI 2008) |

**Figure 5** Parcel map of Colorado Springs with property wildfire risk ratings

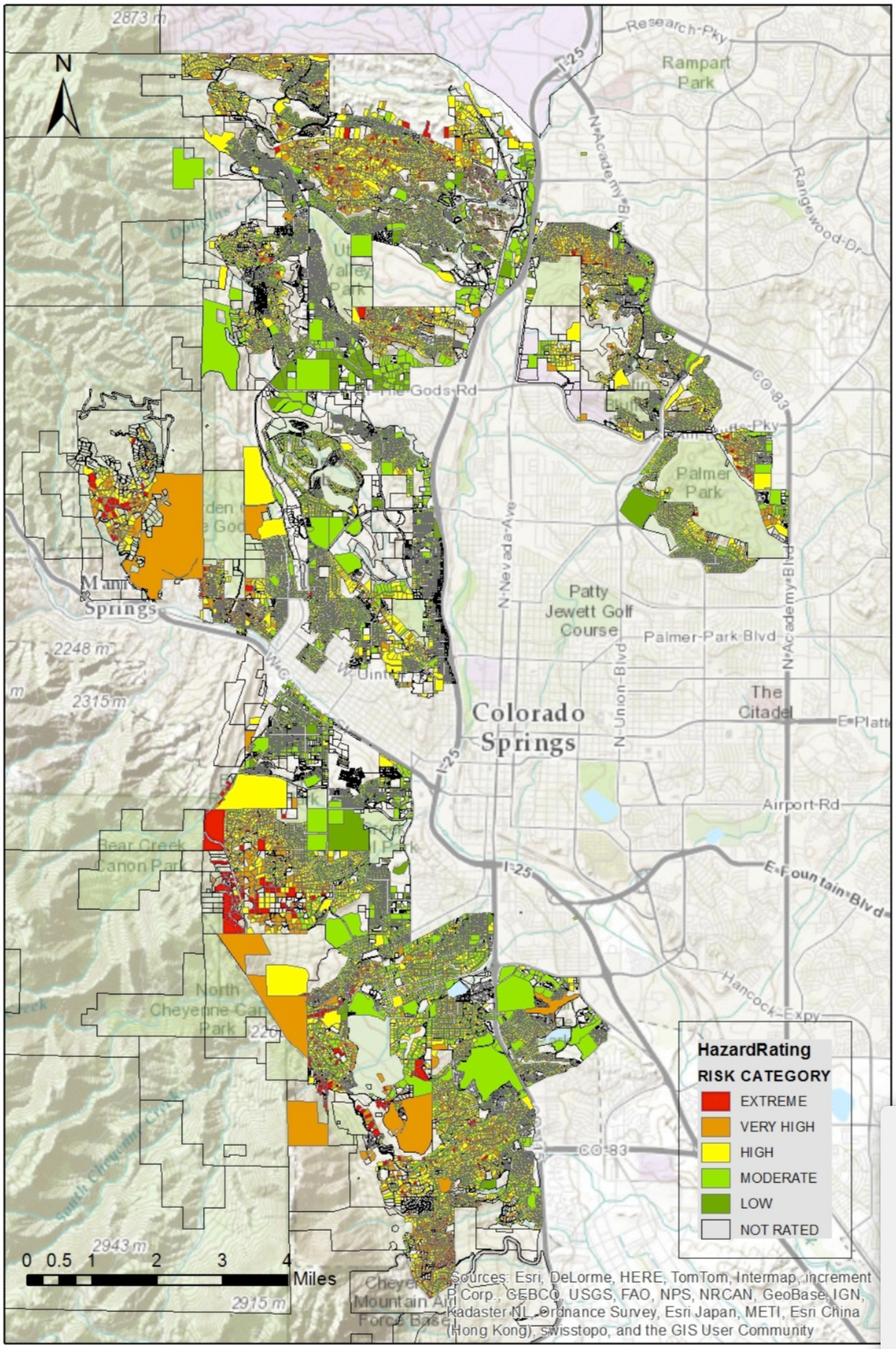
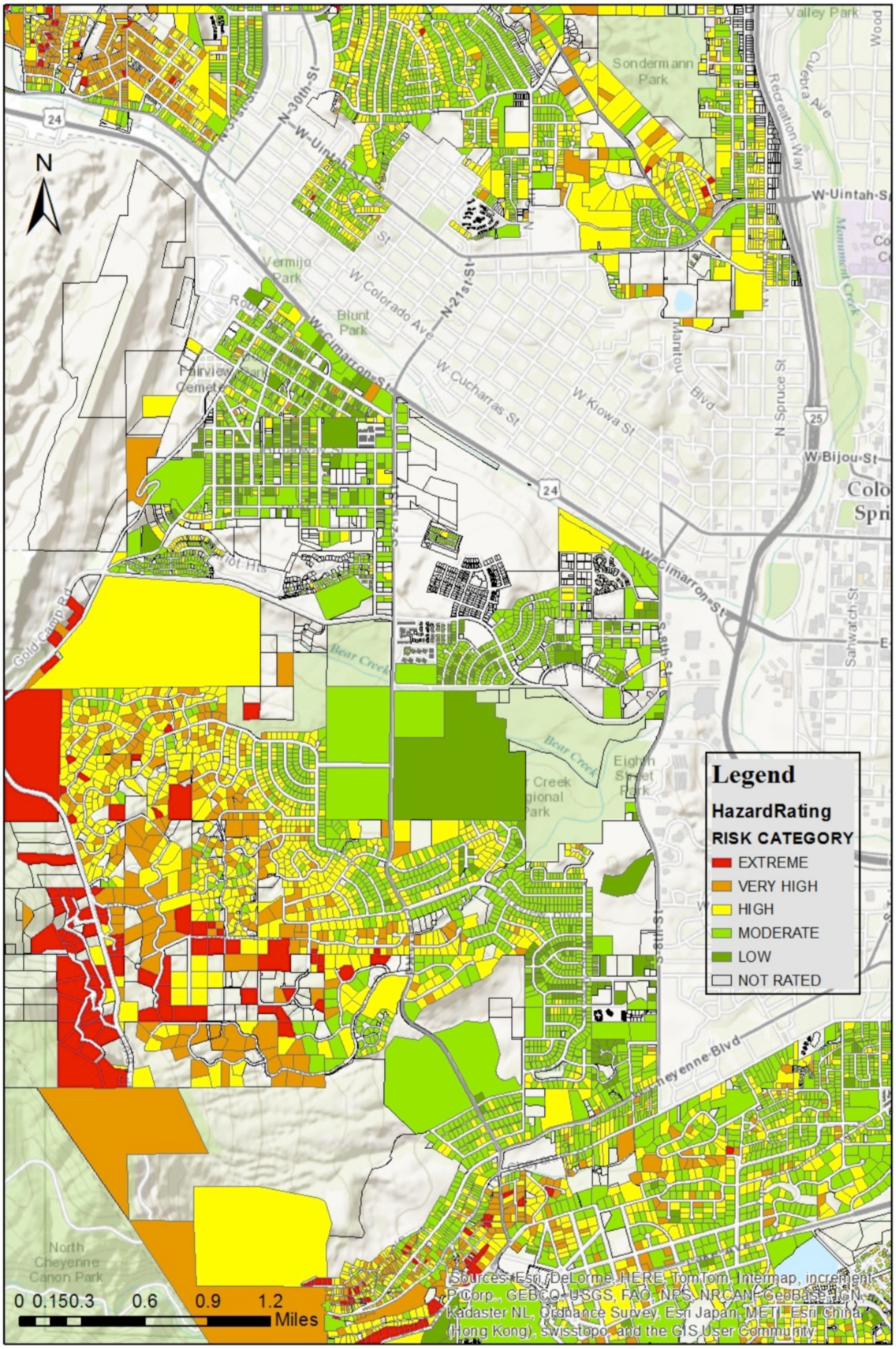


**Figure 6** Parcel map of Colorado Springs with property wildfire risk ratings



**EViews Code**

```
genr lnsaleprice = log(saleprice)
series Dfinished_basement = @recode(finished_basement_=''yes'', 1, 0)
series Dextreme = @recode(riskcatego=''EXTREME'', 1, 0)
series Dveryhigh = @recode(riskcatego=''VERY HIGH'', 1, 0)
series Dhigh = @recode(riskcatego=''HIGH'', 1, 0)
series Dmoderate = @recode(riskcatego=''MODERATE'', 1, 0)
series Dother_risk = dhigh +dmoderate+dveryhigh
ls lnsaleprice c airportdistance golfdistance hospdistance librarydistance
schooldistance highwaydistance citiesdistance churchdistance beds baths age
dfinished_basement total_living_square_ftg lot_square_ftg dextreme dother_risk
```