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Responding to Risky Neighbors: Testing for Spatial Spillover Effects for Defensible Space in a Fire-Prone WUI Community

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Abstract

Often, factors that determine the risk of an environmental hazard occur at landscape scales, and risk mitigation requires action by multiple private property owners. How property owners respond to risk mitigation on neighboring lands depends on whether mitigation actions are strategic complements or strategic substitutes. We test for these neighbor interactions with a case study on wildfire risk mitigation on private properties. We use two measures of wildfire risk mitigation—an assessment by a wildfire professional and a self-assessment by homeowners. Taken together, the two assessments provide the first empirical explanation for strategic complements in wildfire risk mitigation and a more complete picture of how homeowners respond to this landscape-scale risk. We find homeowners that mitigate risk on their land are more likely to have neighbors that do the same, and homeowners that fail to mitigate risk are more likely to have neighbors that fail to do so as well. Due to spatial spillovers, motivating a few key residents to take action could reduce risk across the landscape.

Keywords WUI · Neighbor effects · Spatial spillovers · Wildfire · Defensible space · Endogenous risk

> Your own property is concerned when your neighbor's house is on fire. ~Horace

1 Introduction

Often, factors that determine the risk of an environmental hazard occur at landscape scales, and risk mitigation requires action by multiple private property owners. Examples include the prevention of invasive species spread (Epanchin-Niell et al. 2010; Fenichel et al. 2014), preventing hypoxia in large river basins (Burkart and James 1999; Wu and Tanaka 2005), maintaining habitat for sensitive species (Innes et al. 1998; Parkhurst and Shogren 2007), and mitigating wildfire risk (here and in Brenkert-Smith et al. 2006; Busby et al. 2012; Fleeger and Becker 2010; Shafran 2008). Such cases of interdependent risk give rise to strategic action by

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property owners, spatial externalities, and spatial spillover effects (LeSage 1999). As others have shown, final outcomes depend on whether risk mitigation actions between properties act as strategic substitutes or strategic complements (Bulow et al. 1985; Heal and Kunreuther 2007). Strategic substitutes arise due to decreasing returns to risk mitigation, that is, when mitigation on one property decreases the benefits of mitigation on neighboring properties. In such cases, mitigation at one location may make mitigation at another less important, and a centralized decision maker could effectively optimize the level of mitigation across a landscape (Konoshima et al. 2008). However, when the decisions of where to mitigate and at what level are spread across economic actors, strategic interaction opens the door to free riding and under-provision of risk mitigation (Shogren and Crocker 1991). When mitigation on one property increases the benefits to mitigation on neighboring properties, conditions are ripe for strategic complements. Increasing returns to mitigation occur for threshold and weakest-link public goods, leading to coordination problems with at least two Nash equilibria—one where mitigation is near the optimal level and one where mitigation is near zero (Heal and Kunreuther 2007; Hirshleifer 1983).

More broadly, the role of returns to scale has also been shown to be important for determining levels of privately provided environmental and public goods ranging from land conservation (Albers et al. 2008a, b, Parkhurst and Shogren 2007) to technology and knowledge diffusion (Audretsch and Feldman 1996; Anselin et al. 1997; Cooke 2002).

Empirical evidence suggests that whether strategic complements or substitutes exist depends less on the physical processes that create the risk and more on individuals' perception of the risk, experience with similar risks, whether they think increasing or decreasing returns to scale exist for risk mitigation, and the efficacy of risk mitigation. Usually, personal experience leads to more mitigating behavior (Lindell and Prater 2000; Russell et al. 1995; Cohn et al. 2008; Brenkert-Smith et al. 2006). The effect is stronger when the experience is personal and direct, but even the experiences of family members and close friends lead some people to mitigate risk (Turner et al. 1986; Lindell and Perry 2000). Close encounters make the perception of the hazard more real, demonstrate the extent of possible damages, and lead people to believe similar events could happen in the future (Weinstein 1989). Unfortunately, any effects of personal experience decline over time, resulting in the possibility of short term influences but not necessarily long term effects on risk perceptions (Weinstein 1989; Burton 1993; Sims and Baumann 1983).

Increased risk perceptions, however, do not always lead to more mitigating behavior (Lindell and Perry 2000; Bubeck et al. 2012; Wachinger et al. 2013; McCaffrey et al. 2013), and some experiences with natural hazards lead people to take fewer precautionary actions. One common problem, for example, is the "gambler's fallacy"—the belief that if a catastrophic event has happened before, it is less likely to happen again. People may believe they have "had their disaster" (Gregory 1995; Whitehead et al. 2000). In places where natural disasters are common, such as in earthquake or fire prone regions, people may also accept such events as a way of life and do less to mitigate risk (Tierney 1994). In places where natural disasters are uncommon, but where a traumatic event has taken place, feelings of hopelessness may prevail; residents that believe the hazard is random and uncontrollable may perceive mitigation as pointless (Winter and Fried 2000). This perceived effectiveness, or efficacy, of mitigation has been shown to be an important predictor of risk mitigating behavior (Martin et al. 2009; Kellstedt et al. 2008; Lindell and Whitney 2000).

Wildfire in communities is a classic example of landscape scale interdependent risk. As Horace said, "Your own property is concerned when your neighbor's house is on fire,"[1]

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[1] In the original Latin, "Tua res agitur, paries cum proximus ardet."

(Horace 20 B.C., Epistles 1.18.84-85). Homeowners can take action to reduce the likelihood of damages to their home, but exposure to fire generally comes from the broader landscape and neighboring properties. Dense fuels on adjacent properties can carry the fire from one property to the next through strong heat fluxes and airborne embers (Trelles and Pagni 1997; FUSEE 2007; Murphy et al. 2007; Blanchi and Leonard 2005). A post-fire review of the Guejito and Witch fires that burned in California in 2007 showed that two out of every three structures were lost directly from embers jumping from one structure to the next or indirectly from embers spreading to the vegetation on neighboring properties (Maranghides and Mell 2009).

Losses and damages from wildfire have increased dramatically in recent years. In 2017, wildfires in California burned more than one million acres, destroyed over 8900 structures, and caused 2 firefighter and more than 40 civilian fatalities; wildfires in Montana burned more than one million acres and led to several firefighter fatalities; and wildfires in Portugal and Spain caused over 100 fatalities and more than 200 injuries. To reduce risk, wildfire professionals recommend residents reduce flammable vegetation within 30 m of their homes, use fire resistant building materials, and in general, maintain the home ignition zone to create what is referred to as “defensible space” around a home (Cohen 2004). These actions not only make it less likely that the house will catch fire, but also create a safe space for firefighters to defend the home in the event of a wildfire. Following the 2010 Four mile Canyon Fire outside of Boulder, Colorado, post-fire analysis found that 83% of homes in the burn area that had gone through the county’s mitigation process to create defensible space survived the fire, compared to only 63% of the homes that had not. Homes that completed actions based on newer standards faired even better, with a 100% survival rate for homes that had participated in the mitigation process after 2000 (van Heuven 2013). From a practical standpoint, property insurers and mortgage lenders are beginning to account for these externalities and include risk from surrounding properties in their underwriting decisions (Botts et al. 2015).

Other papers have addressed the effect of neighbors’ actions on efficacy of defensible space and modeled the wildfire risk externality between neighbors, though without any real consensus on whether strategic substitutes or strategic complements exist for wildfire risk mitigation. Butry and Donovan (2008) divide threats to homes into a two-step process that includes attacks from wildfire and the probability of the home catching fire. They model the process such that frequency of attacks a home experiences is a function of neighbors’ actions, and the probability of catching fire is a function of own actions. Neighbors’ actions, therefore, reduce the perceived benefits of a household’s mitigation actions. This approach to modeling fire risk implicitly assumes strategic substitutes. Similar assumptions are made by Steelman and Burke (2007) and Busby and Albers (2010).

The few empirical studies, however, find that neighbors’ mitigation efforts increase the perceived benefits of own actions, suggesting strategic complements. Shafran (2008), which we build on, uses a spatial lag model and home assessments done by wildfire professionals to show defensible space created on neighboring properties has a positive effect on households’ defensible space. Brenkert-Smith et al. (2006) find informal interactions with neighbors encourage collaboration on fuels projects. Schulte and Miller (2010) find mitigation increases when households believe neighbors’ mitigation decreases their own risk, and Steinberg (2005) concludes households believe mitigation efforts are meaningless if their neighbors do not also take action.

The empirical literature to date involves either subjective measures of mitigation reported by homeowners or more objective measures from fire professionals. In this paper, we extend the literature in two key directions. First, we test for strategic interactions in a new case study using property-level assessments of wildfire risk mitigation. Second, we pair the assessments completed by a wildfire professional with a homeowner survey. The combined dataset allows us to observe the spatial distribution of wildfire mitigation behavior on private parcels while gleaning additional insights into whether residents actually consider proximate neighbors, and if they do consider them, how those considerations affect mitigation. A wildfire professional and layperson, even one that owns and resides on a property, may have differing notions of what wildfire risk mitigation looks like. It is important to understand both of these perspectives because wildfire professionals are implementing community wildfire mitigation and education programs based on their assessments of parcel wildfire risk within the community, and homeowners are taking action based on their understandings of wildfire risk on their parcels. More broadly, the addition of the survey data allows us to contribute to the literature on spatial spillover effects and to more completely model risk mitigation behaviors. It allows for an investigation of how the mitigation level on neighboring properties is correlated with perceptions of the probability and consequences of a hazard. We examine households' perception of this risk externality and whether it is correlated with levels of mitigation they undertake.

This work builds on the broader literature on spatial spillovers and landscape-scale risk and the literature on wildfire risk mitigation on private land. There is a paucity of research at the juncture of these two literatures. Champ et al. (2013) find that homeowners generally underestimate their risk compared to a wildfire professional's rating and that risk perception and mitigation actions are jointly determined by characteristics of both the homeowner and the home site. Olsen et al. (2017) find self-assessments of wildfire risk are correlated with results of a computational wildfire risk model, but homeowners tend to overstate the likelihood of fire considerably compared to risk calculated by a computer model. Meldrum et al. (2015) attribute some of the differences between professional and homeowner risk measures to the weight given to various threats; homeowners tend to downplay the role defensible space has in reducing risk and overplay the role background fuels have in increasing risk. Of course, it could be that homeowners understand the risk even if they do not calculate it the same way a wildfire professional or computer model would. Both Olsen et al. (2017) and Fischer et al. (2014) find risk mitigation increases with the level of concern and values at risk, and several hedonic studies have shown that buyers are willing to accept some risk in exchange for other home amenities (Donovan et al. 2007; Loomis 2004; Champ et al. 2009). Shafran (2008) and Taylor et al. (2013) both look at mitigation of wildfire risk on private land using data from professional parcel level risk assessments and find empirical evidence of strategic complementarity in defensible space.

2 Spatial Analysis and Econometric Model

The existence of spatial spillovers and neighbor effects has been motivated with a number of theoretical models (Steelman and Burke 2007, Butry and Donovan 2008, Shafran 2008, Busby and Albers 2010). Most of these models are a variant on the Ehrlich and Becker (1972) model of endogenous risk, which we present briefly here. Our fundamental assumption is that households can affect their risk exposure by creating defensible space, and decisions to complete those actions depend on personal characteristics and the surrounding landscape. Let the household's perceived probability of loss from wildfire be $p\left(x_i, \sum_{j \neq i} w_{ij} x_j, H_i\right)$, where x_i is the amount of defensible space around household i's home measured by the distance from the house to overgrown, dense, or unmaintained vegetation (in our data, x_i is measured by both a wildfire professional and self-assessed by homeowners), $\sum_{j \neq i} w_{ij} x_j$ is a weighted average of defensible space surrounding neighboring homes, w_{ij} is the weight given between observations i and j, and H_i is a vector of household i's characteristics, which includes demographic variables and property-level characteristics not directly related to defensible space such as proximity to steep terrain.[2] Given income M, potential losses L, and a normalized price of defensible space equal to one, we define $U_g = U(M - x_i)$ and $U_b = U(M - x_i - L)$ as utility in the good (without wildfire losses) and bad (with wildfire losses) states, respectively. Expected utility is

$$EU = \left(1 - p\left(x_i, \sum_{j \neq i} w_{ij}x_j, H_i\right)\right)U_g + p\left(x_i, \sum_{j \neq i} w_{ij}x_j, H_i\right)U_b \tag{1}$$

Assuming the utility and probability functions are continuous and twice differentiable such that $U' > 0$, $U'' < 0$, $p_1\langle 0$, $p_2\langle 0$, $p_{11}\rangle 0$, $p_{22}\rangle 0$, the first order condition for an interior optimum is

$$-p_1\left[U_g - U_b\right] = (1 - p)U_g^{'} + pU_b^{'} \tag{2}$$

Subscripts on the probability function denote partial derivatives with respect to the first and second arguments. That is, p_1 is the marginal effect on the perceived probability of losses of own mitigation, and p_2 is the marginal effect on the perceived probability of losses of neighbors' mitigation. The left side of (2) is the marginal gain from the reduction in expected losses. The right side is the decline in utility due to mitigation expenses in both states of the world, i.e., the marginal cost of protection.

The first order condition implicitly defines reaction functions based on neighbors' actions, $x_i\left(\sum_{j \neq i} w_{ij}x_j\right)$, of which we are interested in the slope. Applying the implicit function theorem to the first order condition gives the marginal effect of neighbors' actions on household mitigation decisions

$$\frac{dx_i}{d\left(\sum_{j \neq i} w_{ij}x_j\right)} = \frac{p_{12}\left[U_g - U_b\right] - p_2\left[U_g^{'} - U_b^{'}\right]}{D} \tag{3}$$

where D is the second order condition, given by

$$D = -p_{11}\left[U_g - U_b\right] + 2p_1\left[U_g' - U_b'\right] + (1 - p)U_g^{''} + pU_b^{''} \leq 0 \tag{4}$$

Mitigation actions are strategic substitutes if and only if $dx_i/d\left(\sum_{j \neq i} w_{ij}x_j\right) \leq 0$. The second order sufficiency condition ($D \leq 0$) guarantees the reaction function in (3) takes the opposite sign of the numerator. We assume non-increasing marginal utility, so $-p_2\left(U_g^{'} - U_b^{'}\right) \leq 0$. The net effect of mitigation depends on how homeowners believe neighbors' actions affect the marginal productivity of their own actions (the sign of p_{12}), the size of losses ($U_g - U_b$), the marginal cost of protection ($U_g' - U_b'$), and the size of the spillover from mitigation (p_2).

Strategic substitutes exist if and only if

$$p_{12}\left[U_g - U_b\right] - p_2\left[U_g^{'} - U_b^{'}\right] > 0.$$

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[2] From the viewpoint of individual i, $\sum_{j \neq i} w_{ij}x_j$ can more generally be thought of as off-site factors that affect risk, for example, accumulated fuels on federal lands, risky power lines, etc.

A necessary, but not sufficient, condition for strategic substitutes is that homeowners believe neighbors' actions decrease the marginal productivity of their own actions, such that $p_{12} > 0$. Shafran (2008) assumes the marginal utility of wealth is constant ($U_g' - U_b' = 0$), so in his model $p_{12} > 0$ is a sufficient condition for strategic substitutes. In the model presented here, however, neighbors' actions could be effective enough ($|p_2|$ large) to incite homeowners to mitigate. In this case, a large negative p_2, which would indicate a large externality in the reduction of risk, can increase the expected gains of mitigation enough to cause strategic complements. This may be the case for threshold or weakest-link public goods, for which neighboring lands pose enough risk that any mitigation is perceived as pointless.

A sufficient condition for strategic complements is that homeowners believe neighbors' actions increase the marginal productivity of their own actions ($p_{12} \leq 0$). Often, factors like fire regime of the landscape and parcel size create conditions under which meaningful reduction in risk can only happen with widespread mitigation efforts. From an objective standpoint, one homeowner's mitigation actions increase the benefits of mitigation on neighboring properties. With strategic complements, at least two Nash equilibria exist, one where everyone mitigates and one where nobody does, and tipping between them is possible (Heal and Kunreuther 2007).

The effect in Eq. (3) is measured empirically with an econometric model of defensible space with a spatial lag,

$$x_i = \alpha + \rho \sum_{j \neq i} w_{ij} x_j + \gamma H_i + \varepsilon_i \tag{5}$$

The coefficient ρ gives the effect of neighbors' defensible space on household i's defensible space (i.e., the slope of the reaction function, Eq. 3). The vector H_i contains information on household and property characteristics, including responses from a survey that directly addresses the beliefs about effectiveness of own actions given actions on neighboring lands. Positive values for ρ indicate the presence of spatial complements and clustering of neighbors with similar levels of defensible space. Negative values indicate the presence of spatial substitutes and neighbors with statistically different levels of defensible space. A value that is not statistically significant would indicate that we cannot infer anything about spillovers from the data.

We use two different sources for x_i and x_j to measure ρ. One model uses both x_i and x_j as measured by the wildfire professional to get at a more objective look at strategic interaction. The other model uses x_i as measured by the homeowner and x_j as measured by the professional to get at how homeowners view their own defensible space in relation to their neighbors' property. The survey also includes questions directly asking about perceived efficacy of mitigation in light of perceptions about risk from neighbors.

We explored using various definitions of "neighbor", including k-nearest neighbors, distance-based definitions of neighbor, and sphere of influence (SOI) neighbors.[3] SOI neighbor sets are constructed by first drawing a circle around each point whose radius is the distance to the nearest neighbor; any properties with overlapping circles are SOI neighbors of each other. We do not find any obvious choice between neighbor definitions given the variation in property sizes in our dataset. Properties range from small residential lots to a property 1500 hectares in size, from closely built homes to a property whose closest neighbor is 3 km away. For some, therefore, nearest-neighbor definitions include far-away neighbors that are not likely to influence outcomes, and for others, distance based definitions lump together entire

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[3] For discussion on neighbor choices and spatial weights, see Cressie (1993, pp. 384–385), Schabenberger and Gotway (2004, p. 18), Waller and Gotway (2004, pp. 223–225), Fortin and Dale (2005, pp. 113–118), O'Sullivan and Unwin (2003, pp. 193–194), and Banerjee et al. (2004, pp. 70–71).

communities where more fuel is likely to be on neighboring properties. Additional problems arise when we try to use our paired dataset because not all of the properties assessed by the wildfire professional completed a survey. We discuss these issues more thoroughly in the results section, but our general approach is to test several definitions of neighbor and a variety of weighting methods to check if results are consistent across approaches, or if they differ, to use that information to provide insight about neighbor-to-neighbor effects. We further address the issue of varied parcel size by comparing results for two subsets of our data, one subset with small parcels with neighbors, on average, within 60 m of each other (smaller than 0.1 hectares, or precisely, houses on less than 0.25 acres as the properties were measured in imperial units) and one subset with houses on more than 16 hectares (precisely, more than 40 acres). Owners of small parcels rely on neighbors to effectively create defensible space and may be more likely to show strategic behavior; whereas, owners of larger parcels can more effectively control the risk they face.

It is possible that clustering of mitigation actions between neighbors occurs not because of spillover effects for defensible space, but because of other spatial characteristics that are not accounted for in our model. For example, neighbors with similar risk preferences may also prefer similar housing characteristics; soil conditions and historic vegetation levels may affect current vegetation levels; or spatial proximity may create social norms, shared experiences, and shared knowledge. Such conditions lead to spatial dependence in the errors. We account for spatial autocorrelation with an error term of the form

$$\varepsilon_i = \lambda \sum_{j \neq i} w_{ij} e_j + u_i ; u \sim N\left(\mu, \sigma^2\right) \tag{5}$$

where a statistically significant λ indicates the presence of spatial autocorrelation.

We use a procedure for estimating regression coefficients that allows for both spatial lags and spatial errors simultaneously (Piras 2010). The procedure iterates between generalized method of moments and instrumental variable estimations for coefficients of spatial autoregressive models with heteroskedasticity. As a robustness check, we also test for the presence of spatial lags and spatial autocorrelation with tests that check for the presence of a spatial lag, a spatial lag in the presence of an omitted spatial error (robust spatial lag test), spatially correlated errors, and spatially correlated errors in the presence of an omitted spatial lag (robust spatial error test) (Anselin 1988, 2002; Anselin et al. 1996). Data manipulation and regression analysis are done in R (version 3.0.1, R Development Core Team 2005) using the sphet package (Piras 2010).

3 Study Area and Data

The primary area of concern for wildland fire is an area called the wildland urban interface (WUI). On an individual homeowner scale, the wildland-urban interface is an area where human-made infrastructure is in or adjacent to areas prone to wildfire. On a community scale, the interface is an area where conditions can make a community vulnerable to a wildfire disaster (https://www.srs.fs.usda.gov/factsheet/pdf/wui-varieddef.pdf). The WUI is one of the fastest growing areas of residential development (Martinuzzi et al. 2015) and accounts for over 38% of homes throughout the United States and over half of homes in 19 of the 48 contiguous states (Stewart et al. 2006). An estimated 72,000 U.S. communities, or about 65% of the American WUI, are in high-risk areas for wildfire (Theobald and Romme 2007).

Fig. 1 Map of Colorado and study area

In these communities, responsibility for risk mitigation and fire protection is shared between private residents and a patchwork of federal, state, and local agencies.

We focus on seven WUI communities in Southwest Colorado, spanning Delta, Gunnison, Ouray, and San Miguel Counties. These communities include the fire protection districts of Cedaredge, Crawford, Gunnison, Hotchkiss, Loghill Village, Paonia, and Telluride (Fig. 1). The vegetation varies from a mixture of grasses and sagebrush, pinion-juniper and Gambel oak, and mixed conifer, consistent with the elevation changes across the study area. The regional climate is dry with slow-growing vegetation. Fuels in the study area, therefore, did not change substantially during the assessment period. The leading cause of wildfires in the area is lightning, and all of the communities have an elevated fire risk as defined by their Community Wildfire Protection Plans (CWPPs) and the West Region Wildfire Council (WRWC) (2012). The communities generally had some standards in place related to wildfire and were part of community outreach efforts to reduce fuels. However, significant differences were observed for defensible space among properties in the communities; trying to understand these differences is the primary motivation for this research.

Led by the WRWC, each community underwent an assessment of wildfire risk that included property-level assessments of every privately-owned, residential parcel with a home larger than 800 square feet. During the assessment, each home in our study area was assigned to one of the following four categories describing their defensible space as measure by the distance from the home to dense vegetation: more than 150 feet; 31–150 feet; 10–30 feet; or less than 10 feet. We convert these categories into a continuous variable using the midpoints (i.e., 90, 20, and 5) of the defensible space categories and 200 as the distance for the “more than 150 feet” category.[4] The assessment also included the level of background fuels, dis-

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[4] We tested several specifications and cut-off points for vegetation distances. Ultimately, the results were very similar regardless of specification.

tance from dangerous topography, and property accessibility as explanatory variables. The level of background fuels was assessed based on the dominant vegetation of the surrounding properties, which influences the likelihood of wildfire spreading onto the property. Levels of background fuels are as follows: grasses, forbs, or tundra; light brush and/or small trees; dense brush or timber, down and dead fuel. For purposes of this analysis we included a dummy variable *BackgroundFuel* that equals one if fuels were either dense brush, timber, or down and dead fuel. Fire tends to move up steep slopes, putting homes near ridges, steep drainages, and canyons (so called dangerous topography) at greater risk of damages. The distance from dangerous topography categories in the assessment are as follows: more than 150 feet, 50–150 feet, and less than 50 feet. Properties less than 50 feet from dangerous topography were indicated with the dummy variable *Topography*. Multiple roads allow better firefighter access to the property. Difficult access and egress were measured with a dummy variable *NoAccess* if there was only one road in and out of the neighborhood.

The assessment was done by a wildfire professional familiar with the communities, using attributes related to wildfire risk and the likelihood of a home on the property surviving wildfire. The assessments for properties within a given community were completed within 1 month; assessments for all communities occurred between August 2011 and July 2014. In total, parcel level wildfire risk assessments were completed for more than 4600 properties. When possible, the professional assessment was done on the property with the resident present. WRWC sought permission to enter properties through numerous requests, including in-person at homeowners' association meetings, mailed postcards, email notices, inclusion in newsletters, and posted flyers. For interested residents, the wildfire professional provided in-person, step-by-step analysis of their property's wildfire risk with the opportunity to ask questions or describe the specifics of their properties. Remaining properties were either assessed without the homeowner present, or, when permission to enter was not received, assessed from public roadways, information on the county assessor's website, or with aerial photography. The data were geo-coded to identify neighbors and calculate distances between homes.

As part of those efforts, residents of each assessed property were also mailed a survey designed to collect information on their experience with wildfire, knowledge of wildfire risk, attitudes about wildfire, social interactions, information sources, incentives and barriers toward undertaking mitigation actions, and demographic characteristics. The survey, administered just after the professional assessments were completed, also asked residents to assess their property based on the same attributes related to wildfire risk that were assessed by the wildfire professional. The survey used slightly different wording than the professional assessment in an attempt to be as clear as possible. For example, the professional assessment measured defensible space using standards in Colorado State Forest Service Quick Guide Series FIRE 2012-1 (Colorado State Forest Service 2012). Homeowners may not know what defensible space is, much less be familiar with the Colorado State Forest Service's standards. The survey question, therefore, asked, "What is the closest distance from your house to overgrown, dense, or unmaintained vegetation?" and included the same distance categories as in the assessment. A similar approach was taken for all risk-related questions in the survey.

Of the 3862 initial surveys that were mailed, 351 were undelivered. An additional 58 surveys were completed by respondents reached by methods other than mail (e.g., community meetings, newspaper ads). Respondents in 1685 households completed the survey for a response rate of 47% (1685/[3862 + 58 − 351]). The data were then matched with county assessor data that included the square footage of the house and acreage of the property. Observations were dropped that did not have complete responses for all the variables of interest. The largest loss in observations occurred when matching properties from the risk assessment with county tax assessor data for square footage and acreage (491 observations dropped). The final dataset contains 3892 properties with professionally assessed data, 1451 of which also had matching survey responses.

4 Results

Table 1 summarizes results for both risk assessments. Associated variable names used in the analysis are shown in italics next to the risk category. Recall, *BackgroundFuel*, *Topography*, and *NoAccess* are binary, equaling one, respectively, for dense brush and/or dense trees; less than 50 feet to a ridge, steep drainage, or narrow canyon; and lack of multiple roads. The wildfire professional tended to credit homes with less defensible space than the households did and consider background fuels to be higher. Average defensible space was about 63 feet (19.2 m) in the professional assessment and 80 feet (24.4 m) in the homeowner assessment. If there is disagreement on objective factors that affect risk (e.g., how far dense vegetation is from the home), it is reasonable to believe that professionals and households also disagree on the subjective level of risk to a home. This gap between professionals' and the general public's risk perceptions has been observed elsewhere in the literature (Burton and Kates 1964; Lichtenstein et al. 1978; Slovic 1987; Olsen et al. 2017), and has been attributed to the complexity of hazards (Tversky and Kahneman 1974; Slovic et al. 1974) and the tendency for the public and professionals to attribute risk to different sources (Cohn et al. 2008). We explore that gap more fully in a companion paper (Meldrum et al. 2015). Here we merely point at that, if these differences affect how households perceive their risk, they may also affect how they respond to that risk. Importantly, the wildfire professional and households generally agree on distance to dangerous topography and the availability of roads for evacuation. Judging distance does not seem to be as much of an issue as interpreting wildfire fuels, which may point to an issue of shared (or lack of shared) understanding of fuels.

Descriptive statistics of the matched professional and household assessments are given in Table 2. Associated variable names used in the analysis are shown in italics next to the survey question. We focus on survey questions potentially related to the effect neighbors' actions have on household behavior. Survey respondents had slightly smaller lots and slightly smaller and less expensive homes than the community averages. Defensible space levels as measured by the wildfire professional, however, does not vary significantly between respondents and non-respondents. About half of all survey respondents reported talking to their neighbors about wildfire risk. Forty-seven percent of survey respondents report being very aware of wildfire risk when they moved in. A large percentage of respondents report taking action to reduce risk about the same time as their neighbor (36%), and a quarter of respondents report working on both their land and their neighbor's land. In all, just under half report having neighbors that have done something to reduce risk of wildfire, and a third report having at least one neighbor that is adding to their risk.

Table 2 also shows mean survey responses for the question about the chance wildfire will reach the respondent's property (*FireProbability*), and, if a wildfire reaches the property, the chance that the home will be damaged (*FireConsequence*). The average respondent reports about a 20% chance of a wildfire starting on or spreading to his or her property during the survey year, and should that happen, about a 40% chance that they would experience damages. While seemingly high, these homeowner-assessed probabilities are similar to those found by

Table 1 Percent of respondents in risk categories. Each question corresponds to an element of risk measured by the wildfire professional and household

	Results of professional assessment (n = 3892) (%)	Results of household assessment (n = 1367) (%)
What is the closest distance from your house to overgrown, dense, or unmaintained vegetation? *DefensibleSpace*		
> 150 feet	14	19
31–150 feet	25	40
10–30 feet	36	31
< 10 feet	24	10
Which of the following best describes the dominant vegetation on your property and those properties immediately surrounding you? *BackgroundFuel*		
Grasses	16	18
Light brush and/or isolated trees	27	48
Dense brush and/or dense trees	57	33
What is the closest distance from your house to a ridge, steep drainage, or narrow canyon? *Topography*		
> 150 feet	62	65
50–150 feet	23	17
< 50 feet	14	16
If the road you use to access your current residence was blocked due to a wildfire, is there another road you could use to get out of your community? *NoAccess*		
Yes	45	45
No	55	54

Olsen et al. (2017), in which survey respondents reported a 68% chance of a wildfire burning near their home in the next 5 years and a 31% chance of damages.[5]

Table 3 shows mean defensible space distances from both the professional assessment and the household assessment and mean probabilities for the *FireProbability* and *FireConsequence* questions. Means are grouped by answers to survey questions, and *p* values are given for tests that the mean values for defensible space are equal between the two response categories to show which variables may influence defensible space outcomes, perceived chances of wildfire, and perceived chances of damages. The comparisons reveal a complicated picture of beliefs about defensible space. Households who report being very aware of wildfire and those who report working with their neighbors to reduce wildfire risk report significantly more defensible space (86 ft. and 98 ft., respectively) than those who were less aware or who did not work with neighbors (76 ft. and 78 feet, respectively). These differences, however, do not show up when looking at the professional assessment. Households with neighbors who have done something to reduce risk of wildfire or who talk to their neighbors about wildfire risk report having more defensible space (83 ft. for those with neighbors that have taken action compared to 78 ft. for those without such neighbors, and 83 ft. for those who talk with neighbors compared to 78 ft. for those who do not), but the wildfire professional actually finds their defensible space to be smaller. Households who believe a neighbor is increasing their risk have less defensible space, according to both the professional and household

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[5] Note the difference in timeframes. Our survey asks about the chances of wildfire and damages during the survey year. Olsen et al. (2017) ask about the chances of wildfire and damages within the next 5 years.

Table 2 Mean values or distribution of professional and household assessments, with standard errors in parentheses

Defensible space assessed by wildfire professional (feet) *DefensibleSpace*	
All properties (n = 3892)	64.3 (31.4)
Survey respondents (n = 1367)	62.9 (30.8)
Defensible space self-assessed by homeowner	80.4 (66.4)
Size of parcel (acres) *LotSize*	
All properties	15.6 (86.4)
Survey respondents	13.4 (44.2)
House Size (sq ft) *HouseSize*	
All properties	2870 (3914)
Survey respondents	2577 (1657)
Assessed value of structure *HouseValue*	
All properties	\$651,001 (\$1330,920)
Survey respondents	\$499,301 (\$906,267)
Assessed value of land *LandValue*	
All properties	\$232,705 (\$345,454)
Survey respondents	\$187,003 (\$271,449)
Household income (n = 1183)	\$109,065 (\$79,885)
What do you think is the chance that a wildfire will start on or spread to your property this year? (0 = no chance; 100 = for sure) *FireProbability*	20.4% (17.8%)
If a wildfire starts on or spreads to your property this year, what do you think is the chance that your home will be destroyed or severely damaged? (0 = no chance; 100 = for sure) *FireConsequence*	39.1% (29.2%)
Joint probability of wildfire on property and damages to home (Calculated)	9.6% (13.3%)
How aware of wildfire risk were you when you bought or decided to rent your current residence? *RiskAware*	
Not aware or somewhat aware	52%
Very aware	47%
Have you ever talked about wildfire issues with a neighbor? *TalkFire*	
No	51%
Yes	48%
Have any of your neighbors done anything to reduce the risk of wildfire on their property?[a] *NeighborAction*	
No	28%
Yes	46%
Don’t know	26%
If any of your neighbors have taken action to reduce the risk, when did they undertake the action(s) on their property in relation to any actions you have undertaken? (n = 657)	
You have not taken any action	8%
They took action before you did	14%
They took action after you did	18%
They plan to take action	0%

Table 2 continued

You took action around the same time	36%
Don't know	25%
Have you ever worked with any of your neighbors to reduce the risk of wildfire on your property or that of your neighbors? (n = 662)	
No	60%
Yes, on your property	12%
Yes, on your neighbors' properties	4%
Yes, on both your property and your neighbors' properties	24%
Do you have any neighbors who are **not** taking action to address what you would consider sources of wildfire risk in the event of a wildfire (e.g., dense vegetation) on their property? *NeighborRisk*	
No	31%
Yes	34%
Don't know	35%

Variable names are given in italics

[a] The survey included the following language to define neighbor: "Please think about the properties across the street, next to, or bordering your property (may include vacant lots or publicly owned land). Even if you live on a large property and your neighbors are far away, the following questions refer to the owners/managers of these adjacent properties as your *neighbors.* The properties themselves are referred to as *neighboring properties.*"

assessments (58 ft. and 77 ft. for those with risky neighbors; 68 ft. and 92 ft. for those without such neighbors), which is consistent with strategic complements. Beliefs about the likelihood of a wildfire occurring on the property increase with awareness, neighbors who have done something to reduce risk and neighbors that increase risk, and among neighbors who talk about wildfire. Expectations about damages increase among those who were less aware of wildfire risk and for those who do not have neighbors who have reduced risk but report having neighbors who increase risk. In general, interactions with and perceptions of neighbors have a significant effect on both perceived and actual levels of defensible space, suggesting the formation of a shared reality among neighbors (Echterhoff et al. 2009).

Property size is an important determinant of mitigation actions, risk perceptions, and neighbor influences. Figure 2 shows the number of properties with neighbors within 60 m and within half a kilometer of their homes. Two-thirds of homes in our sample do not have any neighbors within 60 m of their homes; the other third have at least one neighbor within 60 m, which implies the recommended distance for defensible space spills on to neighboring properties. A third of homes in our sample have fewer than 8 neighbors within half kilometer of their home; a quarter of the sample has fewer than 5 neighbors; and 174 homes have no neighbors at all within half kilometer.

Table 3 shows that larger properties have significantly more defensible space than smaller properties (91 ft. compared to 51 ft.), believe there is a greater chance of a wildfire reaching their property, but believe the chance of damages is lower. Figure 3 shows correlations of neighbors' defensible space for different levels of k-nearest neighbors, calculated for all properties, the subset of the data with properties smaller than 0.25 acres (about 0.1 hectares), and the subset of the data with properties larger than 40 acres (a common size for large properties in western United States, roughly equal to 16 hectares). The small-property dataset has 719 properties; the large-property dataset has 377 properties. Smaller parcels have more highly correlated levels of defensible space than the overall sample for up to 7 neighbors, but less correlation with more distant neighbors. This could indicate spatial complements, but it could

Table 3 Mean defensible space, self-assessed chance of wildfire, and self-assessed chance of damages, by response categories to survey questions

	Defensible space, professional assessment (ft)	Defensible space, household assessment (ft)	Chance of wildfire (%)	Chance of damage (%)
How aware of wildfire risk were you when you bought or decided to rent your current residence? *RiskAware*				
Not aware or somewhat aware	59.4	75.7	19.9	40.8
Very Aware	64.1	85.9	21.0	37.1
p value	0.17	0.00	0.26	0.02
Have you ever worked with any of your neighbors to reduce the risk of wildfire on your property or that of your neighbors?				
Yes, on both properties	55.0	97.6	21.2	36.7
No	58.3	78.3	22.0	38.1
p value	0.55	0.00	0.65	0.59
Have any of your neighbors done anything to reduce the risk of wildfire on their property? *NeighborAction*				
Yes	56.8	83.4	22.3	36.9
No	65.6	77.8	18.8	40.9
p value	0.01	0.10	0.00	0.01
Do you have any neighbors who are **not** taking action to address what you would consider sources of wildfire risk in the event of a wildfire (e.g., dense vegetation) on their property? *NeighborRisk*				
Yes	57.5	76.6	25.2	43.1
No	67.5	91.7	15.7	32.0
p value	0.02	0.00	0.00	0.00
Have you ever talked about wildfire issues with a neighbor? *TalkFire*				
Yes	58.0	83.2	23.0	38.9
No	64.8	77.6	18.0	39.2
p value	0.05	0.11	0.00	0.88
Size of the property, from the county assessor data *LotSize*				
0.25 acres or smaller	50.9	73.9	16.6	47.8
40 acres or larger	91.1	115.5	21.8	31.1
p value	0.00	0.00	0.00	0.00

also indicate shared local norms and dominant vegetation that characterize neighborhoods. We can only speculate about the cause of the concave shape. It may be that a critical mass of neighbors is the key to tipping between an outcome with little defensible space and an outcome with increased defensible space. There is little correlation among neighbors' defensible spaces levels for large properties, and while smaller properties see a decline in correlation of defensible space as the number of neighbors considered expands, large properties actually see an increase. There may be an average or natural vegetation level that correlations for increasing number of neighbors is capturing. We revisit the role of property size in the regression results.

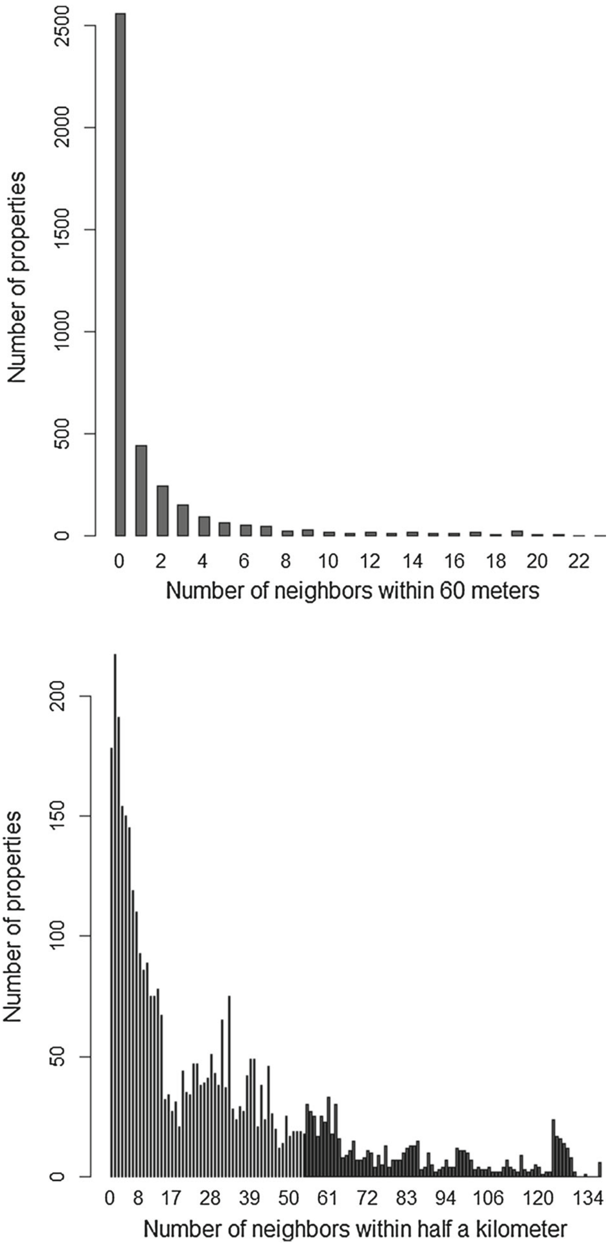

Fig. 2 Number of properties with neighbors within 60 m and within half a kilometer

We test more formally for neighbor influences in the full dataset using Lagrange multiplier tests (Table 4) for misspecification in the linear model. These tests check for spatial lags, spatially correlated errors, robust tests for each in the presence of the other, and a portmanteau test for both a spatial lag and spatial errors (SARMA). The Lagrange multiplier tests for simple spatial lag and spatial autocorrelation are both significant for a broad range of neighbor

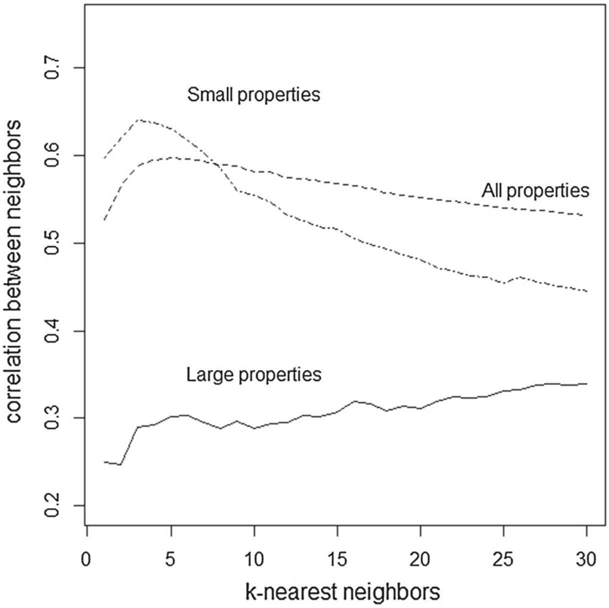

Fig. 3 Correlation of neighbors' defensible space for different levels of k-nearest neighbors. X-axis is k-nearest neighbor definition used to calculate correlation coefficients for defensible space

Table 4 Test statistics for Lagrange multiplier tests for spatial lag and spatial errors. All tests gave significant at 1%

	5 neighbors	10 neighbors	Inverse distance	Inverse distance squared	Sphere of influence
Lagged dependent variable	851.5	988.3	1205.6	887.8	573.7
Spatially correlated errors	883.4	1186.4	1403.3	897.7	550.1
Robust lagged dependent variable	34.7	22.2	33.5	37.1	33.3
Robust spatially correlated errors	66.6	220.3	231.2	47.1	9.7
SARMA	918.1	1208.6	1436.8	934.9	583.4

definitions. The robustness tests show that when the lagged dependent variable is accounted for, there is still a significant amount of correlation in the errors, and when the lagged errors are accounted for, there is still a significant spatial lag. All tests were significant at the 0.01 level. We, therefore, use an econometric model that accounts for both spatial lag and spatial error simultaneously (Piras 2010).

Table 5 shows the results for regressions using data from the professional assessment. These models and data are similar to those used in Shafran (2008) and Taylor et al. (2013), which both use professional assessments. In all specifications except the sphere of influence weights matrix, the spatial lag and spatial error terms are statistically significant and positive, indicating both spatial complements and spatial clustering in the errors. The sphere of influence criterion puts more weight on nearby properties than do the other weight criteria. The average number of neighbors using a sphere of influence definition is 3.4 neighbors. Larger homes on larger properties have more defensible space, perhaps indicating more available resources to undertake defensible space, a greater ability to remove trees without affecting the secluded or forested feel of their property, more control and responsibility for the ignition zone since they do not share it with other neighbors, and more values at risk of wildfire. Properties with high background fuels (*BackgroundFuel*) and near dangerous topography (*Topography*) tend to have less defensible space, compounding their risk of wildfire. These results are consistent with those in Shafran (2008), who found evidence of spatial complements and that defensible space increases with lot size and house size, and with Taylor et al. (2013), who found evidence of spatial complements and that some heavy background fuels led to less defensible space.

The last two columns of Table 5 show the regression results for the subsets of small and large properties using 5-nearest neighbor definitions of neighbor. Coefficients on both the spatial lag and spatial error term for the small properties are significant and larger in magnitude than those for the entire dataset. Neither coefficient, however, is significant in the subset of large properties. Large properties have more control over their defensible space and wildfire risk, and we fail to find evidence of neighbor-to-neighbor influences in that subset. Interestingly, the only significant effect we find on road access appears in the subset for large properties. Large properties without adequate escape routes tend to have more defensible space.

Models in Table 6 incorporate data from the survey. Incomplete coverage precludes the use of a spatial econometrics model with the survey data. Instead we used fixed effects for each fire district and a *Lagged Neighbors* variable equal to the average amount of defensible space of the 5-nearest houses, as measured in the professional assessment. That is, the value of *Lagged Neighbors* has the same value as the weighted lagged term in the 5-neighbors model in Table 5, and its coefficients in the defensible space models have the same interpretation as ρ. Due to space, the fire protection fixed effects are not shown in Table 6, though they were included in the models and were statistically significant, indicating vegetation levels may be characteristic of the neighborhood the home is in.

The coefficients on the spatial lag and neighborhood fixed effects are significant in most models, with the effect on *Lagged Neighbors* positive in models of defensible space and negative in models of chance of wildfire occurrence and damages. The survey results, therefore, suggest a spatial lag with strategic complements and some spatial endogeneity of defensible space levels. Homeowners that maintain their own defensible space are more likely to have neighbors that maintain their defensible space, and homeowners that fail to maintain their defensible space are more likely to have neighbors that fail to do so as well. Almost none of the survey responses were significantly correlated with either professionally assessed or the household assessed levels of defensible space. The one exception was risk awareness, which is associated with more defensible space as assessed by the households but not as assessed by the wildfire professional.

Coefficients on survey response variables were statistically significant in models of chances of wildfire occurrence and damages, which address perceptions about the chance of wildfire reaching the property and the chance of damages should wildfire reach the property. The negative coefficients on *Lagged Neighbors* indicate that more defensible space is correlated with lower expectations that a wildfire will reach the property and cause damages. High background fuels are positively correlated with perceptions of both the chance of a wildfire and the chance of damage, as does believing a neighbor is increasing risk. Larger homes and lot sizes decreased both expectations. Lack of access to the property and talking to neighbors about wildfire are associated with higher perceptions that wildfire will start or spread to the property. Risk awareness and having neighbors that took action reduce the perceived chance of damages should wildfire reach the property. People with large lots and

Table 5 Regression models of defensible space

Weight matrix	5-nearest	10-nearest	SOI	Inverse distance	Inverse square distance	5-nearest (small)	5-nearest (large)
ρ	0.2*** (0.1)	0.4*** (0.1)	0.1** (0.1)	0.6*** (0.1)	0.2*** (0.1)	0.3* (0.1)	0.27 (0.2)
λ	0.4*** (0.0)	0.3*** (0.1)	0.3*** (0.0)	0.4*** (0.1)	0.4*** (0.0)	0.5*** (0.1)	−0.1 (0.2)
Intercept	64.2*** (4.2)	70.0*** (4.7)	71.4*** (4.2)	66.1*** (5.7)	58.9*** (4.4)	58.8*** (11.0)	98.5*** (20.0)
LotSize (Acres)	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	0.02 (0.02)	−4.36 (6.6)	−0.01 (0.01)
HouseSize (1000 sq ft)	0.4 (0.2)	0.5* (0.3)	0.3 (0.2)	0.5* (0.3)	0.4 (0.2)	0.4 (0.3)	−0.5 (0.01)
BackgroundFuel	−46.1*** (2.8)	−49.1*** (2.8)	−49.6*** (2.8)	−50.8*** (2.727)	−43.4*** (2.9)	−38.0*** (6.3)	−42.7*** (6.3)
Topography	−17.5*** (1.9)	−20.3*** (2.0)	−15.4*** (1.9)	−20.1*** (2.0)	−16.5*** (1.9)	−16.1*** (3.0)	−15.4* (8.7)
NoAccess	2.8 (2.0)	0.5 (2.2)	2.7 (1.9)	0.7 (2.3)	2.6 (1.9)	5.2 (4.9)	−17.7** (7.4)
Wald test that both ρ and λ are zero	486.2***	563.7***	331.0***	355.7***	458.4***	100.0***	3.3*

Coefficient values for regressions with standard errors in parentheses. Statistical significance codes are as follows: 10%* 5%** 1%***

Table 6 Regression models of professional assessment of defensible space, household assessment of defensible space, perceived chances of wildfire reaching the property, and damages occurring

Dependent variable	Defensible space, professional assessment	Defensible space, household assessment	Chance of wildfire *FireProbability*	Chance of damage *FireConsequence*
Lagged Neighbors	0.6*** (0.03)	0.1** (0.04)	– 0.02* (0.1)	– 0.06*** (0.02)
LotSize (Acres)	0.07** (0.03)	0.2*** (0.04)	– 0.01 (0.01)	– 0.05*** (0.02)
HouseSize (1000 sq ft)	2.5*** (0.8)	3.4*** (1.1)	– 0.5* (0.3)	– 2.2*** (0.4)
BackgroundFuel	– 36.2*** (3.4)	– 16.4*** (4.4)	3.6*** (1.1)	7.8*** (1.9)
Topography	– 19.1*** (3.9)	– 15.3*** (5.0)	– 0.3 1.3	2.3 (2.2)
NoAccess	– 1.1 (2.8)	1.5 (3.6)	2.3** (0.9)	0.1 (1.6)
NeighborRisk	0.5 (2.9)	– 5.5 (3.7)	3.6*** (1.0)	5.4*** (1.6)
TalkFire	1.7 (3.0)	5.8 (3.9)	1.9* (1.0)	0.02 (1.7)
RiskAware	2.0 (2.7)	7.9** (3.4)	0.2 (0.9)	– 2.6* (1.5)
NeighborAction	– 3.8 (3.0)	6.2 (3.9)	– 0.8 (1.0)	– 7.1*** (1.7)
Intercept	43.2*** (5.2)	64.2*** (6.7)	10.6*** (1.7)	47.6*** (2.9)

Models have fire protection district fixed effects variables that were statistically significant but are not included in the table. Coefficient values for regressions with standard errors in parentheses. Statistical significance codes are as follows: 10%* 5%** 1%***

large homes generally have more defensible space, and perhaps rightly so, perceive both the chance of wildfire reaching the property and the chance of damages should wildfire reach the property to be lower.

5 Discussion

Homes in the WUI generally have less defensible space than wildfire professionals would like. That does not in itself mean that levels of defensible space are less than optimal from the standpoint of the homeowners. Rapid growth in the WUI suggests people are willing to purchase homes in high risk areas. Any policy to affect mitigation levels on private lands would, therefore, have to convince residents that they misunderstood their risk, convince residents that they misunderstood potential damages, or change the incentives residents face. Generally, these policies assume a "risk perception gap" exists between the public and the professional firefighting community. This gap has been observed for hazards in general (Slovic 1987) and specifically for wildfire risks in WUI communities (Cohn et al. 2008; Champ et al. 2009; Gordon et al. 2010; Meldrum et al. 2013; Olsen et al. 2017).

It may be, however, that the level of defensible space is suboptimal from the standpoint of the homeowner. The existence of spatial complements suggests this may be likely either due to a coordination failure or due to heterogeneity among homeowners. One-third of our survey respondents report having a neighbor that they think is increasing their risk. Perceived likelihood of fire reaching the property and causing damages go up if a neighbor is perceived as not taking action. Those risk perceptions do not necessarily lead to observable changes in defensible space. Rather, the only consistent predictor we find for levels of defensible space on a given property is the level of defensible space on neighboring properties, at least for smaller properties. How residents respond to wildfire risk depends less on the physical processes that create the risk and more on individuals' perception of the risk and their ability to mitigate it. These influences disappear entirely on larger properties where owners are less dependent on neighbors to control their risk, tend to have more defensible space, and seem to be less influenced by neighbors' actions.

Others have stressed the role of personal ties, social norms, and camaraderie in coordinating mitigation actions (Collins and Bolin 2009; Winter et al. 2009; Bihari and Ryan 2012; McCaffrey et al. 2013). Even informal interactions increase wildfire awareness and small-scale collaborative efforts to reduce wildfire risk (Brenkert-Smith 2010). We find working and talking with neighbors about wildfire increase the amount of defensible space people think they have. Because they relate to physical and social structures, such effects may explain the persistent spatial autocorrelation in our models and give further support for community level mitigation efforts (McGee and Russell 2003; Brenkert-Smith 2010). Neighbors naturally share background fuels, topography, and preferences for house location. The evidence for spatial autocorrelation, in many cases, was stronger than the evidence for spatial lags.

Policies have attempted to overcome the risk perception gap and suboptimal levels of defensible space with direct regulation and fees for homeowners in high risk areas. California has statewide building code requirements and minimum defensible space standards that include a 100 foot buffer in very high wildfire risk areas. The state also levies a $150 firefighting fee on rural households that goes toward suppression and mitigation. Similar fees exist in Idaho, Montana, Oregon, and Washington. The Oregon State Department of Forestry maintains maps of high risk areas and establishes minimum standards for mitigating wildfire risk. Oregon homes in high risk areas are liable to inspection, and if fuels are too high on their property, the homeowner is given 2 years to meet the state standards. Fees for noncompliance can be up to $100,000. Colorado has rejected statewide regulation, but has proposed audits of homes in high risk areas that insurance companies could include in their underwriting activities. Colorado also subsidizes wildfire risk mitigation on private property through an income tax deduction of up to $2500.

Our results show that policies that are effective in getting single homeowners to mitigate risk may have benefits that spillover from that property. Neighbors may encourage each other, and can lead to landscape level changes. It is particularly important to target owners of properties with dense vegetation, who seem to be holding things back. Without time series data on mitigation levels, we cannot tell how quickly these social influences occur or exactly how targeting individual homeowners could aggregate to landscape level risk mitigation. Aerial photography data and the ability to analyze it, however, are becoming more and more available. We believe this is an important next step for research and that it is just a matter of time before all of the pieces for such analysis are in place.

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Appendix 1. Wildfire hazard structure survey used by West Region Wildfire Council

Access	
Structure address posted at driveway entrance?	
Posted and reflective	0
Posted, NOT reflective	5
Not visible from road	15
Ingress and Egress	
Two or more roads in/out	0
One road in/out	10
Width of driveway	
Greater than 24 feet wide	0
Between 20 and 24 feet wide	5
Less than 20 feet wide	10
Vegetation and topography	
Distance to dangerous topography	
More than 150 feet	0
50–150 feet	30
Less than 50 feet	75
Predominant background fuel type in neighborhood	
Light (grasses, forbs, tundra)	25
Moderate (light brush, small trees)	50
Heavy (dense brush or timber, down and dead fuel)	75
Defensible space (CSFS 6.302 Standards)	
More than 150 feet	0
30–150 feet	50
10–30 feet	75
Less than 10 feet	100
Structure	
Roofing material	
Tile, metal, asphalt	0
Wood (shake shingle)	200
Building exterior	
Non-combustible siding (stucco, cement/Masonite)	0
Log, heavy timbers	20
Wood, vinyl, or wood shake	60
Location of woodpiles and combustibles (light flashy vegetation, shrubs, trees, trash)	
None of more than 30 feet from structure	0
10–30 feet from structure	10
Less than 10 feet from structure	30
Balcony, deck, or porch	
None/non-combustible	0
Combustible material	20

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