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Carolyn Kousky, Sheila Olmstead and Roger Sedjo
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1. Introduction

Wildfires in the United States generate annual emergency suppression expenditures at the federal and state levels reaching into the billions of dollars, as well as economic damages for insured and uninsured losses (and loss of life) on an even greater scale. The impacts of wildfires on human life (both homeowners and firefighters), built structures, and natural resources have drawn significant public attention to this issue in recent years. The Station Fire north of Los Angeles that began in August 2009 required fire suppression expenditures of more than $100 million, killed two firefighters, burned many civilians, and destroyed about 90 homes. The 1991 Oakland/Berkeley Hills fire, the costliest in California's history, killed 25 people, injured 150, and did an estimated $1.5 billion in damage (Carle 2002). The subject is of international importance, as well. In February 2009, more than 200 people were killed when brushfires in Australia burned out of control through residential areas. Forest fires in southern Greece in the summer of 2007 killed 84 people. In the summer of 2010, wildfires in Russia caused billions of dollars of damage and, later that same year, the worst wildfire in Israel's history burned thousands of acres and killed more than 40 people.

Despite these high-profile events, land development in the wildland-urban interface (WUI), where housing and fire-prone vegetation mix or exist in close proximity, has proceeded at a rapid pace. In 2000, 12.5 million U.S. homes were located within the WUI, a 52 percent increase over 1970, and a substantial majority of these (65 percent) were in high severity fire regime classes (Theobald and Romme 2007). This trend is likely to continue; U.S. land in developed uses is expected to increase by 70 million acres between 2003 and 2030, with the largest fraction converted from forests (Alig and Plantinga 2004). While the extent of the WUI can be a large percentage of a state's area in the east, California has the highest number of homes in the WUI (Radeloff *et al.* 2005), which, along with fire risk, often makes this state of particular concern, although the problem in the United States is not isolated to California or the West.

While empirical economic analysis should have much to contribute to the challenging questions regarding the interaction of wildfire risk and household behavior, the existing literature on the topic is thin. Most chapters in this book enhance our understanding of the social and institutional problem of managing fire through theoretical modeling and qualitative description of important economic and legal issues. This chapter focuses, instead, on the significant potential contributions of empirical microeconomic analysis to the understanding of the impacts of fire risk and fire policy on household behavior, and vice-versa, which have important implications for social welfare.

We examine several key questions at the intersection of private homeowner behavior and wildfire that deserve greater attention from empirical economists. Section 2 introduces each of these topics in turn, discussing the nature of the empirical relationships predicted by economic theory and what is currently known from the literature. We then turn in Section 3 to identifying the challenges for conducting new empirical research in these areas, and how they can be overcome. We conclude by discussing how the empirical analyses we recommend can inform public policy decisions regarding wildfire management.

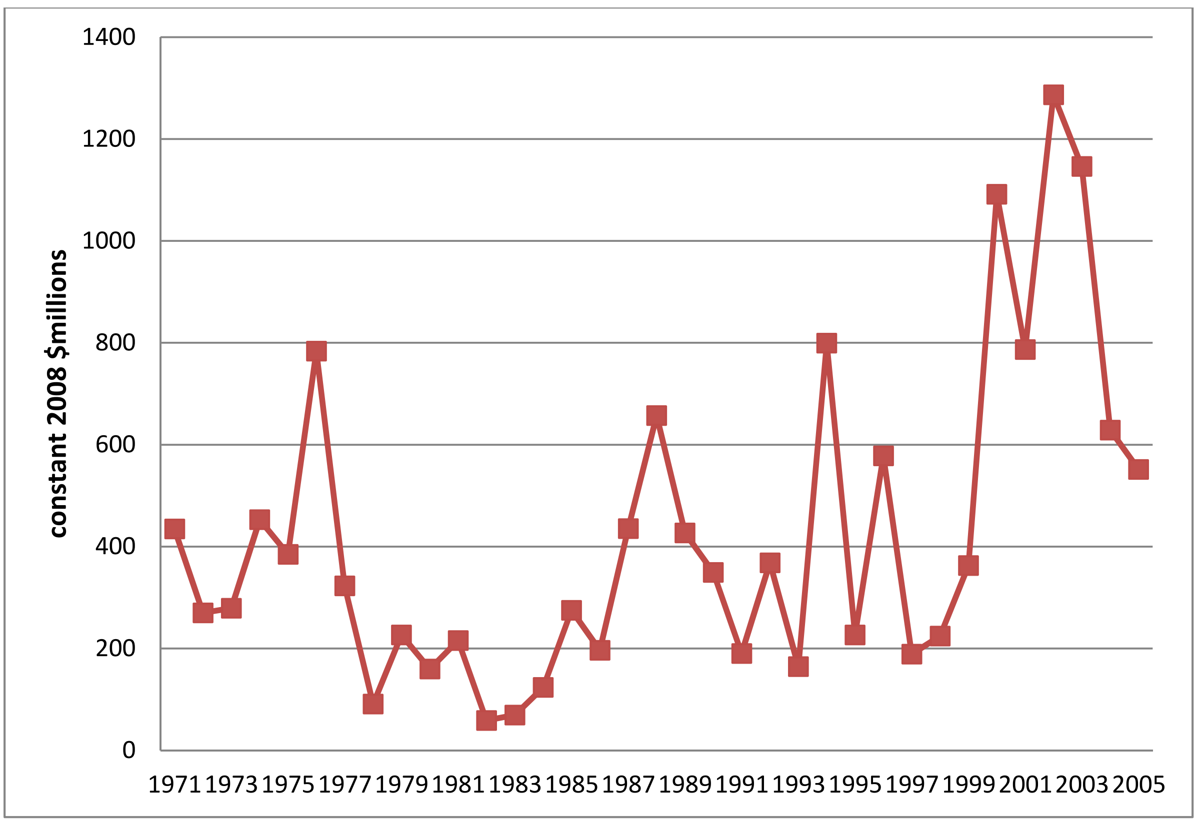
2. Homeowners and Wildfire: Four Research Topics

In this section, we consider four key economic issues regarding household behavior that, if examined empirically in greater depth by economists, have the potential to improve the efficiency of wildland fire policy: (1) the possible incentive for development provided by fire suppression, (2) the links between information disclosure about fire hazard and household location decisions, (3) the importance of private insurance markets in generating efficient fire policy outcomes, and (4) free-riding in household private mitigation expenditures.

*2.1 **Land Development and Wildfire Suppression***

Natural and social science research has focused on the increasing incidence of large wildland fires in the western United States (Allen *et al.* 2002; Whitlock 2004; Westerling *et al.* 2006).[1] Mirroring this trend, and the trend in damages discussed in Section 1, annual federal fire suppression costs in the United States have increased significantly since 1970 (Calkin *et al*. 2005).

Figure 1. USFS Annual Fire Suppression Expenditures, 1971-2005



Source: Graphed by the authors from data made available by the U.S. Forest Service, Rocky Mountain Research Station, converted to constant dollars.

Figure 1 illustrates the increase in suppression expenditures over the past 35 years by the U.S. Forest Service (USFS), which receives about 70 percent of the funds appropriated by Congress for wildfire preparedness and operations. During the decade ending in 1980, USFS spent $340 million per year, on average, fighting fires. For the decade ending in 2005, expenditures averaged $685 million per year, with annual expenditures in three of those years exceeding $1 billion (Calkin *et al*. 2005).[2]

These trends could be explained by more development in the WUI, which can contribute to increases in fire incidence (Cardille *et al.* 2001), by climate change (Westerling *et al*. 2006), as well as by the effects of decades of suppression itself, which increases the intensity of fires in some ecosystems through fuel buildup (Prestemon *et al.* 2002). Development also raises suppression costs, since firefighting is complicated by development (Gill and Stephens 2009).[3] Some have suggested that incentives within the Forest Service, itself, which has by necessity shifted away from resource extraction since the 1990s (Thomas 2000) and now finds a significant portion of its budget devoted to suppression efforts, play an important role in the escalation of these costs (Lueck, this volume).[4] It is also possible that federal fire suppression efforts, themselves, contribute to increased development in fire-hazard areas, further increasing costs.

Intuition from Economic Theory

Public suppression activity is an implicit subsidy, driving a wedge between private benefits and costs in household and firm location decisions (Kousky and Olmstead 2010). Since the benefits of development in forested and fire-prone regions are enjoyed by landowners, if the costs of fire suppression, when fires occur, are borne by taxpayers at large, excessive development will result. The implicit subsidy represented by public fire suppression may skew land use toward residential and other development, further increasing both the costs of the next fire (because additional structures and populations are now affected) and the costs of future suppression (because it is more difficult and dangerous to fight forest fires when structures and people must be protected). When combined with the known effects of climate change and fuel buildup, the effects of induced land development on suppression expenditures may be very important.

Conclusions from Related Literature

Economists have shown in other contexts that this disassociation of the benefits and costs of locating in a hazardous area can lead to an overinvestment in risky locations (Krutilla 1966), a phenomenon that has been called the "safe development paradox" (Burby 2006). For example, subsidies that reduce crop insurance premium rates below actuarially fair levels may increase the amount of land farmers cultivate, and agricultural disaster payments have a similar effect (Goodwin *et al*. 2004, Wu 1999). Such induced development has not been found in coastal areas behind shoreline protection, likely due to the high amenity values of locating on the coast (Hillyer *et al*. 1997, Cordes and Yezer 1998). Examination of coastal areas, does, however, suggest that the availability of flood insurance through the National Flood Insurance Program may spur development, and certainly does not hinder it (Cross 1989, Cordes and Yezer 1998).

Subsidized insurance is not the only means through which governments may induce land development in hazard-prone areas. Consider the fact that the construction of flood control and drainage infrastructure by the U.S. Army Corps of Engineers caused 30 percent of the observed conversion of land from forested wetlands to agricultural use in the Mississippi Delta between 1935 and 1984 (Stavins and Jaffe 1990). Through direct expenditure on risk reduction, the public sector provides an implicit subsidy for development. In the case of fire, the welfare costs of this activity include not only rapidly escalating suppression costs, but also the fire losses attributable to the subsidy (lives, structures, and natural resources) and other social costs of excessive land conversion.

Research by economists is beginning to investigate this potentially critical link between fire suppression and development, and suggests that suppression does induce some development (Kousky and Olmstead 2010).[5] As with all natural hazards, the degree to which the public sector subsidizes fire risk reduction may vary depending on the distribution of land ownership within a region. For example, a large private landowner may internalize the costs of wildfire risk by engaging in its own suppression or mitigation activities (Lueck, this volume). Small-scale landowners may, likewise, contract to divide up responsibility for providing these public goods (Yoder, this volume; Bennett, this volume). Such contracts, like all Coasian solutions, are less likely to arise among a large number of small private landowners, or in any other case in which transaction costs are high. If fire suppression and mitigation activities are impure public goods (offering some private benefit, as well as pure public benefits), then, in theory, federal suppression activities could either crowd in or crowd out such spending (Kotchen 2005). In Australia, it appears that a greater state role in fire management may crowd out private provision (Bennett, this volume).

2.2 ***Disclosure of Fire Hazard Information***

Several states have enacted policies that disclose fire hazard information to homeowners. For example, following the 1991 Oakland Hills fire, California required its Department of Forestry and Fire Protection (CalFIRE) to identify Very High Fire Hazard Severity Zones (VHFHSZs). Maps designating these zones were made in 1996 and updated in 2008. A disclosure law passed in 1998 addressing multiple natural hazards requires sellers of property in

VHFSZs to disclose to buyers the fire risk. As another example, under Oregon's Forestland-Urban Interface Fire Protection Act, sellers must disclose if a property is located in a forestland-urban interface area.[6] The Act may also require landowners to create fuel breaks along property lines and roadsides, the size of which varies by fire risk classification, which ranges from "low" to "extreme."[7] Several other states have developed fire hazard rating systems that can be applied by local land-use and fire-management officials to map fire risk within their communities.[8] The extent to which this information is easily available to landowners varies by state, an interesting source of variation that could be exploited for empirical analysis of the effectiveness of such policies.

Intuition from Economic Theory

The risks of natural disasters, such as wildfires, earthquakes, and floods, represent disamenities, and should be reflected in home prices and, thus, development patterns, to the extent that the buyers and sellers of property can accurately assess risk. However, if landowners are mistaken in their understanding of the risk they face, they will not fully internalize expected costs. Underestimation of wildfire risk by WUI homeowners is well documented (Beebe and Omni 1993, Kumagi *et al*. 2004, Cohn *et al*. 2008). In theory, this will lead to inefficiently high levels of development and inefficiently low levels of risk mitigation, such as the creation of defensible space in wildfire-prone regions. Property values will be too high, and development patterns may be skewed toward more "safe" uses (e.g., residential) than would occur if the true risk were known. If information disclosure induces an upward correction to landowners' risk perception, the effect should be empirically measurable as a drop in home values or land prices, or a shift in development patterns.

Conclusions from Related Literature

As theory would predict, disclosure of risk information alters consumer behavior in many different settings. Mandatory food safety labeling, such as mercury advisories for fish consumption (Shimshack *et al*. 2007), nutrition labeling (Brown and Schrader 1990, Foster and Just 1989), and the surgeon general's tobacco warning label (Sloan *et al*. 2002, Fenn *et al*. 2001) provide several examples that have been examined empirically. The findings from the literature on these types of information disclosure programs indicate that consumers react rationally to quality or hazard labeling (reducing consumption of "bads" and increasing consumption of "goods") in many, but not all, cases.

The literature on land development patterns and risk information is much less substantial. One survey found that disclosure of earthquake information did little to alter home purchases (Palm 1981). Another suggests that after the provision of information about relative earthquake risk by California in the late 1970s (and the requirement that prospective buyers be notified of a property's location within a zone of heightened risk), individuals paid relatively less for homes in more earthquake-prone areas in Los Angeles County and the San Francisco Bay-area, suggesting that home prices do capitalize earthquake risk (Brookshire *et al*. 1985).[9] Flood risk has been found to be capitalized into property prices, and major flood events can lower home prices, suggesting an updating of risk assessments by homeowners (Bin and Polasky 2004, Carbone *et al*. 2006, Kousky 2010). Of course, homeowners may over- or under-estimate risk, so the simple observation of capitalization of risk into prices does not necessarily imply an efficient market. It does, however, indicate they are aware the risk is not zero.

Previous studies of wildfire risk and housing prices suggest that homeowners do recognize the risk of wildfire in the WUI in the aftermath of a fire event or when information about risk is readily available. For example, home prices in a community two miles from a major wildfire that burned 12,000 acres in Colorado experienced a 15 percent drop, which can be explained by a change in risk perceptions and decreased amenities after the fire in the surrounding region (Loomis 2004). The Colorado Springs fire department rated the wildfire risk of 35,000 parcels of land in the WUI (using information on the construction material of structures as well as proximity to dangerous topography and flammable vegetation), and made risk information available on the internet beginning in 2002 (Donovan *et al.* 2007).[10] The availability of risk ratings online in this case seems to have enabled the capitalization of wildfire risk into housing prices, at least in the short run. Evidence from California suggests that the combination of hazard disclosure and a recent fire are both necessary for a decrease in property prices due to wildfire risk (Troy and Romm 2006).

From these studies, it is clear wildfire risk information can be capitalized into housing prices, but does it alter development patterns, and if so, how? Theoretical models and simulations suggest that development patterns should be impacted by hazard designations (Xu and Wu 2009). There is some suggestive evidence from California that a high fire-hazard designation lowers development. In state responsibility areas (non-federal, non-incorporated land where primary responsibility for fire suppression lies with the state), the fire hazard determinations made by CalFIRE represent the official public estimation of risk. In so-called Local Responsibility Areas (LRAs), CalFIRE provided suggestions of what land should be designated as a VHFHSZ based on fuels, fire history, terrain influences, housing density, and occurrence of severe fire weather, and then local jurisdictions were allowed to alter or reject these maps. Many communities chose to alter or reject the maps, suggesting they believe the stigma of hazard designations would reduce development and lower property values (Troy 2007). For example, despite the fact that the devastating 1991 Oakland Hills fire was the impetus for the legislation, Oakland Hills removed all designations of VHFHSZs in its jurisdiction and eliminated ordinances that had required setbacks and other protective measures (Lefcoe 2004, Troy 2007).

2.3. Insurance for Wildfire

Many homeowners at risk of wildfires may choose to insure their property against damage. In most places, wildfire damage will be covered under a traditional homeowners policy. In very high risk areas, homeowners may instead need to purchase a specific wildfire policy. Premiums will generally be higher in the highest risk areas, and many insurers may make coverage conditional on certain mitigating actions or offer discounts to homeowners who reduce risks. Inspectors can be sent to homes to ensure compliance.

Intuition from Economic Theory

Economic theory predicts that a risk-averse homeowner, maximizing their expected utility (the sole function of which is wealth), will fully insure when the premium of the insurance equals the expected loss. Of course, in practice, private insurance costs more than the expected loss, but levels of risk aversion are often high enough to cover this difference. Further, homeowners insurance is usually required by mortgage lenders. For these reasons, theory would predict that the cost of insurance is internalized by homeowners when making location decisions (assuming they are aware of the rates before purchase). In areas where the risk of damage from wildfire is greater, policies will cost more, reflecting that higher level of risk. This should lead to higher prices and different development patterns than in low-risk areas, all else equal.

In some cases, however, the rates homeowners face may not adequately reflect this risk, distorting decision-making in ways similar to the case of inadequate information or subsidized suppression, both described above. Insurance prices are regulated by the states, and some insurance commissioners may artificially compress rates — allowing less spatial differentiation than a company may desire — introducing some cross-subsidization into insurance markets. They may also suppress rates, capping the premiums insurance companies can charge. Some very high risk areas for other perils, such as the Gulf Coast areas at risk of hurricanes, have seen problems in insurance markets when states restrict the ability of insurers to charge prices they think reflect the risk or when homeowners balk at high prices in risky locations. In many of these instances, the state has stepped in, offering insurance-of-last-resort to homeowners, often at artificially low prices.

California offers wildfire coverage to homeowners through its Fair Access to Insurance Requirements (FAIR) plans. FAIR plans were established following riots and civil disorder in the late 1960s. States that offered FAIR plans were provided with federal riot insurance. Many of the programs have expanded to offer broader lines of coverage to homeowners that cannot find a private policy. In most areas of California, FAIR coverage is only available to those residents that have been turned down by private insurance companies, and the wildfire coverage is only available in certain high-risk areas. By offering coverage in locations that the private sector deems too risky to insure – indeed, in areas where some insurers dropped policies after large fires made them wary of the underwriting the risk – this practice subsidizes development in risky locations (Troy 2007).

Some insurance companies offer reduced premiums to homeowners that adopt risk-mitigating activities. State programs may do this, as well. For example, California's FAIR plan provides lower rates for homeowners that clear brush or have an approved roofing material, to induce adoption of such practices by homeowners. Whether these spur additional investment in risk reduction depends on the magnitude of the expected savings compared to the cost of the investments. Further, many other variables may influence a homeowner's decision to adopt risk mitigation measures, as discussed further below.

Conclusions from Related Literature

American insurance markets, including pricing, are regulated by the states. Insurance companies have been moving to more detailed modeling of wildfire risk using GIS technologies. This allows them to combine information on vegetation, topography, climate, building codes, accessibility, and details of the home to generate property-specific rates (Miller 2007). However, in other settings, some state insurance commissioners appear to weight low prices and availability of policies more heavily than solvency considerations or management of catastrophe risk (Klein and Wang 2007). As noted above, this may lead to rate compression and suppression, potentially leading to lower home prices and excess development.

Subsidized insurance for other natural hazards, such as floods and droughts, influences land development, particularly for agricultural and residential use (Galloway *et al.* 2006). As mentioned earlier, subsidies that reduce crop insurance premium rates below actuarially fair levels may increase the amount of land farmers cultivate; agricultural disaster payments have a similar effect (Wu 1999, Goodwin *et al*. 2004). There has been little empirical work, however, on the effects of subsidized insurance on development in fire-prone regions.

Insurance may, however, play a limited role in decision-making if homeowners are unaware of the difference in premiums between high and low risk areas until after they have closed on a property. For instance, one study found that in Boulder, Colorado, a majority of home buyers did not know of the flood risk or the cost of flood insurance until the time of closing or later (Chivers and Flores 2002). Without such information known *ex ante*, homeowners will not make substantively different decisions.

2.4. Private Fire Risk Mitigation and Free-Riding

In addition to location decisions and the purchase of insurance, there are several actions that homeowners can take to reduce the risk of fire damage to their home. These include clearing areas of defensible space around the home and choosing fire-resistant building materials. At the community level, actions such as making roads easily accessible to fire-fighting crews can also reduce the risk of damage.

Intuition from Economic Theory

Risk-reducing activities like these generate both private goods (in the form of reduced risk of personal damage from fire) and public goods (in the form of reduced risk to one's neighbors). Public goods are non-excludable, meaning it is impossible to prevent others from consuming the good, and non-rival, meaning one person's consumption does not diminish another's. Economic theory predicts that individuals will under-invest in public goods, "free-riding" on the investment of others. Just as in the case of suppression, private homeowners do have an incentive to create organizations that capture some of the potential benefits from increased public good provision through private contracts (Lueck, this volume). However, private markets will generally provide less than the efficient quantity of public goods. With respect to reducing fuel loads, homeowners may not only free-ride on their neighbors' actions, but also on those taken by subdivision associations, city and county governments, state governments, and federal agencies.

Conclusions from Related Literature

Though none of the research topics we cover in this chapter have received significant attention from empirical economists, the question of private homeowner investment in fire risk mitigation has generated a greater deal of research than the other three topics. Economists have noted the propensity for homeowners in fire-prone areas to under-invest in averting activities such as fuel treatment and the development of "defensible space", although a key explanation here appears to the be the public good nature of these investments. For example, a household's defensible space decision in Boulder County, Colorado, appears to depend on defensible space outcomes at neighboring sites (Shafran 2008). Research on other hazards suggests several additional reasons why homeowners may under-invest in risk reduction measures, including an underestimation of the probability of a loss, budget constraints, myopic behavior, and not wanting to be the only one in their neighborhood adopting such behavior (Kunreuther 2006).

Unlike private mitigation activities for other natural hazards (e.g., earthquakes), mitigation to reduce the risk of wildland fire may involve activities that reduce household utility by diminishing the amenity values of a property – for example, felling trees near the home may reduce the quality of a view (Winter and Fried 2000). This provides an additional disincentive to invest in mitigation. These issues have been explored using game theory, experimental economics, and mail surveys of homeowner preferences (McKee *et al.* 2004; Holmes *et al.* 2009; Busby and Albers 2010).

In theory, the landowner's decision about the desired level of private mitigation should be made jointly with their decision about investment in private insurance. As the chapter by Jonathan Yoder points out, these choices are also made within the context of legal liability for mitigation, prevention and suppression activities. Talberth *et al*. (2006) find that households do, in fact, make investment decisions about wildfire insurance, private averting activities, and public mitigation at the neighborhood level jointly.[11] Insurance companies, themselves, have begun to recognize this fact – for example, as mentioned above, California's FAIR program, while subsidizing wildfire risk, has introduced economic incentives for the creation of defensible space, the use of fire-resistant building materials, and improved firefighter access (Monrovia Fire Safe Council 2004). Household investment in risk mitigation is, of course, also linked with the question of information disclosure addressed earlier. Providing households with information on their objective fire risk seems to reduce the number of households that over-invest in averting activities (those in low risk classes), as well as the number in high risk classes that are under-investing (Talberth *et al*. 2006).

3. Challenges for Empirical Work on Homeowners and Fire Policy

Several challenges plague empirical investigation of the topics discussed in Section 2, the most notable of which we will review here: endogeneity, data availability, sample selection, and determining the optimal level of public good provision. Some are challenges for research on all of the topics we discuss in Section 2, and others are specific to a subset of these topics. We discuss each of these challenges in turn in the paragraphs that follow.

3.1 The Challenge of Endogeneity

One key challenge for empirical work on household behavior and wildfire policy is endogeneity, a ubiquitous source of bias in statistical analysis. Trying to untangle the relationship between suppression policy and location decisions offers an intuitive example. Development may increase suppression efforts, because human-ignited fires are more common in developed areas, and fire agencies exert tremendous effort to protect structures, compared to areas with no development. But from a policy perspective, we may want to identify the opposite relationship – the causal impact of suppression on development. This problem of "reverse causality" can be overcome through the use of statistical natural experiments and quasi-experimental techniques. Exogenous variation in suppression efforts can be exploited to estimate the relationship between development and suppression.[12] Shifts in federal suppression policies over time have been used for this purpose, and preliminary analysis suggests that suppression does induce development on private land near federal land affected by federal fire suppression efforts (Kousky and Olmstead 2010). State-level variation in suppression efforts, or variation over time in the costs of suppression, could also be used for this purpose.

A related challenge is underlying heterogeneity across land parcels that may be correlated both with development (or another measure of land values, such as home prices) and with the wildfire policy of interest. In the case of wildfire policy, amenity values may play this role. Several of the characteristics that increase the risk of wildfire damage (such as location on a ridge, or the density of trees on a property or in nearby forested land) also have an amenity value, such as improving views, for example, or increasing access to recreation. Thus, the underlying variables of a wildfire risk index are likely to be positively correlated with home prices or development. Researchers may, thus, need to instrument for risk ratings to statistically identify the negative impact of information disclosure of a property's risk rating on market value.[13] As another example, amenity values are a source of positive correlation between insurance prices and home prices, again requiring an instrument for insurance prices. Identifying valid instruments can be difficult in practice.

3.2 The Challenge of Data Availability

The sparse availability of data on land use change over time impacts the possibility of new empirical work on each of the topics we broached in Section 2. Comprehensive land cover and land use data are a satellite-era phenomenon; the publicly-available land use data for the United States, for example, begin around 1970, and in most cases offer snapshots of land use over intervals of five years or more, with "current" observations lagging the present day by several years. The available time series on land cover have improved tremendously since 1970 in the fineness of spatial resolution (helpful in cases where policy shifts differ across small geographic units), but the temporal scale remains quite coarse. This is a real challenge for the natural experiments and quasi-experimental approaches needed to deal with the problem of endogeneity discussed above, in which we ideally would observe land use choices immediately before and after some important discontinuity over time.

Again taking the case of research on the impacts of fire suppression is instructive. The relatively “late start” of land use observations in 1970, relative to the onset of large-scale federal fire suppression efforts (around 1910), make questions about the impacts of early federal suppression policy on household location decisions statistically un-answerable. For post-1970 policy analysis, it must be true that the relatively large windows represented by the time-step of most land-use data overlap sufficiently with the policy change of interest, but not too much with other confounding policy changes; otherwise, the data cannot be used to assess policy impacts. For example, if you observe land use 1992 and 2000, but you want to assess the impact of a policy shift that took place in 1996, it is difficult to build a statistical case suggesting an effect of that policy change if the case cannot be made that no other important confounding events took place during that eight-year window.

On the positive side, current or relatively recent geographical information system (GIS) snapshots of land use are now available for most of the United States, opening up new opportunities for research. To examine trends in the WUI, such databases must also identify low density development. A new database, Land Cover Trends, from the U. S. Geological Survey, begins to help overcome these difficulties.[14] Land cover types include “developed” land, which comprises both intense urbanization and low-density residential development. Land cover is available for five observation periods between 1973 and 2000, ranging from six to eight years in length. As a substitute for land-use data based on satellite observations, some authors investigating wildfires have turned to Census data (Gude *et al.* 2008), which is available for much earlier periods than land-use data, though the 10-year temporal resolution is at least as coarse. At the level of the Census tract (or higher levels of aggregation), maps of housing density can be developed based on Census estimates. For the particular question of the impacts of fire suppression policies on development, land values or home values might prove to be a fruitful source of data, since they may be observed much more frequently than land cover (e.g., monthly). However, obtaining these data from private sources can be costly.

For many research questions, parcel level data would be ideal. Even if such data is available on home prices, it may not contain information on mitigating actions the homeowner has adopted and it certainly will not indicate if the property has wildfire insurance. Both private insurance companies and public programs are concerned about privacy issues in releasing property-level data. Without such information, research on the effects of insurance on mitigation decisions is difficult. In research on hazards other than wildfire, some progress has been made using insurance data aggregated to the census tract or another geographical unit. This may be possible for wildfire research, as well.

3.3 The Challenge of Selection Bias

A third challenge to empirical research is selection bias. Attempting to estimate the effects of risk disclosure on land development patterns provides an example. In California, communities could adopt, alter, or reject outright the maps that designated VHVHSZs. Any empirical assessment of the impact of disclosure on development would have to carefully control for this sample selection problem. Which communities chose to disclose the information to the buyers and sellers of land, which did not, and to what extent is the selection into disclosure, itself, correlated with development patterns? To the extent that this correlation exists, empirical estimates of the impact of disclosure on development that do not account for selection will be biased. Similar questions of voluntary disclosure have been examined in financial markets, environmental regulation, and other areas in which incentives to disclose clearly vary depending on costs. Selection is thus not an uncommon problem in empirical microeconomics and, while it is a valid concern, it can often be addressed econometrically.[15]

3.4 The Challenge of Determining the Optimal Level of Public Good Provision

A final challenge relates to research on all of the topics we have investigated in this chapter. Fundamentally, wildfire suppression, mitigation, and information provision are public goods. And determining the optimal level of public goods provision is a classic problem in microeconomics. The demand curve for a public good sums over the willingness to pay of all parties benefiting from the good, but consumers' true willingness to pay is difficult to estimate, for reasons related to free-riding, itself. If one conducts a survey, asking homeowners how much they are willing to pay for fire risk reduction through mitigation activities, and the survey respondents believe that they will realistically have to bear these costs in the future, and that the costs depend on their answer, their answer will lie below their true willingness to pay. If, on the other hand, they do not anticipate that their answer will affect their future costs, they will over-state their willingness to pay. This problem is a significant empirical challenge to establishing efficient public policies regarding public and private fire suppression and mitigation of fire risk – after all, if a state or local government cannot determine the optimal level of these activities, this is a difficult starting point for policy-making. Survey methods in economics, including contingent valuation, can be designed to reduce this bias.

Once efficient levels of suppression or mitigation have been determined, policies must be adopted to achieve these goals. It is in this process that the empirical research we recommend in this chapter may be most useful.

4. Potential Contributions to Public Policy from Empirical Research

U.S. western and southeastern states are plagued by annual fire seasons that put people (residents and firefighters) and structures at risk. The location of development, the mitigation and insurance choices adopted by homeowners, and the information available to homeowners about wildfire risk are undoubtedly behavioral determinants of the damages wildfires will cause. Applying empirical economic research to illuminate the impact of past, current and potential future public policies affecting homeowner decisions through these levers is key to improving outcomes.

Current fire management policy does not account for the possibility that suppression, itself, may draw additional people and structures into harm's way, though the opposite problem, the increase in suppression expenditures due to development in the wildland/urban interface, is widely recognized (U.S. Department of Agriculture 2006). Expanding our understanding of the potential of wildfire policy to affect development patterns is essential for informing suppression policies at the federal and state levels. Research on the impacts of suppression policy on location decisions is also tightly linked to the issue of disaster mitigation, more broadly, through the safe development paradox – an issue that is increasingly important as climate change is expected to increase the frequency and/or magnitude of many natural disasters (e.g., hurricanes, floods, and droughts), as well as wildland fires. Research in these areas can prove useful in both thinking about policy responses to the existing context, in which significant populations are already at risk, and policy strategies going forward (e.g., zoning), which may influence the direction of future land development so as to mitigate risk.

Over the past two decades there has been significant growth in the use of information disclosure programs as a method of environmental and natural resource management. Relatively little is known, however, about behavioral responses to information disclosure policies. Particularly when they do not mandate any particular behavioral change, disclosure policies may be more politically palatable than more prescriptive policies. If they do not provide new information or if the involved parties do not think the information is relevant, however, they may not be worth the cost. Essentially all of the public and private solutions to managing wildfire risk in the WUI rely on informed homeowners. Empirical research on the effectiveness of information disclosure policies with different characteristics can assist in the design of such disclosure policies for wildfire as well as other hazards, from flooding to earthquakes.

Following Hurricane Katrina there has been increased discussion at the federal and state levels of the role of the government in catastrophe insurance markets. In high risk areas, private insurance companies may choose to not offer policies if they cannot charge prices that will cover the risk. This has largely been a concern along the Gulf Coast with hurricane risk, but has anecdotally been a difficulty in some high-fire risk areas, as well. State insurance programs, such as the California FAIR program discussed above, often fill the gap. To date, in most of the country, availability of wildfire coverage has not been a problem. Should it become increasingly difficult for homeowners to find insurance, creating a large burden on states, the federal government may be called on to intervene. For example, a federal flood insurance program offers policies directly to homeowners, and a federal terrorism program offers reinsurance to private companies. Many government programs, however, shift some of the costs of residing in high-risk areas from those at risk to others in the state or country. Empirical research on how insurance availability, pricing, and mitigation incentives alter homeowner behavior can inform how the government should (or should not) intervene in the insurance market.

The basic idea of any policy for public goods provision is to better align private incentives with the common good. To overcome the free-riding challenge, many local and state governments in fire-prone regions simply mandate certain risk-reduction efforts by homeowners, though such policies often focus on the construction of new subdivisions in the WUI, rather than on the retro-fitting of existing development. To further determine optimal levels of public and private risk reduction investments or the nature and extent of mandates for such actions, empirical evidence on when and where free-riding is a problem in practice is needed.

Other approaches, which harness market forces more effectively than outright mandates, include reductions in insurance premiums to compensate homeowners for undertaking mitigating actions. For example, California's FAIR plan provides lower rates for homeowners that clear brush or have an approved roofing material. Another market-based incentive is a requirement that homeowners share some liability for the costs of suppression with the public sector, if private mitigation activities are not sufficiently undertaken, and fire ignition or spread can be reasonably attributed to a particular property – Oregon's Forestland-Urban Interface Fire Protection Act provides one example of this. Alternatively, the public sector can directly subsidize mitigation on private property. Empirical analysis suggests that both cost-sharing of mitigation activities and cost-sharing of suppression do provide incentives for fuel treatment by private non-industrial forest owners (Amacher *et al*. 2006).[16] Analysis regarding the effect of such policies, and the others we have discussed here, on private investment in fire mitigation by homeowners will inform policy formulation at the state and local level in the future, when development in the WUI will be even more extensive.

5. Communicating the Contributions of Empirical Social Science Research on Fire Policy

In this chapter, we have advocated for the increased application of the tools of empirical microeconomics to the subject of wildfire policy. Researchers bringing a social science lens to these questions operate within the context of many decades of work on fire science, and a public wildland fire policy apparatus that, to the extent that it draws upon peer-reviewed literatures at all in policy formulation, is grounded in the natural and physical sciences. If economists performing empirical analysis of policies regarding fire suppression, insurance, and the disclosure of risk information hope to influence the future direction of such policies, care must be taken to communicate results and underlying models in ways that are useful to policymakers who may be unfamiliar with our methods.

The central contribution that economists can make to policy analysis is a focus on causality above all else. Having operated since the beginning days of the discipline in a context in which observational data, rather than experimental data, is the subject of most analysis, the statistical techniques of modern micro-econometricians have evolved to wring convincing causal effects out of noisy processes. In most cases, we have no choice –the randomized controlled experiments that are the gold standard of the scientific endeavor cannot be conducted in most economic contexts.[17] Thus, statistical techniques must employ identification strategies that simulate the workings of an actual experiment, using observational data.

These techniques, while valuable for policy analysis, can seem opaque to bench scientists, who tend to focus on causality when running experiments, and description or prediction when using observational data. The analysis of observational data to estimate "associations," or correlational, rather than causal, relationships between two variables is not at all uncommon in natural and physical science research. In contrast, natural experiments in economics typically "clean" away the effects of possible confounding variables through the use of sets of dummy variables (fixed effects), so that the coefficients of interest identify causal relationships. In doing so, economists can be confident in delivering unbiased estimates of policy impacts to the policy process – no small contribution.

However, these models may have little or no other descriptive power. For example, Kousky and Olmstead (2010) estimate the determinants of residential development in forested areas using a set of instruments for public fire suppression policies, as well as sets of fixed effects representing each parcel of land, state, and year (as well as interactions between these covariates). Their estimates suggest causal impacts of public suppression activities on development. But one cannot easily retrieve from such a model the effects of things like transportation networks or economic growth on development – things that most educated laypersons would expect to see included. These variables, and everything else that might vary over time and space and be correlated with development, are subsumed by the fixed effects, so we can be certain that they are not confounding our main result. But this fact may seem opaque to practitioners of statistics outside of economics.

There is much that economists can do to bridge this divide. We can discuss clearly the ways in which modern microeconometrics attempts to replicate, to the extent possible with observational data, the design of randomized experiments. We can introduce descriptive elements into models that treat all possible confounding variables with generic fixed effects, by estimating second-stage models that decompose these fixed effects so as to reveal the influence on the dependent variable of particular covariates. We can be explicit about the limits of the causal effects we estimate, which may be valid only within a narrow range, or only in particular cases. Using these approaches may make it more likely that economic analyses will have an impact on public policy toward wildland fire suppression, mitigation, and risk management. This is a critical endeavor. In the absence of convincing and well-communicated work by economists on the behavioral aspects of wildland fire policy, analyses by natural and physical scientists, which tend not to consider household and firm behavior or other economic phenomena, will remain the only contributions that are called upon in policy formulation.

6. Conclusions

Wildfire risk management has not received the attention from empirical economists that it has from researchers in other disciplines. This is unfortunate, as we argue here, since empirical economic research has much to contribute to the topic and much to offer policymakers. Fire suppression, information disclosure, insurance, and mitigation policies all create incentives that influence landowner behavior. The goal of these policies is usually to reduce the risk of damage from wildfire but how well such policies do at achieving this goal, whether they have other unintended effects, and how they operate together are all questions that empirical economists can illuminate.

As discussed in this chapter, there are several challenges to addressing the many open research questions, perhaps explaining the relatively small literature to date. These include problems of endogeneity, limited data availability, and sample selection. These are not new problems to empirical economists, however. The focus of empirical economic research on establishing causality with observational data has led to the development of a host of tools that can be exploited to overcome these challenges. Coupled with new datasets, particularly GIS data on land use, much forward progress should be possible. With concerted effort on the part of economists at explaining their tools to policymakers and researchers in other disciplines, an improved understanding of the behavioral side of wildfire risk management can be developed, and used to improve future policy at the federal, state, and local levels.

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[1] About 60 percent of the observed increase in large wildfires since 1970 has occurred in the Northern Rockies, and most of the remaining increase in the Sierra Nevada, Southern Cascades, and Coast Ranges of northern California and southern Oregon (Westerling *et al*. 2006). While the increase in large western wildfire occurrence is well-documented, there is less agreement over the causes of this increase (Johnston and Klick, this volume).

[2] All fire suppression expenditures have been converted to constant 2008 dollars.

[3] An audit by the U.S. Department of Agriculture's Office of the Inspector General names WUI development, and the concomitant expectation of private property protection in suppression efforts, as the single biggest cause of increases in USFS large fire suppression costs between 2000 and 2006 (U.S. Department of Agriculture 2006).

[4] Several analyses have recently drawn attention to the weak incentives for cost containment in reactive federal fire suppression (e.g., National Academy of Public Administration 2002, Donovan *et al*. 2008).

[5] A growing literature models economically optimal public fire presuppression and suppression effort (Prestemon *et al*. 2001; Yoder 2004; Mercer *et al*. 2007) but does not account for the interaction with development.

[6] For a description, see http://www.oregon.gov/ODF/FIRE/SB360/sb360.shtml.

[7] This Oregon policy is also related to both the location decision research described earlier, and to fire insurance questions addressed later in the chapter. Once property owners have met the fuel-reduction standards required for their property under the Act, they obtain a certification form from the state Department of Forestry, which relieves the owner from liability for potential fire suppression cost recovery. If a landowner has property within the designated forestland-urban interface, but does not have a current certification for fuel reduction undertaken, the state can seek to recover some fire suppression costs (capped at $100,000), should a fire originate on the owner's property.

[8] For a comprehensive list, see Wildland/Urban Interface Fire Working Team (2008).

[9] The premium for a property located outside designated areas of higher earthquake risk was about one-half the value of a swimming pool, or one-third the value of a view (Brookshire *et al*. 1985).

[10] Risk ratings can be re-adjusted by the Department in response to homeowner investments in wildfire risk mitigation, such as the replacement of wood-shingle roofs with less flammable materials (Donovan *et al*. 2007).
[11] The analysis used a contingent valuation survey of just over 1,000 households near Albuquerque, New Mexico, and laboratory experiments which recruited 72 subjects for 15 rounds, each representing a year of household decision-making (Talberth *et al*. 2006).
[12] For a summary of the use of these methods in environmental economics and their advantages, see Greenstone and Gayer (2009).
[13] One solution is to estimate a hedonic price function that controls for the underlying variables used to assign disclosed wildfire risk ratings, as well as the ratings, themselves, as in Donovan *et al*. (2007).
[14] The database is a set of randomly-selected 10km x 10km sample blocks, with 30-40 sample bocks in each of the 84 Level III Ecoregions in the lower 48 states. See Loveland *et al*. (1999) for a description of the Land Cover Trends project. Additional information is available from the project's website: http://landcovertrends.usgs.gov.
[15] In at least one case, the selection problem has an upside – it may provide a source of variation that could be exploited by researchers. In California's VHVHSZ designation program, the fact that some jurisdictions altered these maps and some did not creates the opportunity to compare development on land that is technically high-hazard (as designated by CalFIRE) and in which the risk is accurately disclosed with land on which the risk is the same, but risk information is not disclosed to buyers and sellers of property. Whether estimating such a model, while also accounting for the bias introduced by selection, would be empirically tractable, is an open question.
[16] Government cost-sharing of private fuel reduction does not always reduce social losses in the simulations in this study, but it can yield bigger reductions in social damages than requiring cost-sharing of suppression when fire risk is high (Amacher *et al*. 2006).
[17] However, economists have also orchestrated an impressive and increasing number of actual social experiments, from early large-scale efforts such as the RAND Health Insurance Experiment of the mid-1970s (Newhouse 1993) and those involving the negative income tax, known today as the earned income tax credit (Ross 1970), to modern applications in labor (List and Rasul 2010), development (Banerjee and Duflo 2009), education (Angrist 2004), and other fields of economics (Levitt and List 2009).