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The Economic Incidence of Wildfire Suppression in the United States†

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This study measures the degree to which public expenditures on wildfire protection subsidize development in harm's way. We use administrative data on firefighting expenditures to measure the causal effect of nearby homes on the amount spent to extinguish wildfires. We use these estimates in an actuarial calculation yielding geographically differentiated expected implicit subsidies for homes across the western United States. The expected net present value of this subsidy can exceed 20 percent of home value, increases with fire hazard, and decreases surprisingly steeply with development density. We discuss potential behavioral responses by individuals and local governments using a simple economic model. (*JEL* D91, Q23, Q54, R52, R58)

Driven by climate change, land use decisions, and other factors, annual wildland firefighting costs for the US federal government have more than doubled in real terms over the past 30 years and are expected to keep growing.[1] During the fire season, tens of thousands of firefighters and many millions of dollars' worth of equipment are continuously dispatched throughout the United States, often with the goal of preventing damage to private homes. As we show, these costly efforts to avoid property damage represent a large share of the total cost imposed by wildfires. While much of the cost of defending threatened homes is borne by the federal and state governments, decisions about where and how to build these homes are largely made by localities and individual homeowners.

This allocation of costs and benefits has historical roots. Fire protection in US cities has long been provided by local governments, but fire management for the forests

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[1] National Interagency Fire Center (2021).

and grasslands that cover the rest of the western United States is the job of federal or state land management agencies, especially the US Forest Service (USFS). In recent decades, rapid development outside cities has added many homes near these wildland areas in the so-called "wildland–urban interface," or WUI (Radeloff et al. 2018). Compared to cities, fire hazard in the WUI is higher, on average, and more spatially differentiated. Predictably high-risk portions of this landscape—based on topography, vegetation, and climate—experience repeated, costly fires.

The combination of public fire protection and spatially heterogeneous risk has two implications. First, because the federal government bears much of the cost, wildland firefighting represents a transfer of wealth to homeowners in high-risk locations. Second, the guarantee of federal protection creates the potential for moral hazard. Homeowners do not internalize the expected costs of future fire protection when choosing where to live or how to design and maintain their homes. Perhaps just as importantly, local governments do not internalize these costs in zoning, land use, and building code decisions.

Firefighting costs represent a major component of the total social cost imposed by wildfires. Wildfires are unusual among natural hazards in that it is possible to prevent property damage during an incident through large investments of manpower and equipment. Unlike cyclones or earthquakes, for example, most wildfires that would otherwise threaten private property are extinguished through firefighting efforts that avert or dramatically reduce damages. From 1985 to 2019 total wildfire property damages in the United States were about $70 billion, while direct firefighting costs for federal agencies alone (which omit state and local costs) totaled $48 billion.[2] Public spending on floods, cyclones, and other disasters comes largely in the form of rebuilding grants or insurance subsidies to individual households. Identifying the beneficiaries of such spending is comparatively straightforward. Because wildfire spending comes instead through firefighting expenditures, understanding the beneficiaries of that spending requires a more involved analysis that has not previously been undertaken.

This study provides the first estimates of the geographically differentiated implicit subsidy to homeowners due to fire protection at the individual parcel level for homes throughout the western United States. We begin with a simple conceptual model of disaster protection spending and housing development decisions. We then set out to estimate the key unknown parameter in that model, the government's ex ante expected cost of protecting each home from wildfires in a given location. To do this, we combine parcel-level data on the universe of homes in the West with administrative data on historical firefighting expenditures. We assembled these expenditure data from the administrative records of six different federal and state agencies, which we obtained through multiple Freedom of Information Act and public records requests. This yields the most comprehensive dataset on wildland firefighting costs in existence.

[2] Direct federal firefighting costs are annual totals from the National Interagency Fire Center. Damage data through 2017 are from Munich RE NatCatService and are overall losses (insured and uninsured) for wildfires and heat waves in the United States. Damage data for 2018 and 2019 are approximate annual figures from the Insurance Information Institute. All dollar amounts in the paper are in 2017 dollars.

Our empirical design takes advantage of variation in ignition locations to identify the degree to which incident-level firefighting expenditures increase when homes are built in harm's way. We find that residential development dramatically increases firefighting costs. Efforts to protect private homes appear to account for the majority of wildland firefighting expenditures. Perhaps more surprisingly, once development reaches a relatively low density threshold, further increases in the number or total value of threatened homes have little effect on firefighting costs. The difference in response costs between a fire threatening dozens of homes and a fire threatening several hundred or even several thousand homes is strikingly small.

Finally, we build from these estimates to calculate geographically differentiated implicit subsidies for all homes in the western United States. These subsidy estimates are actuarial measures of the expected additional future costs to the government to protect a home from wildfires. As expected, these subsidies are large in high-fire-hazard areas. Furthermore, the nonrival aspect of fire protection revealed by our empirical exercise means that development density is also an important determinant of per home implicit subsidies. Overall, we find that firefighting represents a large transfer to landowners in high-risk, low-density places. In our highest-risk categories, the net present value (NPV) of fire protection costs exceeds 20 percent of the transaction value of the property.

These implicit subsidies create the potential for efficiency costs along several margins. The first is the location of new residential development. Because new development is relatively price elastic in regions with high fire protection costs, there may be excess development in high-cost areas. We provide back-of-the-envelope estimates for this expansion of the WUI footprint. Second, providing fire protection for free reduces incentives to capitalize on the economies of density that we measure, effectively subsidizing large lot sizes and low-density development. To the extent that sprawl also results from other preexisting market failures, this subsidy may exacerbate these inefficiencies. Finally, freely provided fire protection could affect the design and maintenance of WUI homes. The promise of aggressive firefighting at no cost may reduce private incentives to choose fireproof building materials and clear brush around homes, actions that can decrease the threat to homes during a wildfire. Similarly, federally financed firefighting may limit incentives for cities and states to create and enforce wildland building codes and defensible space regulations. To the extent that the subsidies we measure cause behavioral responses along these margins, these effects could be mitigated through policies that lead individuals and localities to internalize a larger share of the cost of wildfire suppression. We discuss how the empirical approach that we develop can be used to calculate such a differentiated fire protection fee.

The importance of these issues is likely to increase as the climate changes and new development proceeds in wildland areas. Scientists predict considerable new construction over the next several decades in fire-prone locations throughout the West that currently have no or very little development (Gude, Rasker, and van den Noort 2008). Mann et al. (2014) forecast that land use changes in California through 2050 will be dominated by the conversion of undeveloped or sparsely developed areas to low- and medium-density housing use. Much of this new development is predicted to occur in areas that the state has designated as "very high" wildfire hazard zones. At the same time, climate change is predicted to make wildfires more frequent and more severe.

From a fiscal perspective, our results imply that wildland firefighting is a previously unappreciated mechanism for redistribution to particular geographic areas. For example, we find that the annual implicit subsidies to homeowners in Montana and Idaho via firefighting are larger than federal transfers to those states under the Temporary Assistance to Needy Families program (TANF).[3] Contrary to conventional wisdom (e.g., Davis 1995), we do not find that federal fire protection spending is regressive. This is because fire protection costs are highest in rural and exurban parts of the West where incomes and land values are generally low.

More broadly, this study underscores the importance of institutions in responding to the impacts of climate change. The growing literature on climate adaptation has tended to emphasize private responses (e.g., Barreca et al. 2016; Burke and Emerick 2016; Auffhammer 2018), but many important adaptive responses to climate change are likely to occur through government investments in public goods like infrastructure, national security, scientific research, public health, and emergency response. This study's results are a reminder that these large public investments will confront pressing economic questions about moral hazard, distributional impacts, and allocative efficiency.

Our setting has some particular parallels to flood risk. Economists have studied behavioral responses to subsidized federal flood insurance and ex post rebuilding assistance (Kousky, Luttmer, and Zeckhauser 2006; Smith et al. 2006; Boustan, Kahn, and Rhode 2012; Deryugina 2017; Gregory 2017). Several of these studies find that such policies encourage rebuilding in high-risk areas after losses, which is also an issue for fires. However, development in high-fire-hazard areas includes substantial new construction, including in undeveloped areas (Radeloff et al. 2005). Construction in new areas is likely to be more price elastic than rebuilding in an existing location, implying potentially larger responses to subsidies. In addition, one home's expected losses in a flood (and thus the value of insurance subsidies) do not usually depend on the number of nearby homes, while we show that the per capita costs of protecting a home from wildfire depend strongly on density.

This paper makes several contributions. Introducing administrative data on firefighting expenditures allows us to provide the first quantitative estimates of the spatially differentiated implicit subsidy and thus the optimal "fire protection fee" for every home in the western United States. Researchers and policymakers have long recognized the outsize role of the federal government in wildfire protection, but ours is the first study to quantify these subsidies.[4] Our empirical strategy also allows us to present causally identified evidence of a nonlinear response of firefighting costs to the number of threatened homes, with important implications

[3] Federal TANF expenditures in FY2016 were $32 million for Montana and $26 million for Idaho (US Department of Health and Human Services, Office of Family Assistance, "TANF Financial Data–FY 2016," February 2018; see sheet C.1).

[4] Examples of academic studies that speculate about the importance of moral hazard in this setting include Davis 1995; Loomis 2004; Stetler, Venn, and Calkin 2010; Lueck and Yoder 2016; and Simon 2017. Policy examples include US Department of Interior and Department of Agriculture 1995; Hill 2005; and USDA Office of Inspector General 2006.

for development density. From a methodological perspective, the introduction of parcel-level data on 18 million western homes allows us to be geographically precise about risks and costs relative to existing work on wildfires that relies on spatially coarse aggregate data. This specificity represents a valuable advance, since fire and other disaster risks can vary substantially over small distances. Finally, we embed our empirical results in a simple economic model that demonstrates the potential economic and policy implications of the subsidies that we measure.

The paper is organized as follows: Section I provides an overview of wildland fire institutions and explains how they motivate our empirical approach. Section II establishes the economic context for our empirical analysis through a simple conceptual framework, and Section III discusses the data. Section IV measures the cost of saving homes during wildfires, Section V estimates implicit subsidies to homeowners, Section VI considers the potential implications of the subsidies we measure, and Section VII concludes.

I. Wildland Firefighting in the United States

Wildland firefighting in the United States is provided by a patchwork of federal, state, and local government agencies. Broadly speaking, financial and operational responsibility for a wildfire is determined by its ignition location and the area affected (Hoover and Lindsay 2017). For fires on national forest land, for example, primary responsibility rests with the USFS. A handful of federal government agencies manage large amounts of public land and thus oversee significant firefighting activity. These include the USFS, the Bureau of Land Management, the National Park Service, the Bureau of Indian Affairs, and the U.S. Fish and Wildlife Service. States are responsible for incidents on state lands and private unincorporated areas. The largest state fire service is the California Department of Forestry and Fire Protection (CAL FIRE), which is responsible for large areas of mostly private land in California. Incidents within cities are initially the responsibility of local fire departments. When fires affect multiple jurisdictions, responsibility is apportioned by law and by cooperative agreements.[5] Regardless of the managing agency, large incidents feature aid and cooperation across many different jurisdictions.

Many large wildfires begin on lands where federal or sometimes state agencies bear financial responsibility for firefighting. The federal government also bears a portion of costs incurred by state and local governments through the FEMA Fire Management Assistance Grant (FMAG) program. This program reimburses 75 percent of state and local firefighting costs for qualifying large fires. Thus, the federal government absorbs a large share of wildland firefighting expenses through both direct expenditures and indirect support.

Existing case studies indicate that firefighting costs are disproportionately driven by structures as opposed to other goals like saving lives or protecting natural resources. It requires significantly more manpower and equipment (e.g., air support, bulldozers) to stop a fire in place before it reaches homes as opposed to letting it

[5] An example is the California Master Cooperative Wildland Fire Management and Stafford Act Response Agreement, which includes California and five federal agencies.

burn to a road, ridge, or other barrier. Interviews with Forest Service managers suggest that 50 to 95 percent of federal firefighting costs come from efforts to prevent damage to homes (USDA Office of Inspector General 2006). Case studies of small samples of fires have found statistical results in line with these estimates (Gebert, Calkin, and Yoder 2007; Liang et al. 2008; Gude et al. 2013).

The overall increase in wildland firefighting costs over the past several decades has been attributed to three factors: increased human habitation, climate change, and the buildup of increasingly dangerous fuel loads. Numerous descriptive studies in forestry and urban planning document widespread, ongoing housing construction in high-hazard areas (Radeloff et al. 2005; Hammer, Stewart, and Radeloff 2009; Martinuzzi et al. 2015; Radeloff et al. 2018). At the same time, changes in climate have affected the amount and combustibility of fuel available for fires (Abatzoglou and Williams 2016). Past fire suppression has also altered the type and extent of fuels in the western United States (Stephens et al. 2016). Many scientists argue that more prescribed and managed fires would reduce the risk of dangerous wildfires and lower overall expenditures on fire management. Efforts to implement these recommendations have proven politically unpopular and have met with limited success. Prescribed fire is particularly difficult to use in areas with private homes because of concerns about threats to structures.

The complexity of the wildfire problem introduces a number of potential inefficiencies. There may be spillovers in protection benefits between adjacent landowners, dynamic tradeoffs of firefighting today with fuel loads tomorrow, and political economy considerations in fire management.[6] Home prices in wildland areas decrease after nearby fires or wildfire information campaigns, suggesting this risk is imperfectly salient (Loomis 2004; Donovan, Champ, and Butry 2007; McCoy and Walsh 2018). Such inattentiveness to private wildfire costs may affect individuals' location and maintenance decisions by reducing perceived private costs in high-risk areas.

Our study addresses the external costs of individuals' decisions in terms of increased federal and state expenditures on fire protection. The potential behavioral effects of the subsidies that we measure do not depend on whether homeowners accurately perceive these public costs.[7] Moreover, if wildfire protection were to be priced via an up-front corrective tax on new construction (as we discuss in Section VIB), the cost would presumably be highly salient.

Implications for Measurement.—This study uses administrative expenditure data along with plausibly exogenous variation in ignition locations to estimate the amount of money that is spent to protect homes from wildfires. This approach quantifies the spatially varying implicit subsidy to homeowners, a parameter that is directly useful for economic and policy analysis. Our estimates reveal the fiscal and distributional consequences of federal firefighting policy. In addition, combined with existing estimates of supply and demand for new construction, our estimates can be used to

[6] See Lueck and Yoder (2016) for a review of economic issues in wildland fire.
[7] Similarly, a polluting firm's output does not depend on whether the firm knows the external costs of pollution, since it only considers private costs.

estimate expected quantity changes relative to optimal pricing of fire protection and the resulting deadweight loss.

An alternative approach would be to measure changes in construction and home prices in response to policy differences over time or space. If feasible identifying variation could be found, such an approach could directly quantify moral hazard in WUI housing development. While our method of calculating the implicit subsidy does not deliver the same kind of direct evidence of moral hazard, it has other empirical and conceptual advantages. First, existing firefighting policies provide little credible identifying variation. We are not aware of any part of the United States where no effort is made to protect homes during a wildfire. Existing policies generate only small, difficult-to-interpret differences in perceived protection.[8] Given the evidence that wildfire risk is imperfectly salient, it seems unlikely that home buyers correctly perceive small differences in the risk of property damage when firefighting rules shift. Moreover, responses to these policy differences have limited applicability to the main questions of interest. When considering the effects of providing fire protection for free, the welfare-relevant counterfactual is a scenario where homeowners or local governments internalize this cost (for example, through a tax at the time of construction that equals expected future protection costs). The response to a transparent up-front tax would presumably be different than responses to the opaque subtleties of firefighting dispatch rules. One final advantage of our approach is that the resulting estimates are calculated for the entire western United States as opposed to a particular policy change or boundary.[9]

II. Conceptual Framework

This section summarizes the stylized model that guides the empirical analysis (see Appendix Section D for a detailed treatment). N individuals choose to live in a safe or a risky location. The safe place delivers a constant reservation utility while utility in the risky place depends on individual tastes, disaster-related costs, and home prices. Taste parameter θ_i, with cumulative distribution function F_θ, is the difference between individual i's utility in the risky place (before disaster costs and home prices) and the safe place. Expected private disaster-related costs are π, which we develop below. The marginal cost of identical, competitively supplied, risky-place homes given population n is $s(n)$. The equilibrium risky-place population is the number of households whose relative taste exceeds housing and private disaster costs, or $N\left[\left(1 - F_\theta\left(\pi + s(n)\right)\right)\right]$.

The probability of a disaster in the risky place is ϕ. During a disaster, the government makes defensive expenditures f (e.g., firefighting) that reduce losses H for each risky-place household. The response $f(n)$ is chosen to minimize the sum of

[8] Even in the few remote areas with no local fire service, neighboring jurisdictions may help when wildfires threaten homes. Furthermore, firefighting responsibility depends on the ignition location (frequently federal lands), not just the home's location.

[9] We see research that leverages variation in protection policy in special instances where it exists as a potential complement to our approach. The one relevant paper that we are aware of is a 2012 working paper that studies construction near public lands after the 1988 Yellowstone fires changed federal firefighting policies (Kousky and Olmstead 2012).

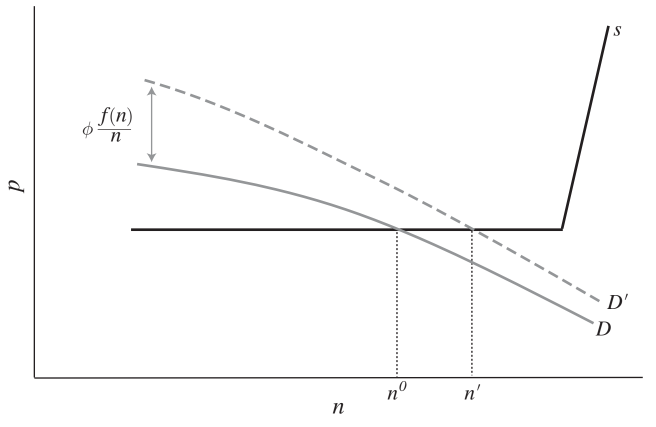

Figure 1. The Market for Housing in a Risky Place

Notes: The figure illustrates population in the risky place under alternative policies for financing defensive expenditures. Line D shows private willingness to pay to locate in the risky place when risky-place residents pay a per capita share of expected defensive expenditures. Line D' shows the higher private-location demand when households are only responsible for their own property losses. Line s is the marginal cost of supplying housing and n^0 and n' are the risky-place populations in these two scenarios. $\phi\frac{f(n)}{n}$ is per capita expected defensive expenditures.

property damages and response costs. Total expected disaster cost in the risky place is $\phi\left[f(n) + nH(f(n))\right]$. Private disaster cost π for a risky-place resident is expected property damage $\phi H(f(n))$ plus expected individual liability for defensive expenditures. We assume that individuals can fully insure all disaster-related costs through competitive insurance markets.

Figure 1 illustrates population in the risky place under two financing rules for defensive expenditures. First, imagine that risky-place residents are accountable for expected damage to their own homes plus a per capita share of expected defensive expenditures, yielding private disaster costs π^0. Line D indicates the share of households (on the horizontal axis) for whom $\theta_i - \pi^0$ exceeds the corresponding value on the vertical axis. There are n_0 individuals who, after subtracting private disaster costs, value the risky place at or above the cost of a home there. Line D' shows the higher demand for the risky place under the status quo policy, where households bear only expected property damages. The vertical distance between these curves is per capita expected defensive expenditures $\phi\frac{f(n)}{n}$, which decrease with n due to the nonrival nature of disaster response (a feature that we confirm in the empirical analysis). The housing supply curve s in this example is drawn as elastic up to a capacity constraint (perhaps due to land availability or regulations). This elasticity has important implications, which we revisit in Section VI.

In our empirical application we use new data on firefighting expenditures to estimate these subsidies directly. The first quantity we measure is the per capita expected protection cost $\phi\frac{f(n)}{n}$ illustrated in Figure 1. This is the relevant measure of the implicit subsidy from the perspective of a local decisionmaker who is considering allowing a fixed amount of development in a currently undeveloped, high-hazard area. Such development is welfare improving if total willingness to pay (WTP) for the risky place among the new residents exceeds the sum of housing costs, expected property losses, and the expected cost of defending homes.[10] We also use variation in the number of homes threatened by the fires in our dataset to measure the implied marginal protection cost of adding more homes in an already-developed location.

III. Data

We construct a dataset that combines administrative data on firefighting expenditures from federal and state agencies with assessor data for nearly all homes in the 11 western states (Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming). Our dataset also includes topographical information, wildfire hazard assessments, and weather conditions from the time and location of the fire ignition. This section provides an overview of the dataset, while a comprehensive account of dataset construction can be found in in the online Appendix.

We collect data on fire-suppression expenditures from five federal agencies and one state agency. The federal agencies are the US Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), the Bureau of Indian Affairs (BIA), and the Federal Emergency Management Agency (FEMA). The state agency is the California Department of Forestry and Fire Protection (CAL FIRE), which has by far the largest spending among individual states. Incident-level expenditures for each agency come from a combination of Freedom of Information Act requests (Public Records Act requests for California) and publicly available sources (NWCG 2017; BLM 2017; BIA 2017; NPS 2017; CAL FIRE 2016). Because fire costs are only reported consistently for large fires and because large fires comprise the bulk of fire-suppression expenditures, we focus our analysis on fires that are 300 acres or larger. For each fire we obtain the topographical conditions (elevation, slope, aspect, and vegetation characteristics) at the ignition point and weather conditions (temperature, precipitation, wind speed, and humidity) at the time of ignition (PRISM Climate Group 2018). We also estimate the distance between the ignition point of each fire and valuable nearby resources, including homes and state and federal highways. The regression analysis in Section IV focuses on the USFS fire suppression data, which cover 1995 to 2014. The calculation of implicit subsidies in Section V uses expenditures from all agencies in the dataset. Section V incorporates additional data on preparedness spending from federal agencies as described in that section.

The real-estate dataset we use is a proprietary compilation of county assessor data (CoreLogic, Inc. 2014). It includes location, transaction values, year of construction, and other relevant information for 18.5 million parcels, or nearly all of the homes in the western United States. We limit this sample to 9.1 million homes in areas with significant wildland vegetation as defined by Radeloff et al. (2018). For each home

[10] Note that this efficiency condition does not require that all risky-place residents bear costs equally. In fact, a policy that assigned responsibility for defensive expenditures in proportion to individual WTP for the risky place could improve welfare by balancing the marginal resident's WTP against marginal (instead of average) defensive expenditures. Absent contracting frictions, households could in principle reproduce this efficient allocation of protection costs through private contracts regardless of the statutory assignment of costs.

our data include a measure of its actual location, which is an improvement over previous studies of wildfires that rely on aggregate housing counts by census block. Census blocks are often quite large in the rural and exurban areas where fire risk is high.

Our final dataset includes 4,663 fires and accounts for \$13.2 billion of suppression costs and links those fires to 8.6 million western US homes in the WUI. Detailed descriptive statistics are given in the online Appendix.

IV. The Cost of Saving Homes during Wildfires

A. *Empirical Strategy*

The first step in our empirical analysis is to establish what share of firefighting expenditures are incurred to protect private homes. Even with zero threatened homes, some effort would likely be devoted to a fire. Our objective is to understand how fire managers change this effort when homes are located in harm's way. We recover this difference empirically by estimating the causal impact of home presence and density on firefighting costs.

Our empirical strategy takes advantage of variation in ignition locations within national forests. Each of the national forests in our dataset experienced multiple large fires during our study period. We compare suppression costs for fires within the same national forest that happened to start at different distances from homes. Some fires start far from private homes—for example, deep in the national forest. Other fires start nearer to homes because the ignition point is closer to the boundary or to a privately owned "inholding" or because new homes have been built near the boundary. Figure 2 illustrates this variation for two national forests. Fires are shown as diamonds and are colored by the distance from the ignition point to the nearest home (top-coded at 30 kilometers).

We take advantage of this variation in ignition locations using a fixed-effects estimation strategy. We model the effect of homes on firefighting costs as

$$ln\left(Cost_{ift}\right) = g\left(Homes_{it}\right) + X_{ift}\rho + \delta_f + \omega_{st} + \eta_{ift}. \tag{1}$$

$Cost_{ift}$ is the suppression cost for fire i in national forest f in month-of-sample t. We are primarily interested in how this cost depends on the potential threat to private homes, $Homes_{it}$. We begin in Section IVB by parameterizing $Homes_{it}$ as the distance from the ignition point of the fire to the nearest home. In Section IVC,we use the total number of homes near the ignition point. In either case our preferred model approximates $g(\cdot)$ with a binned step function to allow a flexible response of costs to threatened homes.

This panel data approach addresses a number of omitted variable concerns. The national-forest fixed effects δ_f control for unobservable determinants of firefighting cost that are constant at the national-forest level. We also include time fixed effects ω_{st} that control flexibly for unobserved changes in firefighting costs over time. Our preferred specification includes state–by–month-of-year fixed effects and state-by-year fixed effects. Intuitively, this identification strategy amounts to

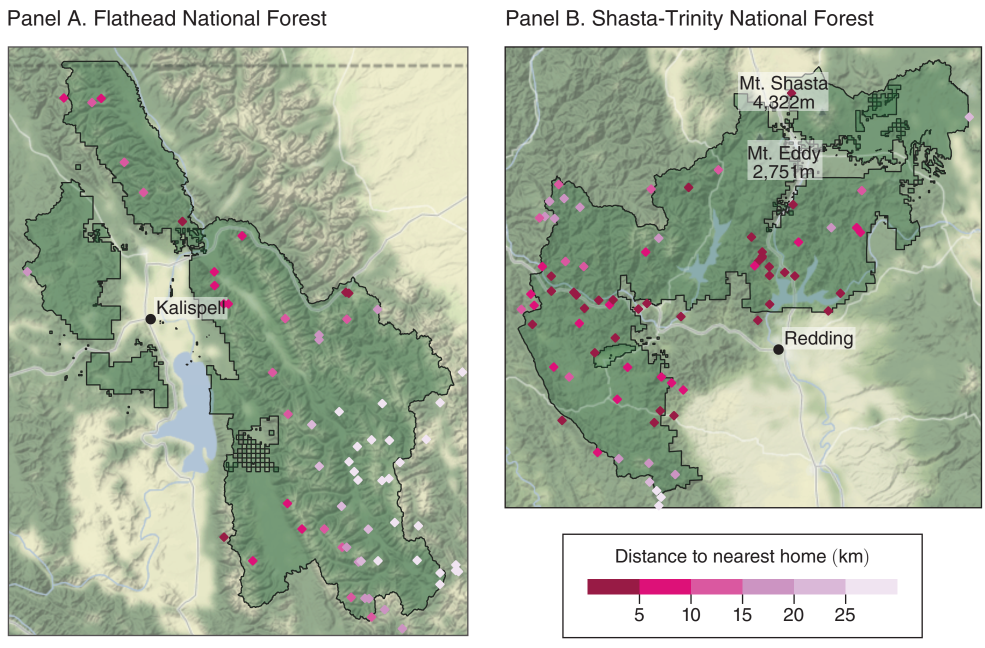

Figure 2. Example National Forest Units

Notes: The figure documents national forest boundaries and fire locations with distance to the nearest home. Each panel shows a single national forest area. Flathead National Forest is in western Montana. Shasta-Trinity National Forest is in Northern California. Diamonds indicate individual wildfires, colored by distance from the recorded ignition point to the nearest home (top-coded at 30 km).

comparing fires in the same national forest during the same time of year and the same year of the sample.

We include additional control variables X_{ift} to address the fact that locations of private homes are not randomly assigned. Even within a given national forest, areas near homes may differ systematically from areas far from homes in ways that affect firefighting cost. The control variables X_{ift} include the terrain slope, geographic aspect, and vegetation type (fuel model) at the ignition point and weather conditions at the ignition point on the ignition day.[11] We also estimate a specification where we limit the sample to fires caused by lightning, which ensures that the location and timing of fires are not driven by the presence of people. The identifying assumption in this analysis is that unobserved determinants of fire cost, η_{ift}, are independent of $Homes_{it}$ conditional on national-forest fixed effects and our other controls.

This empirical strategy based on national forests requires us to restrict the analysis to fires managed by USFS since lands managed by other agencies are not similarly arranged into large, contiguous units.[12] Moreover, Forest Service expenditures account for over 80 percent of expenditures in our dataset due both to the

[11] The weather variables vary over time while the topographic variables are constant.

[12] For example, CAL FIRE incidents occur on diffuse private and state lands while BLM-owned lands often consist of smaller patches of land managed by district offices.

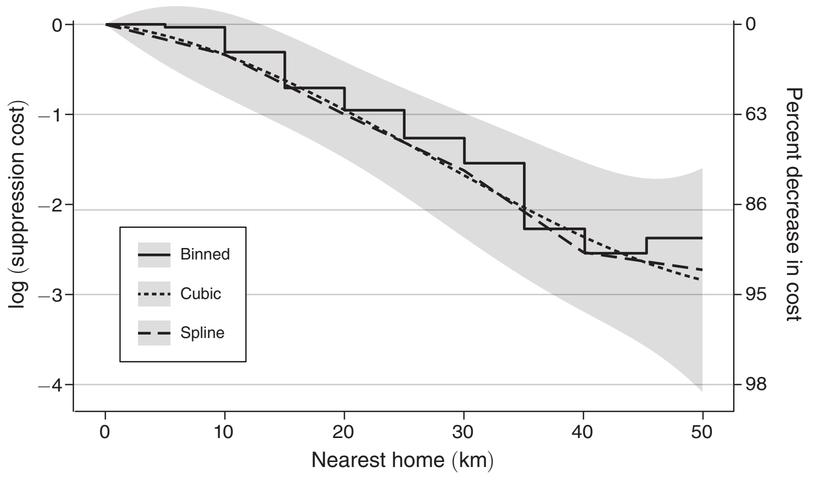

Figure 3. The Effect of Homes on Firefighting Costs

Notes: The figure shows three separate regressions of the natural log of firefighting cost on distance from ignition point to the nearest home. "Cubic" is a third-degree polynomial. The "Binned" step function shows coefficients on indicators for whether the nearest home was within 0–5, 5–10, [. . .,] or 45+ km from the ignition point. "Spline" is a piecewise linear function of distance to the nearest home with knots every ten kilometers. The shaded gray area is the 95 percent confidence interval around the cubic polynomial fit. Each regression includes national-forest fixed effects, state–by–month-of-year fixed effects, state-by-year fixed effects, and additional controls for weather, topography, and vegetation (see text for details). Standard errors are clustered by national forest. The left-hand vertical scale indicates the change in log suppression cost relative to fire less than five kilometers from the nearest home. The right-hand vertical scale shows approximate percentage decrease in cost relative to a fire less than five kilometers from the nearest home, calculated as $\exp(\beta) - 1$ for a coefficient β in the binned regression.

disproportionate role of USFS in fire management and the longer temporal coverage of the USFS data. The online Appendix explores this relationship for other agencies. When adding up historical expenditures associated with each home in Section V, we use data from all agencies.

B. *Proximity to Homes*

We begin by considering a version of equation (1) where the threat to private homes, $Homes_{it}$, is proxied by the distance from the ignition point to the nearest home that existed at the time of the fire. Figure 3 shows estimates from three flexible regression specifications. Each regression includes national-forest fixed effects, state–by–month-of-year fixed effects, and state-by-year fixed effects. The dotted black line shows the estimated marginal effect of distance from a regression of log costs on a cubic polynomial of distance to homes. The shaded gray area is the 95 percent confidence interval. The dashed black line shows a linear spline in distance to homes with knots placed every ten kilometers. Finally, the solid black step function reports coefficients from a binned step-function specification. These coefficients correspond to indicator variables for five-kilometer bins of distance to homes. The omitted category is fires that start less than five kilometers away from homes. Regardless of the functional form that we choose, there is a clear gradient in firefighting costs with distance from nearest home. The relationship is steep, monotonic, and close to linear. Relative to a fire that starts more than 40 kilometers from any home, the log cost of a fire less than 5 kilometers from homes is higher by about 2.4. Taken literally, these estimates imply that a fire that starts less than 5 kilometers from homes would cost about 70 percent less if there were no homes within 25 kilometers and 90 percent less if there were no homes within 40 kilometers.[13]

Table 1 estimates alternative models using the binned specification. Column 2 follows Figure 3 while column 1 omits the additional controls for predetermined fire characteristics. The results are similar in both columns. The online Appendix provides more detail on the estimated effects of the control variables, which are consistent with expectations. For example, firefighting costs are higher where the terrain slopes more steeply, reflecting difficulty of access. Costs also increase with wind speed on the ignition day—consistent with the importance of wind in fire spread—and with vapor pressure deficit (VPD), a measure of atmospheric dryness. Costs are also higher for fires on south- or southwest-facing slopes, which receive additional sun exposure and thus tend to be more readily combustible. The online Appendix shows detailed regression results for all covariates. While we find that many of these covariates have meaningful effects on firefighting costs, including them in the regression has little effect on our estimated distance gradient.

The remaining columns show three robustness checks. Column 3 replaces the time fixed effects with more granular month-of-sample–by–state fixed effects, which allow for arbitrary shocks to firefighting costs in each month of the dataset in each state. These more temporally precise controls absorb higher-frequency local cost fluctuations that might be caused by weather patterns or other factors. This alternative specification produces a similar distance gradient. Column 4 restricts the sample to fires started by lightning. Some types of human-caused fires are more likely to occur near populated areas, introducing a potential identification concern if fires due to arson or campfires or other causes vary systematically in their difficulty to extinguish. The locations of lightning strikes are plausibly random and thus purged of this potential bias. If anything, the estimated distance gradient is steeper when this restriction is applied, though the estimates are not different in a statistical sense. Column 5 restricts the sample to fires occurring in "timber" vegetation, since developed areas are also less likely to be heavily wooded than remote areas. As before, the estimated distance gradient steepens slightly with this restriction. The online Appendix shows that these results are robust to further controlling for the distance from the ignition point to the nearest major road.

The large effects of threatened homes on firefighting costs are likely explained by the high cost of stopping fires in place by digging firelines, dropping retardant from aircraft, and taking other costly measures. An anecdote from Arno and Allison-Bunnell (2002) provides some context: "Consider the campaign against the 217,000-acre Clear Creek Fire on the Salmon-Challis National Forest in central Idaho during the summer of 2000. Although the fire burned mostly in undeveloped mountainous terrain, it was near enough to populated valleys, including

[13] These percentage changes are calculated using the binned specification. Halvorsen and Palmquist (1980) and Kennedy (1981) show that the percentage effect of an indicator variable in a semi-log regression can be approximated as $e^{\beta - 0.5V(\beta)} - 1$, where β is the regression coefficient.

Table 1—The Effect of Proximity to Homes on Firefighting Costs

	(1)	(2)	(3)	(4)	(5)
Distance to homes (kilometers)					
10–20	−0.34	−0.44	−0.52	−0.50	−0.51
	(0.15)	(0.15)	(0.19)	(0.22)	(0.30)
20–30	−0.98	−1.04	−1.15	−1.16	−1.69
	(0.28)	(0.28)	(0.38)	(0.36)	(0.60)
30–40	−1.77	−1.80	−1.79	−1.90	−2.68
	(0.46)	(0.47)	(0.54)	(0.52)	(0.74)
40+	−2.27	−2.40	−2.30	−2.44	−2.55
	(0.44)	(0.42)	(0.48)	(0.51)	(0.89)
Weather, topography, vegetation	No	Yes	Yes	Yes	Yes
Fixed effects					
Unit	Yes	Yes	Yes	Yes	Yes
State × month	Yes	Yes	No	Yes	Yes
State × year	Yes	Yes	No	Yes	Yes
State × month of sample	No	No	Yes	No	No
Subsample				Lightning	Timber
Fires	2,080	2,080	2,080	1,457	765
R^2	0.43	0.46	0.56	0.47	0.58

Notes: The table reports the results of five separate regressions of the natural log of suppression cost on distance to the nearest home. The sample includes western US fires managed by the Forest Service during the years 1995–2014. Rows report coefficients and standard errors on dummy variables corresponding to distance to the nearest home. The omitted category is zero to ten kilometers. Controls for weather, topography, and vegetation include a quadratic in wind speed, a quadratic in temperature, a quadratic in vapor pressure deficit, a quadratic in precipitation, a quadratic in slope angle, an indicator for south or southwest aspects, and fuel-model fixed effects. Weather variables are measured on the day of ignition, and topographic variables are measured at the ignition site. National-forest fixed effects include 86 national forests in the western United States. Standard errors are clustered at the national-forest level.

the town of Salmon, to inspire frenzied efforts to stop the advancing flames with heavy equipment … [and] the monumental expenditure of $71 million […] In contrast, the 182,000-acre Wilderness Complex fire farther west in similar terrain was monitored and allowed to burn with very little suppression effort at a cost of about half a million dollars."

C. *Total Number of Homes*

The results so far show that the presence of nearby private homes strongly affects firefighting costs. We now consider how this effect varies with the number of homes at risk, i.e., the density of development. We fix a radius around each ignition point and estimate a version of Equation 1 that parameterizes $g(Homes_{it})$ as the number of homes within that radius. Our baseline specification uses 30 kilometers; the online Appendix shows results for other radii.

Figure 4 shows results from a binned step-function specification. The reference bin is fires with zero homes within 30 kilometers, and the other bins evenly divide the remaining fires into deciles. The presence of just 1 to 32 homes almost doubles expenditures on a fire. Costs are further increasing over the first few deciles, up to about 100–300 homes. Beyond that, costs change very little. The regression

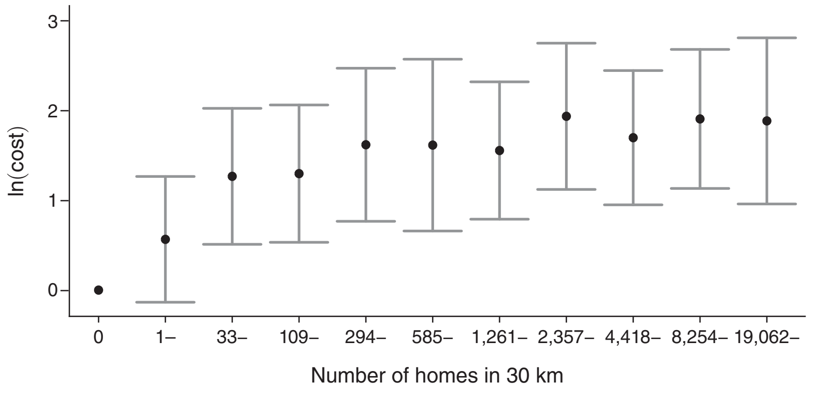

Figure 4. Nonlinear Effects of the Number of Nearby Homes

Notes: The figure shows point estimates and 95 percent confidence intervals from a regression of the natural log of firefighting cost on deciles of home counts within 30 kilometers of the fire's ignition point. The regression includes national-forest fixed effects, state–by–month-of-year fixed effects, state-by-year fixed effects, and additional controls for weather, topography, and vegetation (see text for details). Standard errors are clustered by national forest.

coefficients imply that a fire threatening 300 homes costs about 5 times as much as a fire with no nearby homes while a fire threatening over 10,000 homes costs about 6.5 times as much as a fire with no nearby homes. This strongly nonlinear relationship implies that the benefits of wildland firefighting are essentially nonrival so that marginal protection costs are decreasing in population density.

One way to contextualize these results is to convert the numbers of homes in Figure 4 into conventional measures of residential density, such as the number of homes per unit area. Land-use planners typically work with net density, which measures land consumption per housing unit after subtracting out open space, parks, pasture, roads, and other land uses. To compare to this standard measure, we calculate the average of the reported lot sizes for homes within 30 kilometers of the fire. The median net density across fires in the fourth nonzero bin, where costs level off, is 0.16 homes per acre.[14] Mann et al. (2014) define five tiers of housing density: sparse, low, medium, high, and very high. A value of 0.16 homes per acre is between the cutoffs for "low" and "medium."

D. *Additional Results and Robustness Checks*

In addition to the checks described above we include a more detailed set of additional results and robustness checks in the online Appendix, which we describe here in brief. First, we show that the estimated density effects in Figure 4 are robust to the same checks shown in Table 1, such as limiting to lightning-caused fires or including temporally more precise fixed effects. We also show that using the total

[14] This calculation is meant to provide broad context as opposed to a highly accurate measure of net density. We calculate the mean lot size within 30 kilometers of each fire and then calculate the median average lot size in each decile bin in the figure. These range from 0.11 homes per acre in the leftmost nonzero bin to 0.91 homes per acre in the rightmost bin. The average lot size within 30 kilometers of each fire is sensitive to some very large reported parcels. Lot size is also missing for some homes, which we necessarily omit from this calculation.

transaction value of homes instead of the number of nearby homes yields similar results. Furthermore, we show that the effect of development density on firefighting costs is robust to using different radii around the ignition point.

Our measure of valuable structures threatened by a fire does not include public infrastructure such as school buildings and municipal parks that would also be considered by incident commanders when choosing response levels. This means that our approach assigns the cost of protecting those public goods to nearby homeowners. For local public goods such as schools and parks, this makes intuitive sense, since construction of such local public goods follows as a direct result of housing construction (Brueckner 1997). It should also be noted that built structures in the WUI areas where we are focused are disproportionately residential, with residents who travel by car to more developed commercial areas for shopping, work, and school.

Since firefighting costs are only consistently reported for incidents larger than 300 acres, a potential concern is bias due to sample selection. Our analysis could be affected if the subset of ignitions that reach this size differs with distance from homes in a way that is correlated with suppression costs. For example, one might worry that concentrated initial attack efforts near homes make ignitions near homes unlikely to grow large unless conditions are difficult (e.g., high winds). This selection would result in an upward bias in a naive regression of firefighting costs on distance to homes. We address this concern in several ways. Importantly, we are able to control directly for the most significant potential confounders. Wind, weather conditions, and topography are primary determinants of suppression difficulty and cost (Gebert, Calkin, and Yoder 2007). Table 1 and the online Appendix show that controlling flexibly for these variables improves the model fit while introducing only small changes in the coefficients of interest. The online Appendix also formalizes this sensitivity analysis using the bounding exercise of Oster (2019). Finally, finer-grained time fixed effects reduce the scope for selection due to unobservables that vary over time but are locally constant in space, like fuel dryness or weather patterns. The state–by–month-of-sample fixed effects in column 3 of Table 1 restrict the comparison to fires in a single state that all occurred in the same month. The results are similarly robust to even finer-grained time fixed effects (e.g., state by week-of-sample), but the number of relevant fire observations begins to decrease since not all state-by-week cells contain multiple fires. The online Appendix provides more detail on these various checks.

Because our baseline estimates are not suitable to consider the impact of homes on the frequency of fires in an area, we conduct a separate analysis to investigate how this might impact our findings. As some wildland fires are ignited by humans, increased human population may lead to more ignitions. On the other hand, new homes could be accompanied by greater fire-prevention efforts. We explore this relationship using panel variation in new home construction near each of the national forests in our sample. We find weak evidence of a small, positive effect of new home construction on the number of large fires each year in places that start from a low level of development. Adding an additional 1,000 homes in a relatively undeveloped area is associated with about a 4.2 percent increase in the number of large fires each year, or about 0.06 additional large fires per year. The finding that human presence increases fire frequency is consistent with work by ecologists and geographers (Syphard et al. 2007; Massada et al. 2012; Faivre et al. 2014; Balch et al. 2017). This implies that our estimates may slightly undercount the additional firefighting cost created by new homes.

V. The Implicit Subsidy to Homeowners

This section combines the estimates from Equation 1 with comprehensive real-estate data to calculate geographically differentiated subsidy amounts for every home in the western United States. For each home we first calculate annualized "realized protection costs" that represent the historical cost of protecting the home from wildfires. We then use these realized costs to estimate "expected protection costs" by averaging realized costs over groups of homes at similar risk. These expected protection costs represent the ex ante implicit subsidy to individuals or localities making decisions about WUI housing. Section VA describes the methods for realized and expected protection costs. Section VB summarizes the realized protection cost results, and Section VC presents expected protection costs and their variation across space and income groups.

A. *Methods to Calculate Protection Costs*

We calculate realized and expected protection costs for the 8.6 million WUI homes in our study area. This section describes these calculations in detail.

Realized Protection Costs.—To estimate the historical protection costs attributable to each home, we estimate the expenditures dedicated to defending homes during each observed fire in our dataset, allocate those costs across individual homes, and then sum up the costs allocated to each home across all historical incidents. We report three summary measures of cost that represent different tradeoffs between completeness and the required strength of assumptions. The "suppression-only" measure includes only federal firefighting expenditures directly attributed to individual large wildfires. The "all-sources" measure adds additional expenditures that are clearly related to wildfire protection but where attribution to specific incidents requires more assumptions. Lastly, the "California" measure focuses on a single important state where we have particularly high-quality data on state-level expenditures.

Calculation of "suppression-only" measure: This measure follows directly from the empirical strategy in Section IV. For each fire, we back out the implied home protection cost by using our estimates of Equation 1 to predict the firefighting cost if there had been no homes within 40 kilometers of the ignition point. We allocate this home-related protection cost across the homes that were potentially threatened by the fire using spatial weights. These weights are derived from Equation 1, where the weight for each parcel is the coefficient on the bin indicator corresponding to the distance between the home and the fire. The home-related protection cost is then allocated across all homes threatened by the fire according to the weights. The online Appendix provides more details on how these counterfactual costs are calculated, including an alternative GLM approach (which yields very similar estimates).

We perform this exercise for suppression expenditures incurred by USFS, DOI, and CAL FIRE in response to fires in our sample. For each home, we sum realized protection expenditures by each agency and convert to an annual measure of cost in real 2017 dollars per year. The "suppression only" metric is the sum of the home's USFS and DOI protection costs. This measure is our estimate of the direct cost incurred by the federal government to protect any individual home during the period of our historical data. This metric has the advantage of requiring relatively few assumptions, but it omits potentially important categories of spending.

Calculation of "all-sources" measure: The "all-sources" measure incorporates additional categories of spending to more fully capture the cost of defending homes from wildfires. The next several paragraphs describe these expenses and how we allocate them across homes.

The largest additional category is USFS and DOI costs for wildfire preparedness. These include base salaries and other personnel costs for firefighters, purchase and maintenance expenses for aircraft and equipment, and suppression costs for minor incidents where costs are not separately reported. These costs can be viewed as primarily variable costs incurred in support or anticipation of direct firefighting efforts.[15] We incorporate preparedness costs reported in annual USFS and DOI budget justifications to Congress from 2008–2017 for USFS and 2012–2018 for DOI agencies (USDA 2019; DOI 2018). Including these costs in the analysis requires additional assumptions about how they should be allocated. Our preferred approach allocates these costs in proportion to each home's share of "suppression-only" costs, reflecting the role of these expenditures in supporting direct firefighting efforts.[16] We start by taking 86 percent of total reported preparedness costs, based on the average share of total suppression costs that we find to be attributable to home protection. We then allocate these costs to individual homes within each year (and USFS region, for USFS costs) proportionally based on each home's share of realized "suppression-only" costs.

The "all-sources" measure also includes federal reimbursements for state and local firefighting costs made through the FEMA Fire Management Assistance Grant (FMAG) program. We obtained incident-level data on FMAG reimbursements during 2000–2017 from FEMA (FEMA 2018). After multiplying these costs by 1.33 to reflect that FMAG repays 75 percent of state and local costs, we aggregate them to the state-by-year level and allocate 86 percent of these costs

[15] This interpretation is consistent with the data and with the agencies' own descriptions of this spending. Observed preparedness expenses grew rapidly across the years during our study period as direct firefighting expenses grew, consistent with a variable-cost interpretation. Preparedness spending also varies geographically with firefighting costs. USFS explains that "[p]reparedness funds are allocated to regions based on predicted fire activity and anticipated wildfire workloads […] As the fire season develops and ongoing risk is assessed, national and local resources are repositioned" (USDA 2016, 274).

[16] This approach can similarly be motivated by imagining a hypothetical competitive market for firefighting services with the equilibrium condition that price equal average cost.

proportionally across homes in each state-year based on the distribution of realized "suppression-only" costs, similar to our treatment of preparedness costs.[17]

Calculation of "California" measure: Finally, we calculate a third measure specific to California, which accounts for a disproportionate share of population and wildfire expenditures. Instead of proxying for state-level firefighting costs with FMAG grants, this measure takes advantage of geographically explicit incident-level cost data for California provided by CAL FIRE. The "California" measure allocates these incident expenses over nearby homes using the method described for the "suppression-only" measure. It also includes all elements of the "all-sources" measure, except for the FEMA FMAG reimbursements.

Expected Protection Costs.—To estimate expected protection costs, we group regions with similar fire hazards and other characteristics into actuarial groups and take averages of the historical realized costs for homes in each group. We then calculate the net present value of these expected costs using a 5 percent discount rate. The actuarial groups are defined by six bins of wildfire hazard, five bins of development density, and seven administrative regions for wildfire dispatch, yielding 210 ($6 \times 5 \times 7$) groups.

Wildfire hazard is defined at the parcel level using the spatially explicit wildfire hazard potential (WHP) scores provided by Dillon (2015), which are a physical measure of wildfire hazard based on ecological and topographical factors. The WHP score is a categorical variable with six levels. Development density comes from Gridded Population of the World (GPW), which reports population counts within one-kilometer grid cells (CIESIN 2017). We define five population density bins based on the quintiles of the distribution of GPW grid cells. Geographic regions are based on the seven Geographic Area Coordinating Center (GACC) regions within which firefighting operations are coordinated (NIFC 2019). The online Appendix shows the geographic distribution of each of the characteristics used to define actuarial groups.

We calculate expected protection costs using each of the cost metrics ("suppression only," "all sources," and "California"). These costs represent the expected net present value of future government expenditures to protect a home from wildfires.

B. *Results: Realized Protection Costs*

Table 2 summarizes our estimates of realized protection costs. For each cost component, the table shows the annual cost, the method of assignment to individual incidents, and the summary measures that include the component. Rows A, B, and C are costs from incident-level suppression expenditures by USFS, DOI, and CAL FIRE. Since these expenses are directly attributable to individual wildfires, we can assign them to homes using the method described under "suppression-only" in Section VA. The resulting annual spending to protect homes is about $750 million per year across agencies. Rows D and E are additional costs attributed to home

[17] While the FEMA records contain incident-level cost information, there is no location information or consistent identifier that would allow a reliable merge to other incident-level data sources.

Table 2—Realized Protection Costs by Category (Annual)

	Cost to protect homes ($M/year)	Assignment method	Summary measures		
			SO	AS	CA
Components:					
(A) USFS suppression	459	Observed	✓	✓	✓
(B) DOI suppression	82	Observed	✓	✓	✓
(C) CAL FIRE suppression	210	Observed			✓
(D) USFS preparedness	678	Allocated		✓	✓
(E) DOI preparedness	153	Allocated		✓	✓
(F) FEMA reimbursements	169	Allocated		✓	
Total ($/year)			541	1,541	726
Number of homes (millions)			8.63	8.63	3.48

Notes: This table describes the historical costs of protecting homes from wildfires following the methods described in SectionVA. Costs are reported in 2017 dollars per year. The "summary measures" columns show the components included in the "suppression-only," "all-sources," and "California" cost measures as well as the total annual costs for each measure.

protection from USFS and DOI preparedness spending. These costs are not reported by individual incident and so are allocated across homes using the method described under "all sources" in Section VA. These costs are large, especially for USFS, highlighting the value of accounting for them in "all sources." Row F shows a proxy for state and local firefighting expenses based on federal FMAG grants. These costs, which add an additional $170 million per year, are also allocated across incidents according to the methods and assumptions in Section VA. The final two rows show total annual costs for each of the three cost measures. The "suppression-only" cost metric implies about $540 million of annual federal spending devoted to protecting homes from wildfire. Moving to the "all-sources" metric increases this amount to about $1.5 billion per year. The "California" metric shows that a substantial portion of this spending is in California.

Figure 5 summarizes the variation in realized protection costs with fire hazard and development density. The figure shows average "all-sources" costs for homes in 30 bins defined by wildfire hazard potential (WHP) and population per square kilometer. Average annual protection costs range from less than $100 per home for the lowest-cost cells to more than $3,000 per home in the highest-cost cells. There is a clear graphical relationship between realized protection costs and observable predictors of risk. Moving vertically, average protection costs are clearly increasing with WHP. This relationship is intuitive, but the cost difference between homes in low- and high-WHP areas is substantial. Along the horizontal axis, protection costs strongly decrease with development density. This somewhat more surprising result reflects the nonlinear relationship between firefighting costs and the number of nearby homes that we measured in Section IVC. Instead of being driven purely by idiosyncratic risk, the costs of protecting homes from fires vary in a highly predictable way. Homes in low-density, high-fire-hazard areas are extremely expensive to protect.

C. *Results: Expected Protection Costs*

Table 3 shows our final measures of expected protection costs using all 210 actuarial groups. The table describes the distribution of expected protection costs for

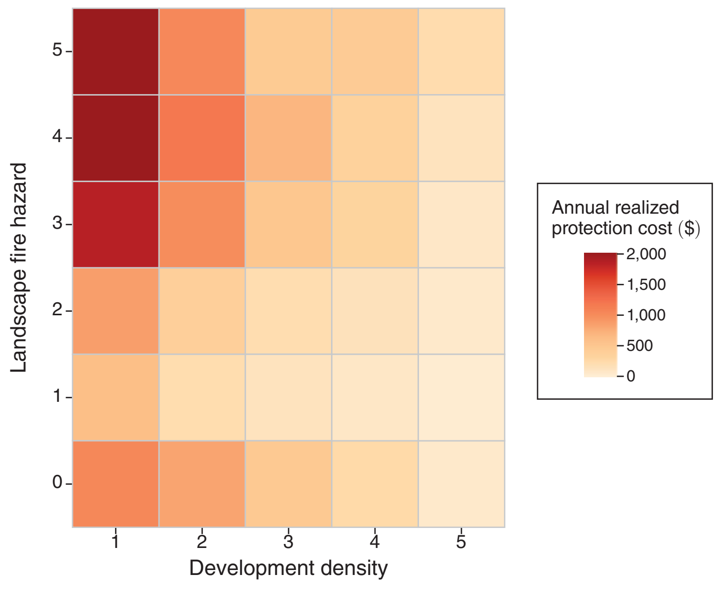

FIGURE 5. REALIZED PROTECTION COSTS FOR 8.6 MILLION WUI HOMES (ANNUAL)

Notes: The figure shows average annual realized protection costs in each cell in units of dollars per year. The horizontal axis bins are quintiles of population density. The vertical axis bins are defined by wildfire hazard potential, or WHP (Dillon 2015). WHP bin zero includes homes with zero WHP, and hazard is increasing across the remaining five WHP bins. These estimates of historical protection cost use the "all-sources" cost metric.

the 8.6 million homes in our study area in eleven western states. The distribution is skewed, with relatively low expected protection costs for many homes but a large tail of homes with very high expected protection costs. Using the "suppression-only" measure, 50 percent of WUI homes have expected protection costs under $825. Five percent of homes have expected costs exceeding $4,100, and 1 percent of homes have expected protection costs exceeding $13,500. Moving to the "all-sources" measure increases costs by about a factor of three. When we restrict the sample to California homes, where we have higher-quality data on state-level expenditures, we find that the expected protection costs are roughly similar to the West-wide "all-sources" distribution.

The table also reports expected protection cost as a share of a home's transaction value.[18] Expected fire protection costs are strikingly large compared to property values for the highest-risk homes. For 5 percent of homes, the NPV of expected "all-sources" cost exceeds 5 percent of property value. For the highest 1 percent of homes, it exceeds 20 percent.

We describe two alternative methods to estimate EPCs in the online Appendix. First, auditors from the USDA Office of the Inspector General have studied federal

[18] The average share of home value for each actuarial group is calculated as $\frac{1}{N}\sum\left(\frac{NPVRealizedProtectionCost}{HomeValue}\right)$. This calculation use the subset of homes for which valid arms-length transaction values are reported, which is about 69 percent of homes in the sample. The online Appendix includes more information on transaction values.

TABLE 3—EXPECTED PROTECTION COSTS FOR 8.6 MILLION WESTERN HOMES

		Per home				
	Homes (M)	Mean	P50	P90	P95	P99
Suppression only ($, NPV)	8.63	1,317	825	2,607	4,189	13,582
Share of value (%)		0.6	0.2	0.9	1.8	7.4
All sources ($, NPV)	8.63	3,749	2,314	7,394	11,718	38,284
Share of value (%)		1.7	0.5	2.6	5.1	21.0
California ($, NPV)	3.48	4,345	2,638	9,883	13,859	27,516
Share of value (%)		1.5	0.5	2.5	4.9	19.4

Notes: The table describes the distribution of expected protection costs for homes in the western United States. These costs represent the additional costs incurred by the federal government to protect each home and are calculated using 210 actuarial groups based on six categories of landscape fire hazard, five categories of housing density, and seven wildland firefighting dispatch regions (GACC regions). The "suppression-only," "all-sources," and "California" cost measures include different categories of costs as described in the text. The costs in rows 1, 3, and 5 are net present values in 2017 dollars using a 5 percent discount rate. Rows 2, 4, and 6 show these expected NPV costs as a proportion of transaction value.

firefighting expenditures using interview methods. USFS managers report that in their experience, 50 to 95 percent of USFS firefighting expenditures are devoted to protecting private structures (USDA Office of Inspector General 2006). Accordingly, our first method reports implicit subsidy estimates that ignore the regression results in Equation 1 and instead use these interviews to identify the share of firefighting expenditures devoted to protecting homes. Specifically, we assume that protecting homes accounts for 72.5 percent of each fire's costs (the midpoint of the reported range). Second, we employ a machine-learning approach to calculating expected protection costs. Rather than taking averages over prespecified hazard, density, and geographic categories, we instead employ a regression tree method to construct actuarial groups that minimize the prediction error for realized protection costs in each group. The online Appendix documents that the distribution of homeowner-level implicit subsidies produced by these two alternative methods is similar to those in Table 3.

D. *Results: Geographic Incidence*

Figures 6 and 7 show regional and local variation in expected protection costs. Both maps plot the ex ante expected protection cost estimates from Section VC. Figure 6 shows averages of these expected costs in 15-kilometer hexagonal cells covering the western United States using the "all-sources" cost measure (results for the other cost measures are in online Appendix C.C.2). The color scale indicates costs and is top-coded so that the darkest red corresponds to per home expected protection costs of $50,000 or more. Expected protection costs are highest in Northern California, central Oregon and Washington, and Idaho and western Montana. These are sparsely populated areas with many areas of high fire hazard.

Protection from wildfires is a surprisingly large part of the bundle of federal benefits to households in these areas. To contextualize our findings, the annual implicit subsidies to homeowners in Montana and Idaho via firefighting are larger than federal transfers to those states under the Temporary Assistance to Needy Families

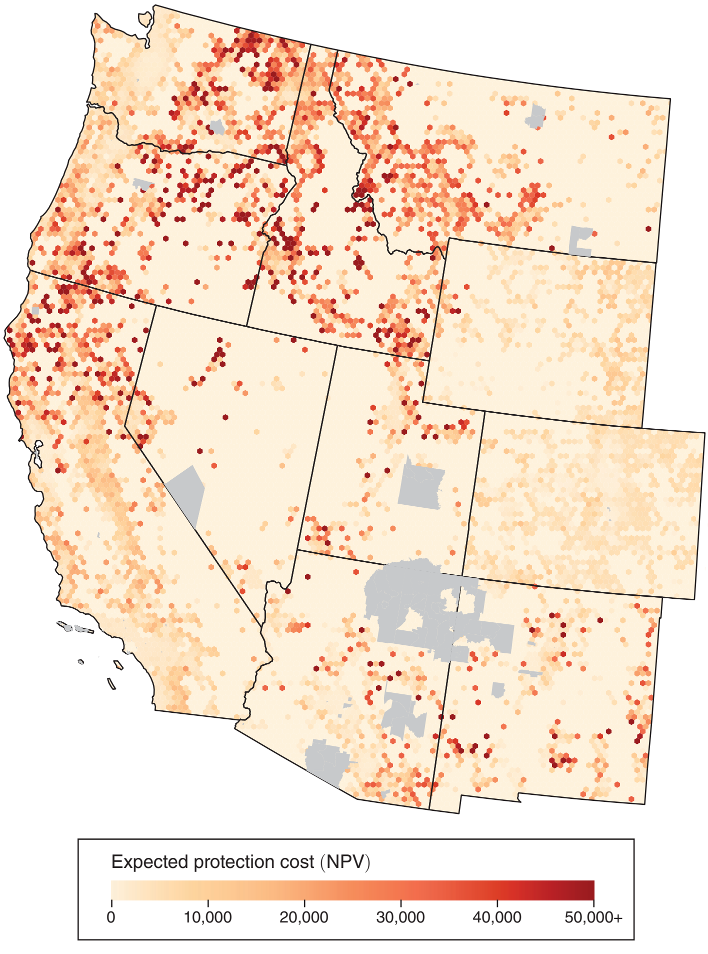

Figure 6. Expected Protection Costs (West-Wide)

Notes: Figure shows average expected protection costs for all single-family homes in the WUI, averaged across 15-kilometer hex cells. Scale is top-coded at \$50,000 per home; gray areas indicate missing data. Estimates of expected protection cost use the "all-sources" cost metric and are calculated as an NPV with a 5 percent discount rate.

(TANF) program (see citation in Footnote 3). Notably, Southern California, which also experiences frequent wildfires, has a somewhat lower expected protection cost. Greater development density in fire-prone parts of Southern California likely reduces per home firefighting costs.

Figure 7 shows the substantial local variation in expected protection costs using smaller, five-kilometer cells. The top panel shows Shasta County in Northern California. Expected protection costs are several hundred dollars per home or less in the more densely developed areas of central Redding and Anderson. Outside of these urban areas, wildfire hazard increases and density decreases rapidly, resulting in much higher expected protection costs. In more remote areas bordering national forests and other public wildlands, costs are tens of thousands of dollars per home. These areas have a high underlying physical hazard of fire, meaning that homes built here are likely to repeatedly require costly firefighting efforts to avoid destruction.

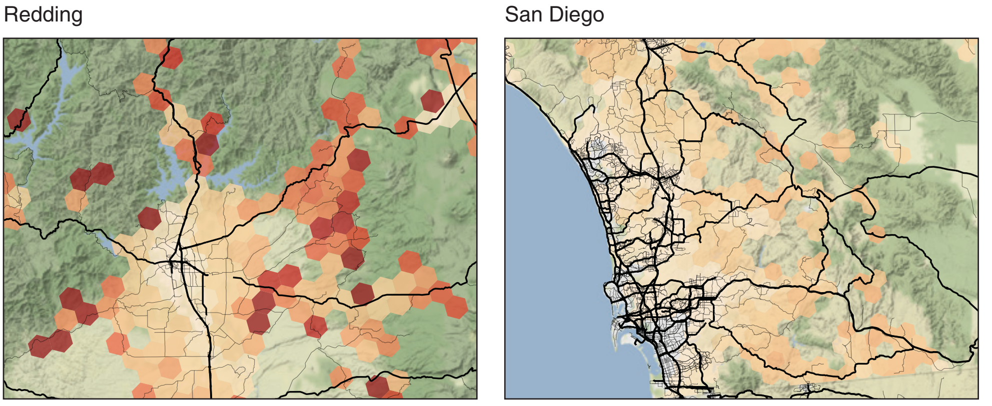

Figure 7. Expected Protection Costs (Local Variation)

Notes: The figure shows average expected protection costs for all single-family homes in the wildland–urban interface (WUI) in Shasta County, California and San Diego County, California averaged across five-kilometer hex cells. The scale is top-coded at $50,000 per home. Estimates of expected protection cost use the "all-sources" cost metric and are calculated as an NPV with a 5 percent discount rate.

In addition, these areas include fewer total homes, raising the per home cost of firefighting. The bottom panel shows San Diego County. Again, expected protection costs are low in the densely developed urban area and higher in the high-fire-hazard, low-density areas near federal- and state-owned lands in the eastern part of the county.

E. *Results: Incidence across Income Groups*

A frequent claim about wildland firefighting is that it mostly benefits the rich (for example, Davis 1995). Our data tell a different story. Figure 8 shows that, on average, homes in low-income parts of the West receive larger implicit subsidies than in high-income areas (probably because expected protection costs are highest in rural and semirural areas). Panel B considers the transaction value of the home, which is a strong predictor of total wealth for most American homeowners. Again, lower-value homes have higher protection costs, on average.[19]

VI. Discussion

This section considers economic and policy implications of our estimated WUI subsidies. Section VIA considers potential efficiency costs. Section VIB discusses policies that could internalize the externalities that we measure.

[19] In this sense, fire protection differs from some other federal environmental programs. The National Flood Insurance Program, the Superfund program, and clean energy tax credits have all been shown to favor higher-income households (Kahn and Smith 2017; Sigman 2001; Borenstein and Davis 2016).

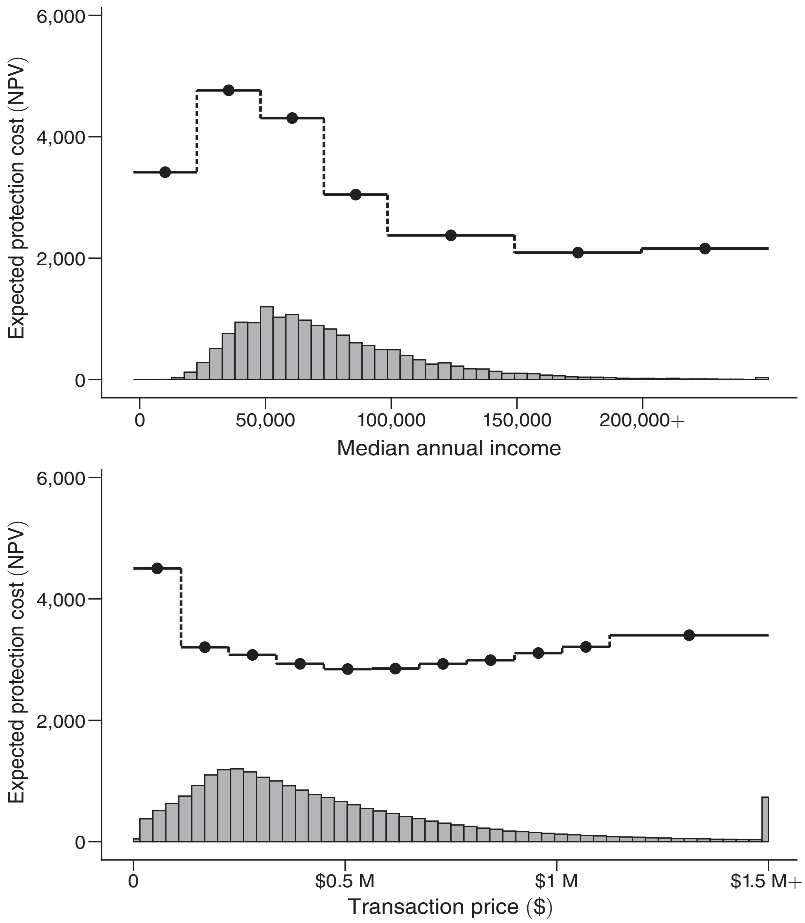

Figure 8. Expected Protection Cost by Income and Home Value

Notes: The figure shows how expected protection costs vary by income and transaction value. The black step function in each panel shows average expected protection costs for each bin of income or transaction value. The gray density shows the distribution of homes. Each home is assigned the median annual income for its census block group from the 2015 American Community Survey.

A. *Potential Implications for Economic Efficiency*

Following the logic of Section II, we separately consider the costs of expanding the WUI footprint into undeveloped areas, adding additional homes in developed areas, and crowding out private protective investments.

Expansion into New High-Risk Areas.—The trend of WUI expansion in high-fire-hazard zones is predicted to continue throughout the West (Gude, Rasker and van den Noort 2008; Mann et al. 2014). Our results imply that the total costs of such expansions can be well above the costs felt by local decision makers. Table 4 shows average expected protection costs as a share of transaction values

Table 4—Implied Changes in Housing Quantity

Fire hazard	Density	EPC ($)	% of price	Homes	% increase Q
Panel A. Highest-hazard areas					
5	1	60,957	30.5	13,446	15.3
4	1	49,584	48.2	36,263	23.7
1–3	1	23,820	23.7	138,421	14.1
5	2	21,828	13.3	16,022	9.7
4	2	24,912	14.6	35,044	10.2
1–3	2	12,487	9.2	165,688	7.1
5	3	10,207	4.6	28,254	4.1
4	3	14,704	7.1	63,261	6.0
1–3	3	6,577	4.3	271,800	3.7
5	4	10,004	4.3	53,332	3.8
4	4	8,173	3.1	139,800	2.8
1–3	4	4,451	2.4	576,875	2.2
5	5	5,244	1.9	66,779	1.8
4	5	3,325	1.2	301,220	1.1
1–3	5	1,717	0.7	1,646,126	0.7
Panel A Total		5,809	3.7	3,552,331	2.7
Panel B. All other WUI areas					
0	1–5	2,309	1.0	5,081,459	1.0

Notes: The table summarizes subsidy rates and back-of-the-envelope quantity changes using the fire hazard and density categories described in the text. "EPC" is the number-of-homes–weighted average of expected protection costs (NPV, 2017 dollars) across geographic regions. "Percent of price" is the average share of transaction value. "Homes" is the number of homes in each row. "Percent increase Q" is the estimated percentage change in the number of homes due to the implicit subsidy from fire suppression. See Section VIA for details.

for various levels of fire hazard and housing density. Panel A shows detailed estimates for wildfire hazard potential (WHP) classes 1 to 5. The column titled "percent of price" shows that the estimated subsidy rates for the highest-cost categories are strikingly high, topping out at a subsidy rate of above 30 percent for more than 49,000 homeowners in the highest-fire-hazard, lowest-density parts of the West. The logic of Section II means that private willingness-to-pay (WTP) for homes in such areas would have to be substantially above private cost for this type of development to improve welfare. The later rows of panel A show that new development at higher densities can be justified by lower private WTP. Finally, panel B separately summarizes subsidy rates for WUI homes in the lowest-fire-hazard areas (WHP class 0), which average about 1 percent of home value.

The final column of Table 4 uses these subsidy rates to conduct a counterfactual thought exercise. This simplified back-of-the-envelope calculation supposes that a local decision maker in each area makes a one-shot decision about the level of development, starting from a base of no WUI homes. Given our estimates and elasticity values from the literature, we can calculate the deviation from the counterfactual home quantity q_0 that would have been chosen if homeowners or local governments were required to pay the expected protection cost for each WUI home. Define τ as the expected protection cost; p as the observed transaction value, which is assumed to equal the constant marginal cost of supplying housing; and counterfactual user cost $p_0 = p + \tau$. The assumption of perfectly elastic WUI supply reflects abundant land for development and few regulatory constraints in the exurban and rural areas where we are focused. The demand elasticity is ϵ, which we set at -1.0 based on existing evidence.[20] The percentage increase in the decisionmaker's chosen housing quantity in a given area due to the subsidy is $\frac{\Delta q}{q_0} = \epsilon \frac{\tau}{p_0}$. Table 4 shows that the implied effects on historical expansion of the WUI are large in high-cost places, reaching above 10 percent for several area categories. The subtotal row for panel A shows that the cumulative effect across groups is a 2.7 percent increase in WUI footprint, which represents about 96,000 additional high-risk WUI homes caused by the subsidy. The estimates in Panel B imply an additional increase of about 48,000 homes.

This calculation ignores many important complications of housing markets and urban development, and the resulting values should thus be interpreted with caution. We leave more detailed calibrations for future work but note two reasons that this approximation may understate the future economic costs of subsidized WUI fire protection. First, our estimates are based on historical averages and thus underestimate future protection costs due to the worsening wildfire problem. Second, this distortion may interact with other distortions—such as the favorable tax treatment of home mortgage interest and zoning restrictions in urban areas—that encourage development outside of cities.

Already-Developed Areas and Private Protective Investments.—We find that once development passes a low threshold, the marginal costs of adding homes in already-developed areas are small even in high-hazard areas. This is because beyond low net densities, the cost of protecting homes during a fire increases very little with additional development. One way of interpreting these economies of density is that firefighting techniques such as bulldozing firelines and deploying aircraft include a fixed-cost component. Once the number of homes in the path of the blaze is large enough to justify such expenditures, additional threatened homes introduce little additional cost. This finding implies that pricing fire protection for new homes at its expected marginal cost could incentivize shifting construction toward already-developed WUI areas and away from undeveloped or sparsely developed locations.

The subsidies we measure may also have implications for risk-reducing investments, particularly fire-resistant construction materials and landscaping practices.[21] Takeup of these "home-hardening" investments is persistently low (Champ, Donovan, and Barth 2013; Dickinson et al. 2015). The externalities that we measure could rationalize limited effort by local governments to mandate such investments through building codes and inspections. In California, for example, local governments have historically resisted the adoption of recommended WUI building codes

[20] The demand elasticity reflects adjustments in both long-distance migration and within-city location choice. Polinsky and Ellwood (1979) finds that the price elasticity of demand for new, detached single-family housing is about -1.0. In a setting somewhat related to ours, Gregory (2017) argues that the long-run population elasticity may be as large as -2.0 based on post-hurricane resettlement decisions for young people and on Kennan and Walker (2011). Anas and Chu (1984) find a within-city location choice elasticity of between -0.27 and -0.87. On the supply side, Saiz (2010) reports elasticities of -1.53, -1.67, and -2.27 for the Denver, Colorado Springs, and Albuquerque areas. These parameters reflect both urban centers and WUI areas and thus likely understate the WUI elasticity. Topel and Rosen (1988) find a US-wide supply elasticity for new housing starts of -3.0. Moreover, the prices we observe are near the minimum profitable construction costs presented in Glaeser and Gyourko (2018).

[21] The expanded theoretical discussion in the online Appendix develops this potential link more fully.

(Miller, Field, and Mach 2020). In fact, reducing the state government's firefighting costs has long been a key argument of policy makers seeking to mandate statewide WUI building standards.[22] Similarly, the USDA Inspector General wrote in 2006 that "[h]omeowner reliance on the federal government to provide wildfire suppression services […] removes incentives for landowners moving into the WUI to take responsibility for their own protection and ensure their homes are constructed and landscaped in ways that reduce wildfire risks" (USDA Office of Inspector General 2006). We see these private and municipal investments as an important area for additional empirical research.

B. *Policies to Internalize Protection Costs*

One candidate policy to mitigate these potential distortions would be to require home builders to pay a fee equal to the net present value of expected protection costs when building a new home in an undeveloped or sparsely developed area. The empirical analysis in this study provides a road map for calculating this spatially specific corrective tax.[23]

In 2014, California began requiring homeowners in the CAL FIRE protection area to pay an equal annual fee of about $150 per year. The fee proved unpopular among homeowners and was suspended in 2017. This study shows that such a fee would need to be much more geographically differentiated in order to correct incentives (as opposed to simply raising revenue). On the other hand, our finding that fire protection spending is concentrated among low-income homeowners means that the design of corrective fees would also need to consider distributional issues. One lesson from this study is that it might be possible to exempt existing homes from such a policy while largely preserving the effect on development incentives, since the protection costs we estimate are not generally high enough to justify the abandonment of existing homes.

An alternative would be to assign firefighting costs to local governments, which would recover them through property taxes or other measures. This approach would incentivize cities and counties to consider fire protection costs in zoning, land use, and building codes. Firefighting could continue to be supplied via the current system of west-wide dispatch, with local governments reimbursing federal agencies for a larger share of costs. A third option, if legally and politically feasible, would be to recover firefighting costs from insurance companies holding homeowners' policies near the ignition point of the fire. Such a rule would increase insurance premiums according to expected firefighting costs.

[22] For example, a statewide ban on untreated wood roofing shingles in 1999 was presented as a measure to reduce the state's firefighting costs: CAL FIRE "is financially responsible for preventing and suppressing fires in 'state responsibility areas' […] Replacing and repairing roofs with fire-retardant roofing materials provides greater fire protection to all structures and lowers public fire suppression costs." See California Assembly Bill 423; Senate Floor Analysis; August 18, 1999; page 3.

[23] Importantly, the effect of such a policy does not depend on the accuracy of individuals' beliefs about wildfire risk. A tax computed by the government and paid at the time of construction would presumably make the external costs of fire protection highly salient.

VII. Conclusion

Unlike other natural hazards, a large share of the total costs of wildfires are due to costly efforts to prevent property damage. We find that protection of private homes accounts for most of the billions of dollars spent by the federal and state governments to combat wildfires each year. Decisions by homeowners and local governments about the construction and maintenance of homes in the WUI therefore generate large cost externalities. We also find that beyond low levels of development, the marginal effect of additional homes on firefighting expenditures is surprisingly small.

We use our results to calculate spatially differentiated implicit subsidies for homeowners throughout the western United States. Wildfire protection represents a large transfer of federal and state revenues to homeowners in high-cost places, making it an important mechanism for redistribution to rural and exurban areas that has not been fully appreciated by economists. Our back-of-the-envelope calculations suggest that free federal fire protection may have increased development in high-fire-hazard areas by 2.5 percent overall and by substantially more than that in the highest-risk areas. The estimated protection costs call into question the net social benefits of converting undeveloped and sparsely developed wildland areas to low-density housing use, a type of new development that is predicted to be widespread in coming decades. At the same time, the low marginal protection costs that we measure in already-developed areas imply substantial benefits from clustered development. The effect of free federal fire protection on individual and municipal incentives for fire-resistant construction and maintenance is an important area for future empirical research.

This study also provides a road map for calculating a spatially differentiated "fire protection fee" for new construction that reflects the expected future costs that would be incurred to protect the home. Such a policy applied to individuals or local governments would change incentives for development in high-hazard areas.

Our estimates are conservative in that they do not take into account predicted increases in wildfire in the coming years and decades due to climate change. Climate scientists project substantial increases (up to 50 percent) in the total area burned annually in the United States by the middle of the twenty-first century (Spracklen et al. 2009; Westerling et al. 2011). These increases in fire danger will imply greater fire protection costs and thus larger implicit subsidies to WUI homeowners in the future.

More broadly, this study underscores the importance of institutions in adapting to climate change. The costs of inefficient policies will increase as the climate warms. For wildfires, as for many other impacts of climate change, the ultimate costs of a warmer planet will be determined not only by the degree of physical change but also by the mediating influence of public policy.

REFERENCES

Abatzoglou, John T., and A. Park Williams. 2016. "Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests." *Proceedings of the National Academy of Sciences* 113 (42): 11770–75.

Anas, Alex, and Chaushie Chu. 1984. "Discrete Choice Models and the Housing Price and Travel to Work Elasticities of Location Demand." *Journal of Urban Economics* 15 (1): 107–23.

Arno, Stephen F., and Steven Allison-Bunnell. 2002. *Flames in Our Forest: Disaster or Renewal?* Washington, DC: Island Press.

Auffhammer, Maximilian. 2022. "Climate Adaptive Response Estimation: Short and Long Run Impacts of Climate Change on Residential Electricity and Natural Gas Consumption." *Journal of Environmental Economics and Management* 114: 102669. https://doi.org/10.1016/j.jeem.2022.102669.

Balch, Jennifer K., Bethany A. Bradley, John T. Abatzoglou, R. Chelsea Nagy, Emily J. Fusco, and Adam L. Mahood. 2017. "Human-Started Wildfires Expand the Fire Niche across the United States." *Proceedings of the National Academy of Sciences* 114 (11): 2946–51.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. 2016. "Adapting to Climate Change: The Remarkable Decline in the US Temperature–Mortality Relationship over the Twentieth Century." *Journal of Political Economy* 124 (1): 105–59.

Baylis, Patrick and Justin Boomhower. 2023. "Replication Data for: The Economic Incidence of Wildfire Suppression in the United States." American Economic Association [publisher], Inter-university Consortium for Political and Social Research [distributor]. https://doi.org/10.3886/E144601V1.

BIA (**Bureau of Indian Affairs**)**.** 2017. "BIA Incident Suppression Costs." Unpublished (accessed June 15, 2018).

BLM (**Bureau of Land Management**)**.** 2017. "BLM Incident Suppression Costs." Unpublished (accessed June 15, 2018).

Borenstein, Severin, and Lucas W. Davis. 2016. "The Distributional Effects of US Clean Energy Tax Credits." *Tax Policy and the Economy* 30 (1): 191–234.

Boustan, Leah Platt, Matthew E. Kahn, and Paul W. Rhode. 2012. "Moving to Higher Ground: Migration Response to Natural Disasters in the Early Twentieth Century." *American Economic Review* 102 (3): 238–44.

Brueckner, Jan K. 1997. "Infrastructure Financing and Urban Development: The Economics of Impact Fees." *Journal of Public Economics* 66 (3): 383–407.

Burke, Marshall, and Kyle Emerick. 2016. "Adaptation to Climate Change: Evidence from US Agriculture." *American Economic Journal: Economic Policy* 8 (3): 106–40.

CAL FIRE (**California Department of Forestry and Fire Protection**)**.** 2016. "CAL FIRE Incident Suppression Costs." Unpublished (accessed June 15, 2018).

Champ, Patricia A., Geoffrey H. Donovan, and Christopher M. Barth. 2013. "Living in a Tinderbox: Wildfire Risk Perceptions and Mitigating Behaviours." *International Journal of Wildland Fire* 22 (6): 832–40.

CIESIN (Center for International Earth Science Information Network). 2017. "Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 10" (accessed June 15, 2018).

CoreLogic, Inc. 2014. "Parcel Deed and Tax Data." Proprietary data access agreement with Stanford University (accessed November 27, 2018).

Davis, Mike. 1995. "The Case for Letting Malibu Burn." *Environmental History Review* 19 (2): 1–36.

DOI (Department of the Interior). 2018. "DOI Budget Justifications." https://www.doi.gov/bpp/budget-justifications (accessed June 17, 2018).

Deryugina, Tatyana. 2017. "The Fiscal Cost of Hurricanes: Disaster Aid versus Social Insurance." *American Economic Journal: Economic Policy* 9 (3): 168–98.

Dickinson, Katherine, Hannah Brenkert-Smith, Patricia Champ, and Nicholas Flores. 2015. "Catching Fire? Social Interactions, Beliefs, and Wildfire Risk Mitigation Behaviors." *Society and Natural Resources* 28 (8): 807–24.

Dillon, Gregory K. 2015. "Wildfire Hazard Potential for the Coterminous United States." Forest Service Research Data Archive. https://www.fs.usda.gov/rds/archive/catalog/RDS-2015-0046 (accessed June 15, 2018).

Donovan, Geoffrey H., Patricia A. Champ, and David T. Butry. 2007. "Wildfire Risk and Housing Prices: A Case Study from Colorado Springs." *Land Economics* 83 (2): 217–33.

Faivre, Nicolas, Yufang Jin, Michael L. Goulden, and James T. Randerson. 2014. "Controls on the Spatial Pattern of Wildfire Ignitions in Southern California." *International Journal of Wildland Fire* 23 (6): 799–811.

FEMA (**Federal Emergency Management Agency**)**.** 2018. "FEMA Reimbursements." Unpublished (accessed June 17, 2018).

Gebert, Krista M., David E. Calkin, and Jonathan Yoder. 2007. "Estimating Suppression Expenditures for Individual Large Wildland Fires." *Western Journal of Applied Forestry* 22 (3): 188–96.

Glaeser, Edward, and Joseph Gyourko. 2018. "The Economic Implications of Housing Supply." *Journal of Economic Perspectives* 32 (1): 3–30.

Gregory, Jesse. 2017. "The Impact of Post-Katrina Rebuilding Grants on the Resettlement Choices of New Orleans Homeowners." Unpublished.

Gude, Patricia, Ray Rasker, and Jeff van den Noort. 2008. "Potential for Future Development on Fire-Prone Lands." *Journal of Forestry* 106 (4): 198–205.

Gude, Patricia H., Kingsford Jones, Ray Rasker, and Mark C. Greenwood. 2013. "Evidence for the Effect of Homes on Wildfire Suppression Costs." *International Journal of Wildland Fire* 22 (4): 537–48.

Halvorsen, Robert, and Raymond Palmquist. 1980. "The Interpretation of Dummy Variables in Semilogarithmic Equations." *American Economic Review* 70 (3): 474–75.

Hammer, Roger B., Susan I. Stewart, and Volker C. Radeloff. 2009. "Demographic Trends, the Wildland–Urban Interface, and Wildfire Management." *Society and Natural Resources* 22 (8): 777–82.

Hill, Elizabeth G. 2005. "A Primer: California's Wildland Fire Protection System." California Legislative Analyst's Office. April 12. https://lao.ca.gov/2005/fire_protection/051205_fire_protection.pdf. (accessed September 23, 2022).

Hoover, Katie, and Bruce R. Lindsay. 2017. *Wildfire Suppression Spending: Background, Issues, and Legislation in the 115th Congress*. Washington, DC: Congressional Research Service.

Kahn, Matthew E., and V. Kerry Smith. 2017. "The Affordability Goal and Prices in the National Flood Insurance Program." NBER Working Paper 24120.

Kennan, John, and James R. Walker. 2011. "The Effect of Expected Income on Individual Migration Decisions." *Econometrica* 79 (1): 211–51.

Kennedy, Peter. 1981. "Estimation with Correctly Interpreted Dummy Variables in Semilogarithmic Equations." *American Economic Review* 71 (4): 801.

Kousky, Carolyn, and Sheila M. Olmstead. 2012. "Induced Development in Risky Locations: Fire Suppression and Land Use in the American West." Unpublished.

Kousky, Carolyn, Erzo F.P. Luttmer, and Richard J. Zeckhauser. 2006. "Private Investment and Government Protection." *Journal of Risk and Uncertainty* 33 (1): 73–100.

Liang, Jingjing, Dave E. Calkin, Krista M. Gebert, Tyron J. Venn, and Robin P. Silverstein. 2008. "Factors Influencing Large Wildland Fire Suppression Expenditures." *International Journal of Wildland Fire* 17 (5): 650–59.

Loomis, John. 2004. "Do Nearby Forest Fires Cause a Reduction in Residential Property Values?" *Journal of Forest Economics* 10 (3): 149–57.

Lueck, Dean, and Jonathan Yoder. 2016. *Clearing the Smoke from Wildfire Policy: An Economic Perspective*. Bozeman, MT: Property and Environmental Research Center.

Mann, Michael L., Peter Berck, Max A. Moritz, Enric Batllori, James G. Baldwin, Conor K. Gately, and D. Richard Cameron. 2014. "Modeling Residential Development in California from 2000 to 2050: Integrating Wildfire Risk, Wildland, and Agricultural Encroachment." *Land Use Policy* 41: 438–52.

Martinuzzi, Sebastián, Susan Stewart, David Helmers, Miranda Mockrin, Roger Hammer, and Volker Radeloff. 2015. "The 2010 Wildland–Urban Interface of the Conterminous United States." Research Map NRS-8. U.S. Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RMAP-8 (accessed June 15, 2018).

Massada, Avi Bar, Alexandra D. Syphard, Susan I. Stewart, and Volker C. Radeloff. 2012. "Wildfire Ignition-Distribution Modelling: A Comparative Study in the Huron–Manistee National Forest, Michigan, USA." *International Journal of Wildland Fire* 22 (2): 174–83.

McCoy, Shawn J., and Randall P. Walsh. 2018. "Wildfire Risk, Salience, and Housing Demand." *Journal of Environmental Economics and Management* 91: 203–28.

Miller, Rebecca K., Christopher B. Field, and Katharine J. Mach. 2020. "Factors Influencing Adoption and Rejection of Fire Hazard Severity Zone Maps in California." *International Journal of Disaster Risk Reduction* 50: 101686.

NIFC (National Interagency Fire Center). 2019. "National GACC Boundaries." ArcGIS Hub. https://hub.arcgis.com/datasets/nifc::national-gacc-boundaries/about (accessed June 15, 2019).

NIFC (National Interagency Fire Center). 2021. "Federal Firefighting Costs (Suppression Only)." https://www.nifc.gov/fire-information/statistics/suppression-costs.

NPS (National Park Service). 2017. "NPS Incident Suppression Costs." Unpublished (accessed June 15, 2018).

NWCG (National Wildfire Coordinating Group). 2017. "National Fire and Aviation Management Web Applications." Frames. https://www.frames.gov/catalog/8127 (accessed June 15, 2018).

Oster, Emily. 2019. "Unobservable Selection and Coefficient Stability: Theory and Evidence." *Journal of Business and Economic Statistics* 37 (2): 187–204.

Polinsky, A. Mitchell, and David T. Ellwood. 1979. "An Empirical Reconciliation of Micro and Grouped Estimates of the Demand for Housing." *Review of Economics and Statistics* 61 (2): 199–205.

PRISM Climate Group, Oregon State University. 2018. "AN81d." https://prism.oregonstate.edu (accessed June 15, 2018).

Radeloff, V.C., R.B. Hammer, S.I. Stewart, J.S. Fried, S.S. Holcomb, and J.F. McKeefry. 2005. "The Wildland–Urban Interface in the United States." *Ecological Applications* 15 (3): 799–805.

Radeloff, Volker C., David P. Helmers, H. Anu Kramer, Miranda H. Mockrin, Patricia M. Alexandre, Avi Bar-Massada, Van Butsic, Todd J. Hawbaker, Sebastián Martinuzzi, Alexandra D. Syphard, and Susan I. Stewart. 2018. "Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk." *Proceedings of the National Academy of Sciences* 115 (13): 3314–19.

Saiz, Albert. 2010. "The Geographic Determinants of Housing Supply." *Quarterly Journal of Economics* 125 (3): 1253–96.

Sigman, Hilary. 2001. "The Pace of Progress at Superfund sites: Policy Goals and Interest Group Influence." *Journal of Law and Economics* 44 (1): 315–43.

Simon, Gregory L. 2017. *Flame and Fortune in the American West: Urban Development, Environmental Change, and the Great Oakland Hills Fire*. Oakland, CA: University of California Press.

Smith, V. Kerry, Jared C. Carbone, Jaren C. Pope, Daniel G. Hallstrom, and Michael E. Darden. 2006. "Adjusting to Natural Disasters." *Journal of Risk and Uncertainty* 33 (1): 37–54.

Spracklen, D.V., L.J. Mickley, J.A. Logan, R.C. Hudman, R. Yevich, M.D. Flannigan, and A.L. Westerling. 2009. "Impacts of Climate Change from 2000 to 2050 on Wildfire Activity and Carbonaceous Aerosol Concentrations in the Western United States." *Journal of Geophysical Research: Atmospheres* 114 (D20).

Stephens, Scott L., Brandon M. Collins, Eric Biber, and Peter Z. Fulé. 2016. "US Federal Fire and Forest Policy: Emphasizing Resilience in Dry Forests." *Ecosphere* 7 (11): e01584.

Stetler, Kyle M., Tyron J. Venn, and David E. Calkin. 2010. "The Effects of Wildfire and Environmental Amenities on Property Values in Northwest Montana, USA." *Ecological Economics* 69 (11): 2233–43.

Syphard, Alexandra D., Volker C. Radeloff, Jon E. Keeley, Todd J. Hawbaker, Murray K. Clayton, Susan I. Stewart, and Roger B. Hammer. 2007. "Human Influence on California Fire Regimes." *Ecological Applications* 17 (5): 1388–1402.

Topel, Robert, and Sherwin Rosen. 1988. "Housing Investment in the United States." *Journal of Political Economy* 96 (4): 718–40.

USDA Office of Inspector General. 2006. *Forest Service Large Fire Suppression Costs*. Washington, DC: US Department of Agriculture.

USDA (U.S. Department of Agriculture). 2016. "Fiscal Year 2017 Budget Justification." https://www.fs.usda.gov/sites/default/files/fy-2017-fs-budget-justification.pdf (accessed September 23, 2022).

USDA (U.S. Department of Agriculture). 2018. "FY 2019 Budget Justification." https://www.fs.usda.gov/sites/default/files/usfs-fy19-budget-justification.pdf (accessed September 23, 2022).

U.S. Department of the Interior and U.S. Department of Agriculture. 1995. "Federal Wildland Fire Management Policy and Program Review Report." December 18. https://www.forestsandrangelands.gov/documents/strategy/foundational/1995_fed_wildland_fire_policy_program_report.pdf (accessed September 23, 2022).

Westerling, A.L., B.P. Bryant, H.K. Preisler, T.P. Holmes, H.G. Hidalgo, T. Das, and S.R. Shrestha. 2011. "Climate Change and Growth Scenarios for California Wildfire." *Climatic Change* 109 (1): 445–63.