Induced development in risky locations:
fire suppression and land use in the American West[*]

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Abstract

We test the hypothesis that efforts by federal agencies to suppress fire on forestland, grassland and shrubland in the Western United States since 1970 have acted as a development subsidy, drawing new low-density residential and commercial development into regions at risk from wildland fire. The analysis exploits a natural experiment – a major shift in federal fire suppression policy that occurred in the aftermath of catastrophic fires in Yellowstone National Park in 1988. We use the Yellowstone event along with other sources of spatial and temporal variation in the benefits and costs of fire suppression between 1970 and 2000 to identify the effects of fire suppression on development. Results suggest that during periods when the federal government has intensified its expected suppression efforts on public lands, private residential and commercial development has accelerated on nearby land that would benefit from that suppression.

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1. Introduction

Millions of American homeowners have developed new properties in the forests, grasslands and shrublands of the American West in the past few decades. Regions like the Southern California mountains, chaparral, and oak woodlands, a stone's throw from major cities, have high amenity value but may also present substantial risk, including the risk of wildfire. Economists have demonstrated that subsidizing development in coastal and other flood-prone regions, through direct infrastructure investment, provision of insurance below actuarially fair rates, and other means may induce development in these regions. In contrast, little attention has been paid to the role of public policies at the federal or any other level in drawing people and structures into regions prone to wildfire. This paper investigates whether federal fire suppression efforts over many decades have acted as an implicit subsidy, inducing development in risky areas.

In 2000, 12.5 million U.S. homes were within the wildland/urban interface (WUI), suburban and exurban areas where homes and other structures intermingle with fire-prone vegetation – a 52 percent increase over 1970. A majority of these (65 percent) are in what ecologists describe as high-severity fire regime classes (Theobald and Romme 2007). In California's San Diego county, alone, three out of four homes built since 1990 are within the WUI. Looking forward, U.S. land in developed uses is expected to increase by 70 million acres between 2003 and 2030, with the largest fraction converted from forests (Alig and Plantinga 2004).

The devastating effects of wildfires in developed areas have drawn significant public attention in recent years. A single fire north of Los Angeles that began in August 2009, the "Station Fire," required fire suppression expenditures of more than $100 million, killed two firefighters, burned many civilians, and destroyed about 90 homes. The 1991 Oakland/Berkeley Hills fire, the worst in California's history, killed 25 people, injured 150, and caused an estimated $1.5 billion in other damages (Carle 2002). Large wildfires affecting residential areas are also common in other high-growth states such as Nevada, Arizona, New Mexico, Colorado, and Washington.[1] The subject is of international importance, as well. In February 2009, more than 200 people were killed when brushfires in Australia burned out of control through residential areas. Forest fires in southern Greece in summer 2007 killed 84 people.

While the benefits of development in forested and fire-prone regions are enjoyed by landowners, the costs of fire suppression, when fires occur, are borne by taxpayers at large.[2] The federal government has played a significant role in wildland fire suppression since approximately 1910. Recent trends in public sector spending on fire suppression are striking. During the decade ending in 1980, the U.S. Forest Service (USFS), which receives about 70 percent of the funds appropriated by Congress for wildfire preparedness and operations, spent $340 million per year, on average, fighting fires; for the decade ending in 2005, expenditures averaged $685 million per year, with annual expenditures in three of those years exceeding $1 billion (Calkin *et al*. 2005).[3] Many state governments also spend significant resources fighting wildfires.[4]

Research in the natural and physical sciences has focused on the causes of an observed increase in U.S. forest fire incidence and acres burned. Natural scientists attribute some of the increase to

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[1] The 2010 fire season has already seen Colorado's most expensive wildfire on record, the Fourmile fire, which destroyed 169 homes near Boulder, CO with total insurance claims of $217 million as of September 20, 2010.

[2] Landowners in fire-prone regions may feel entitled to such subsidies. In the aftermath of the Station Fire, a homeowner quoted in the *Los Angeles Times*, in an article critical of cost-cutting at the U.S. Forest Service, notes: "If their main concern was balancing the budget instead of saving homes, there's something wrong with those priorities" (Pringle 2009).

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

[4] Annual emergency fire suppression expenditures made by the California Department of Forestry and Fire Protection (CalFIRE) averaged $51.5 million per year, 1979-1989; and $258 million per year, 1998-2008 – more than a fivefold increase in less than three decades. See http://www.fire.ca.gov/fire_protection/downloads/Summaryfirecosts05_06.pdf.

climate change, land management changes (primarily grazing and logging practices, which have changed the forest fuel regime in many systems), and the effect of these two forces in combination (Westerling *et al*. 2006, Johnston *et al*. 2009, Calkin *et al*. 2005, Prestemon *et al*. 2002). The observed increase in large Western wildfires may be one important factor contributing to rising suppression expenditures. However, a recent audit of USFS fire suppression costs suggests that the most significant cause of the increase in suppression expenditures is the agency's "efforts to protect private property in the wildland urban interface" (U.S. Department of Agriculture 2006). New development increases suppression costs because it is more difficult, dangerous, and costly to fight fires when people and structures must be protected.

Viewing the problem through the lens of economics, we examine whether federal fire suppression induces land development in fire-prone regions in the U.S. West, an important behavioral factor that has been overlooked. If this is the case, suppression and development may follow each other, in a repeating cycle of increasing social cost. We conduct an econometric analysis of U.S. land-cover trends to estimate the impacts of fire suppression policies on land development, controlling for other factors. Our methods hinge on our ability to identify the effects of changes in the intensity of public fire suppression activities. We exploit temporal and spatial variation in the benefits and costs of federal fire suppression between 1970 and 2000 to identify the effects of suppression on development, relying heavily on a major change in federal fire suppression policy that took place as a result of severe fires affecting Yellowstone National Park in 1988. Results suggest that during periods when the federal government has intensified its expected suppression efforts on public lands, private residential and commercial development has accelerated on nearby land that would benefit from that suppression.

Our work on this issue is related to several other questions in the economics literature. Subsidized insurance and federally-funded risk reduction for other natural hazards, such as floods and droughts, have been demonstrated to influence patterns of land development, particularly for agricultural and residential development. Subsidies that reduce crop insurance premium rates below actuarially fair levels may increase the amount of land farmers cultivate; agricultural disaster payments have a similar effect (Goodwin *et al*. 2004, Wu 1999). Other research has found some evidence that federal flood projects can induce development in the protected area (Krutilla 1966) and that federal flood control and drainage projects have induced conversion of land from forested wetlands to agriculture (Stavins and Jaffe 1990). Examination of coastal areas suggests that the availability of flood insurance through the National Flood Insurance Program may spur development, and certainly does not hinder it (Cross 1989; Cordes and Yezer 1998).

While a small literature models economically optimal public fire suppression effort (see, e.g., Prestemon *et al*. 2001, Yoder 2004, Mercer *et al*. 2007), we know of no prior research examining the potentially critical link between suppression and development. The problem of development in the fire-prone WUI is made even more critical by the demonstrated impacts of climate change on the frequency of large fires in the U.S. West. At the same time that wildland fires are expected to increase in frequency and intensity, other extreme events such as floods, droughts, and hurricanes may also occur more frequently. Our research on the ties between land development and public policy regarding fire risk is tightly linked to the issue of disaster mitigation, more broadly. Lessons learned from this research could prove useful in thinking about policy responses to the existing context, in which significant populations are already at risk, and policy strategies going forward, which may influence the direction of future land development so as to mitigate risk.

2. Policy background and identification strategy

Panel data on annual federal fire suppression expenditures are readily available (at least for the USFS). The simplest approach to testing our hypothesis might be to regress some measure of land development on suppression expenditures. However, this approach would generate biased estimates, due to the endogeneity of suppression expenditures. Development in the WUI appears to increase fire incidence (Cardille *et al*. 2001), as well as the costs of suppression, conditional on fire occurrence, since fire fighting is complicated by development (Gill and Stephens 2009). Thus, while our hypothesis is that suppression expenditures induce development, it is also likely that development increases suppression expenditures.

Seeking an experimental approach out of this conundrum, we turned to the history of federal fire policy. Between approximately 1910 and the late 1970s, public land management policy reflected the conventional wisdom that fire was a hazard that had to be stopped in all circumstances, lest it destroy valuable natural resources. From 1933 through 1978, federal agencies followed the so-called "10am policy": they attempted to extinguish any wildland fire, no matter how it started, by 10:00 on the morning after the fire was detected (Carle 2002). If they did not succeed, they continued their effort, with a new goal of extinguishing the fire by 10:00 on the following morning, continuing in this manner until the fire was out.

However, ecologists had recognized since the early 1900s that fire was an essential part of some forest ecosystems.[5] This point was controversial, and it filtered slowly into public policy. U.S. federal

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[5] One of the first published indications that extinguishing all wildland fires could cause ecological harm was a study suggesting that longleaf pine forests in the American Southeast could not survive without periodic fire, which promoted new seedlings and enabled the trees to compete with other species (Chapman 1932). Ecologist Harold

policy toward wildland fire began to reflect the emerging consensus that some fires must be allowed to burn, or, alternatively, agencies might use "prescribed burns" (setting controlled fires) to simulate the effects of natural fire, at reduced risk (Carle 2002, Gorte 2006). Several federal agencies, most notably the National Park Service and then USFS, began experimenting with so-called "fire management" policies that allowed some "let burns" and prescribed burns. This shift took place slowly during the early and mid-1970s, and in 1978, total fire management became the policy relevant to all federal lands, officially replacing the 10am policy (Carle 2002).[6]

A decade later, more than 1 million acres in Yellowstone National Park were affected by a set of massive fires in Summer and Fall 1988. The largest of these fires was ignited by a carelessly tossed cigarette. There is wide scientific agreement that such major fires were important to the Yellowstone ecosystem, had occurred naturally every 200-400 years, and were overdue. Nonetheless, at least one of the major fires in Yellowstone was an escaped prescribed burn, and the public was outraged. A *New York Times* front-page headline on September 22, 1988 claimed: "Ethic of protecting land fueled Yellowstone's fires". The Yellowstone fires resulted in a backlash against the federal shift to fire management, with an immediate effect on policy (Elfring 1989). For example, prescribed burning by the National Park Service fell from 32,135 acres per year from 1983-1988 to 3,708 acres per year between 1990 and 1994. The effects of the Yellowstone fire waned slowly after 1989, and fire management was again the dominant policy by the early 1990s (Carle 2002).[7]

Biswell's work from the 1940s through the early 1960s suggested that, where fires were suppressed over long periods in the ponderosa pine of California, the resulting fuel buildup generated far more destructive "crown fires," rather than the slow-burning understory fires that occurred pre-suppression (Biswell 1989).

[6] The shift from total fire suppression to fire management took place much earlier in the South (around 1943) than in the rest of the U.S. (Carle 2002). The fact that wildfire-vulnerable lands in the South are predominantly in private ownership provides an interesting distinction (Butry *et al*. 2001). Since most forested lands in the Southeast were managed by private firms for timber and paper production, dynamic profit maximization required the recognition of the natural role of fire in these ecosystems.

[7] The shift back to fire management was influenced by continued scientific evidence supporting a more pragmatic view of the ecological role of fire, as well as several high-profile firefighter deaths during suppression efforts during

This history of major changes in federal fire suppression policy provides a pair of potential experiments. Our hypothesis regarding the link between suppression and development would suggest that the drop in public fire suppression from the policy shift during in the 1970s, all else equal, may have slowed the rate of development on or near lands protected by federal fire suppression efforts. Similarly, if fire suppression increased after the 1988 Yellowstone fires, our hypothesis would suggest an uptick in the rate of development, which would lose momentum as policy shifted again in the early 1990s. The first of these two shifts, while potentially more important from a welfare perspective due to its lasting nature, is simply not "sharp" enough to exploit statistically. The second shift, due to the Yellowstone fires, was sudden, unexpected, and exogenous to other trends in both land development and federal policy. It is, thus, an ideal candidate for a natural experiment, and we exploit it for this purpose.

Our statistical approach also relies on the likely differential spatial effects of federal fire policy shifts, which may depend on: (1) how close a parcel of land is to federal lands within the "umbrella" of federal fire suppression efforts, and (2) how susceptible the parcel is to wildfire. Unlike in the East, a large majority of Western land is owned and managed by federal agencies. Federal land as a percentage of total land area is almost 85 percent in Nevada, more than 50 percent in Utah, Oregon, and Idaho, and between 40 and 50 percent in California, Arizona, Wyoming, and New Mexico (see Figure 1).[8] For this reason, we focus on the western United States in this paper. Western land closer to federal lands affected by fire suppression should have experienced a more significant change in development incentives due to federal policy shifts. Not all federal land is equally affected by the federal suppression

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the 1994-1995 fire season. In 2000, an escaped prescribed burn destroyed some National Lab buildings and 239 homes in Los Alamos, New Mexico, but despite negative media coverage, this did not result in a policy shift, the way the Yellowstone fires did in the late 1980s.

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[8] See, also: http://strangemaps.files.wordpress.com/2008/06/map-owns_the_west.jpg.

effort, however. Five federal agencies receive funds for fire suppression activities: the USFS, National Park Service (NPS), Bureau of Land Management (BLM), Fish and Wildlife Service, and Bureau of Indian Affairs. The most significant federal actors in managing and suppressing wildfire are the first three (USFS, NPS, and BLM); USFS, alone, receives 70 percent of Congressional appropriations for wildfire preparedness and operations.

How close must a parcel of land be to land managed by one of these agencies to benefit from suppression activities, should a fire occur? The distance a firebrand can fly ahead of a fire front is 2.4 km (California Fire Alliance 2001). Thus, at a minimum, private land within 2.4 km of USFS, NPS, and BLM lands would receive significant protection from fire contagion, even if federal fire suppression efforts were exerted only on public lands. In reality, federal firefighting effort often "chases" fires as they move from public to private land, so the umbrella of protection from fire contagion may actually stretch much further.

Finally, some parcels of land are naturally more susceptible to fire than others, due to factors including vegetation and climate. Fire susceptibility, itself, has multiple dimensions. The two most important aspects for our purposes are frequency (how often fire tends to recur in a particular type of ecosystem) and severity (what fraction of different portions of the vegetation are typically affected when a fire occurs). Combining rankings along these two dimensions, scientists classify land by historical "fire regime class," which represents the fire regime typical to a parcel of land before modern mechanical intervention, but including any use of fire by Native Americans before European settlement of the United States (Hann *et al*. 2008). One such classification places parcels of land into seven fire regime classes (see Table 1). As a general rule, frequency and severity are negatively correlated; where fires return frequently, they tend to be less severe – for example, burning primarily the forest understory, without necessarily affecting the canopy, as in the pine-dominated forests of the U.S. southwest and southeast (Kennedy and Fontaine 2009). However, some vegetation types do experience high-severity fires over short frequencies, or low-severity fires over long frequencies. We expect that land within more severe fire regime classes will be relatively more strongly affected by the historical shifts in federal fire policy.

3. Econometric models

We estimate a series of panel data models to identify the effects of federal fire suppression policy on land development. The basic model is (1), in which D_{it} is the average number of acres per year converted to developed uses in parcel *i* between period *t-1* and period *t*. In the basic model, we deal with fire susceptibility by including in D_{it} only those changes in development on fire-prone lands – forests, grassland, and shrubland. Our measure of proximity to federal land, $nearfed_i$, is equal to one if parcel *i* is within 2.4 kilometers of USFS, BLM, or NPS land, and zero otherwise (a conservative measure of susceptibility to fire contagion, or receipt of benefits from suppression). To capture the impact of the change in federal fire suppression policy, $firemgt_t$ is set equal to one if period *t* is a period in which federal "fire management" policy is in place (and zero when a policy of total suppression is in place, during the Yellowstone period). We control for state-level heterogeneity in land development policies and general economic growth (which may also differ across states) using s_s, a set of state fixed effects; y_t, a time trend; and interactions of state fixed effects and the time trend.[9] The error term includes both u_i, to capture non time-varying heterogeneity among land parcels (either a fixed or random effect), and the standard econometric error term , ε_{it}.

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[9] Though federal land holdings have changed to a small degree over time, $nearfed_i$ does not change over time in our models, since we have been unable to obtain time-varying digital maps of federal land holdings. We discuss the implications of this further in Section 6.

$$D_{it}\_fireprone = \beta_1 nearfed_i + \beta_2 firemgt_t + \beta_3 (nearfed_i * firemgt_t) + \beta_4 y_t + \sum_{s=1}^{S} \theta_s s_s + \sum_{s=1}^{S} (\omega_s \, s_s * y_t) + u_i + \varepsilon_{it} \qquad (1)$$

Our hypothesis suggests β_3<0; all else equal, when federal fire management policy is in place, there will be less conversion to developed uses on fire-prone parcels near federal lands. If we have been conservative in defining *nearfed$_i$* using the 2.4-kilometer direct fire contagion distance, then it may also be true that β_2<0; there may be some independent negative effect on development from the shift to fire management from total suppression. When u_i is a fixed effect, β_3 will identify changes in within-parcel development due to the federal fire suppression policy shifts, and we cannot independently identify β_1 or β_4. It is likely that development is increasing over time (β_5>0), and that less development takes place near federal land, *ceteris paribus* – *(*β_1<0), since federal land tends to be rural.

Since we will be looking at land-use change at a relatively fine scale, we expect significant censoring at zero – it may often be the case that no conversion to developed uses takes place during a particular period on a given parcel. A panel Tobit model (2) can account for such censoring of D_{it}. In the Tobit models we estimate, u_i is a random effect (we cannot include a parcel fixed effect due to the incidental parameters problem).

$$D_{it}^{*}\_fireprone = \beta_1 nearfed_i + \beta_2 firemgt_t + \beta_3 (nearfed_i * firemgt_t) + \beta_4 y_t + \sum_{s=1}^{S} \theta_s s_s + \sum_{s=1}^{S} (\omega_s s_s * y_t) + u_i + \varepsilon_{it} \qquad (2)$$

$$D_{it} = \begin{cases} D_{it}^{*} \;\; if \; D_{it}^{*} > 0 \\ 0 \; otherwise \end{cases}$$

Land-use data for the United States is available at intervals of several years (typically five years or more). Our basic models define each observed period *t* as either a “fire management” period or a total fire suppression period, generating the $firemgt_t$ variable that appears in (1) and (2). An alternative model takes a more flexible approach, using an indicator variable for each period (excluding the Yellowstone period, representing total fire suppression), and interacting each of these with $nearfed_i$ (3). We estimate both linear panel models and panel Tobit models of this form in Section 5. The coefficients of interest in these models are the σ_t. If all of the coefficient estimates σ_t are negative, this would be consistent with our having correctly classified each period as either a fire management period, or a total suppression period, in estimating equations (1) and (2). In addition to allowing us to make this comparison, this more flexible approach reveals any differences in the magnitude of the effect of federal policy shifts across periods, relative to the Yellowstone period.

$$D_{it}\_fireprone = \beta_1 nearfed_i + \sum_{t=1}^{T}(\sigma_t y_t * nearfed_i) + \beta_2 y_t + \sum_{s=1}^{S}\theta_s s_s + \sum_{s=1}^{S}(\omega_s s_s * y_t) + u_i + \varepsilon_{it} \qquad (3)$$

Finally, rather than allowing the dependent variable, D_{it}, to capture conversion to developed uses only on land with fire-prone vegetation, we can control directly for the susceptibility of a parcel to fire on the right-hand side of the equation, instead. We do this by introducing a set of dummy variables representing the fire regime classes described in Table 1, $fireregime_k$ (*k*=1, …, 7), and interacting these with $firemgt_t$ and $nearfed_i$ (4), allowing the effects on development of shifts in federal fire suppression policy to vary across land characterized by different historical fire regimes. In these models, D_{it} captures average annual acreage converted between *t*-1 and *t* to developed uses from *all* other land uses, not just from those uses characterized by fire-prone vegetation. If land development in fire regime class *k* has been affected a manner consistent with our hypothesis by shifts in federal fire suppression policy, the sum of β_2, β_3, and α_k should be negative.

$$D_{it} = \beta_1 nearfed_i + \beta_2 firemgt_t + \beta_3(nearfed_i * firemgt_t) + \beta_4 y_t + \sum_{k=1}^{K} \alpha_k(fireregime_k * nearfed_i * firemgt_t) + \sum_{s=1}^{S} \theta_s s_s + \sum_{s=1}^{S} \omega_s(s_s * y_t) + u_i + \varepsilon_{it} \qquad (4)$$

4. Data

We obtained land-use data to construct our dependent variable, D_{it}, from the U.S. Geological Survey (USGS), which has developed a new Land Cover Trends Database, in cooperation with the U.S. Environmental Protection Agency.[10] To our knowledge, these data have not previously been used for economic or policy analysis. The full data comprise a set of randomly-selected sample blocks measuring 10km^2 (about 24,809 acres) from across the United States.[11] These 10 km by 10km sample blocks are our spatial unit of observation, which we call "parcels" for the remainder of the paper. Satellite data and historical aerial photographs were used to determine land cover in five periods: 1973, 1980, 1986, 1992, and 2000.

Within each parcel, there are approximately 27,889 (60m x 60m) pixels. We observe the number of pixels per parcel in each of 11 land cover types: water, developed, mechanically disturbed,

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[10] We thank Benjamin Sleeter at the USGS for all of his assistance in obtaining these data. See Loveland *et al*. (1999) for a description of the Land Cover Trends project. Additional information is available from the project's website: http://landcovertrends.usgs.gov.

[11] Sample blocks were chosen using probability sampling based on ecoregions, or areas of similar ecosystems, with 30-40 sample blocks drawn from each of the 84 Level III Ecoregions in the lower 48 states. Ecoregions group areas with generally similar ecosystems and with similar types, qualities, and quantities of natural resources. Level III is the third of four levels defined by a particular classification regime, the Omernik ecoregion system, which considers the spatial patterns of both the living and non-living components of the region, such as geology, physiography, vegetation, climate, soils, land use, wildlife, water quality, and hydrology. Level III is the most detailed level available nationally for this system of ecoregions.

barren, forest, grassland/shrubland, agriculture, wetland, nonmechanically disturbed, and snow/ice. The "developed" category includes land uses that are not strictly urban, including low-density residential development, and other less intensive uses where both vegetation and structures are present – it is the source of our left-hand side variable. We convert pixels to acres. We then sum the number of acres converted per year to developed uses from other land cover types between *t-1* and *t* to construct each observation of D_{it}.

The five periods in the data incorporate four changes between periods, so T=4. At t=1, we observe the change in developed acreage in each parcel between 1973 and 1980. At t=2, we capture the change between 1980 and 1986, and so on. The fact the periods of observation are not of equal length (they range from six to eight years) is the reason for modeling D_{it} as the average number of acres converted *per year*, per period.

Since our focus is development in fire-prone regions near federal lands, we obtained panel data for each of the 968 Western parcels from USGS.[12] Using GIS, we then combined these parcels (marked as black dots in Figure 2) with a map of federal land holdings for the three agencies that make the vast majority of federal expenditures on fire suppression: BLM, NPS, and USFS (marked in brown, blue and green, respectively, in Figure 2).[13] We obtained the GIS layer of federal lands from the Northern Region Office of the USFS.[14]

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[12] While there are several states in the Eastern United States with significant fire seasons (including Florida, Georgia, and North Carolina), the policy shifts we are exploiting in our empirical strategy are most relevant to Western states.

[13] The fact that we can identify the precise location of each parcel makes these data different from other land-use data typically used by economists. For example, the U.S. Department of Agriculture's Natural Resources Inventory allows researchers to reference the county in which a parcel of land is located, but finer spatial location information is not available.

[14] We thank Krista Gebert at the USFS for her assistance in obtaining these data.

We set $nearfed_i$=1 for each 24,809-acre parcel that includes any land within 2.4 kilometers of these federal land holdings, and $nearfed_i$=0 for all other parcels.[15] In addition, there are 108 parcels that lie completely within federal land. We drop these parcels (11 percent of our original 968) from the regressions, as we would not expect any private development completely within USFS, NPS, or BLM lands. This leaves us with I=860 parcels. Since I=860 and T=4, our sample N comprises 3440 observations. We were able to match the GIS layer of parcels with a layer of U.S. state boundaries from the Census, creating our state fixed effects, s_s.[16] The sample parcels reside in 13 different states (S=13).

To define the variable $firemgt_t$, it is useful to refer to a timeline that depicts the four periods in our data, along with the fire policy shifts essential to our identification strategy (Figure 3). Two periods in the data (1980-1986, and 1992-2000) are quite clearly periods in which federal fire management policy predominates. During the first period, 1973-1980, the federal government was shifting toward the fire management policy, and away from total suppression. While the official switch took place with an announcement at the USFS headquarters in 1978, several sources note that it was implemented on the ground significantly earlier (Carle 2002, Gorte 2006). We set $firemgt_t$=1 for this first period, but the fact that federal policy was in flux at this time is one reason for our estimation of more flexible models as a robustness check, allowing each period to enter the equation on its own, imposing no assumptions about the value of $firemgt_t$. The period 1986-1992 contains the Yellowstone event, and it is the only period in the sample for which $firemgt_t$ is set equal to zero. Since this period, like the first period, actually represents a mix of the two policies (though total suppression was the predominant policy for most of the period), this provides an additional reason for estimating the more flexible models as a robustness check.

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[15] Federal land holdings did change to a small degree between 1973 and 2000. However, to our knowledge, there are no digital maps available of USFS, NPS, and BLM land holdings prior to 1990. Our federal land holdings data are from the year XXXX.

[16] For parcels that cross state boundaries, we assign the state that contains the majority of the parcel.

As discussed in Section 3, we control for the natural susceptibility of a parcel to fire in two different ways. For our basic models (estimating equations 1, 2, and 3), we simply include on the left-hand side only those conversions to developed land from forest, grassland, shrubland.[17] These models, thus, estimate the effects of federal fire policy shifts (and the other covariates) on development only within fire-prone land cover. When estimating equation (4), we instead control for fire susceptibility on the right-hand side, using the seven fire regime classes described in Table 1. These models estimate the effects of federal fire policy shifts (and the other covariates) on development from all other land uses, allowing those effects to vary by fire regime class. We obtained a GIS layer of fire regime classes from USFS. The fire regime class data are available at a much finer scale than our land-use data, so we assigned to each parcel its majority fire regime class.

Summary statistics are reported in Table 2. The mean amount of land converted to "developed" from other land cover per year, per 25,000-acre parcel, is very small – just under four and one-half acres. Though conversion varies significantly over time and space, zeros predominate in the data for our dependent variable. Out of 3440 observations, about 2500 are zeros. Table 2 also emphasizes the very significant federal landholdings in the western United States (as seen in Figures 1 and 2); more than three-quarters of our parcels have some portion within 2.4 kilometers of land managed by the USFS, NPS, or BLM.[18] BLM and USFS land holdings are much more significant than that of the NPS.

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[17] We also include the small amount of conversion from and mechanically and non-mechanically disturbed land Mechanically disturbed land was cleared in a prior period, for development or other purposes. Non-mechanically disturbed land in our sample parcels are primarily areas burned by previous fires.

[18] The proportion with 2.4 kilometers of land managed by each agency add up to more than 0.79 because some parcels lie within this distance of land owned by more than one agency.

The distribution of parcels across historic fire regime classes is also described in Table 2. For most of the sample parcels, the majority fire regime class ranges from one through four, with a smaller number of parcels having a majority of land in classes five and six. None of our sample parcels are designated as majority “water” parcels (fire regime class seven). Since fire regime class six is the only class in which land can be developed, but tends not to burn at all, this will be the excluded category in the models estimating equation (4). Table 3 notes the distribution of states in the sample. Sample parcels lie within 13 different states, but about two-thirds of parcels are contained in the top five states: California, Oregon, Washington, Idaho, and Arizona.

5. Results

We report the results from estimating equations (1) and (2) in Table 4. In column 1, u_i is a fixed effect, and u_i is a random effect in column 2. Column 3 reports the results of a random-effects Tobit model. The dependent variable in all three columns is the average number of acres per year converted to developed uses since the previous period, from all of the land uses that are potentially susceptible to wildfire.

The coefficient estimate of greatest interest is *nearfed*firemgt*, β_3 from equations (1) and (2). Our hypothesis suggests that this coefficient should be negative – that, all else equal, conversion to residential and commercial uses from fire-prone land cover near federal lands should be slower when the predominant federal policy is one of fire management, allowing some natural fires to burn and also using prescribed burning, rather than total fire suppression. In all three models, the estimated coefficient for this variable is negative, but not statistically significant. When we account for the fact that acreage converted is equal to zero much of the time, in column 3, this coefficient estimate increases by well over one order of magnitude, though it is still not statistically different from zero. Given the small amount of land conversion taking place on the sample parcels, overall, the relatively large standard errors on our estimates are not surprising (particularly in the fixed effects model, where the *nearfed*firemgt* estimate exploits only within-parcel variation in development over time).

It may also be the case that our classification of each period as either a purely "fire management" period or a total suppression period has introduced some bias, since two of the four periods in the data include, at least to a small degree, a mix of the two policies. Table 4 reports the results of the more flexible model in equation (4), where we allow each period to enter the equation independently, interacted with $nearfed_i$. The omitted period is 1986-1992, the period containing the Yellowstone event, which resulted in a very significant shift back to total suppression. The periods 1980-1986 and 1992-2000 are periods in which fire management is the predominant federal policy. During 1973-1980, fire management is in ascendancy, but may not be the predominant policy in the very earliest years of the period. If we have classified these periods correctly in our earlier models (in terms of $firemgt_t$=1 or =0), then the coefficients on all of the included interactions between time periods and proximity to federal lands should be negative.

The results of the models in Table 5 are strongly consistent with our hypothesis. First, the coefficients on the three interactions between our observed time periods and proximity to federal lands are negative, in all three of the models reported in Table 5. The coefficients are statistically significant, at least for 1992-2000, in all three models. In the Tobit model, which correctly accounts for the censoring at zero of development conversion, the two periods in which fire management is clearly the predominant policy (1980-86 and 1992-2000) experienced statistically significant reductions in conversion to developed uses near federal lands of approximately the same magnitude, relative to the

Yellowstone period. The coefficient for the earliest period (1973-1980), in which federal agencies may have been transitioning to fire management, suggests that a similar (though smaller) effect may have been present, though the estimate is not statistically different from zero.

The remaining coefficient estimates in Tables 4 and 5 are quite reasonable. In all models that can independently identify the effect of proximity to federal land on conversion (the random effects models), less development appears to occur, *ceteris paribus*, near federal land. While the time trend is positive in all models, it is only statistically significant in the linear random effects model (column 2) in Table 3. However, much of the variation in development over time is absorbed by the interactions between state fixed effects and the time trend. While development may be increasing, generally, over time, the pace of development between 1973 and 2000 varied significantly across the 13 states in our sample.

While ideally we could control for all non-time-varying parcel characteristics with a fixed effect in the Tobit models, we are encouraged by the fact that the fixed effects and random effects coefficients in columns 1 and 2 of Tables 4 and 5 appear to be quite similar. With only one exception, the random effects estimates are smaller than the fixed effects estimates, for our coefficients of greatest interest (the variables interacting proximity to federal lands with federal fire policy). So, while it is possible that our Tobit random effects estimates are biased due to some remaining parcel heterogeneity, the direction of that bias may make our results somewhat conservative.

Table 6 reports results from estimating equation (4), controlling for the effect of a parcel's historic fire regime class on the right-hand side. Results are qualitatively similar to those in Table 4, where the other models using the fire management dummy variable are reported. In Table 6, however, we must interpret the results for this variable, relative to a parcel's fire regime class. The sums of coefficients for *firemgt*, *nearfed*firemgt*, and the fire regime class interaction variables are negative for all but one of the sets of estimates (fire regime class five in the fixed-effects model in column 1). In the Tobit model (column 3), this group of three variables is jointly significant for fire regime classes four and five.[19]

While the interpretation of estimates from these models is not quite as clean as in the basic models, it appears that shift in federal policy did have differential effects on development, depending on the historical (pre-development) frequency and severity of fires on a parcel of land. If a landowner holds a piece of property near federal land, the disincentive for development presented by the federal switch from total fire suppression to fire management is higher (relative to property on land that does not typically burn) where fires tend to be of relatively low frequency, but high severity.

These results would be more consistent with our hypothesis if the results for fire regime class two (relatively high frequency, and high severity) were also significant.[20] However, there are several reasons why this may not be the case. First, our natural experiment exploits variation in federal fire suppression policy due to the Yellowstone fires in 1988. While several fires were involved, in general the event involved fires of the low-frequency, high-severity variety, more typical of fire regime classes four and five than the lower regime classes. So although it would seem that fire regime class two should be the "most risky" from a landowner's perspective, we may simply be picking up the effect of holding property similar in character to that affected by the Yellowstone fires, rather than a pure effect of fire regime class. Second, the excluded fire regime class in the tests we have performed here is class six –

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[19] In the test of joint significance for *firemgt*, *nearfed*firemgt*, and *fireregime4*nearfed*firemgt*, χ_2 (3) = 9.87, and Pr > χ_2 = 0.0197. The joint significance test results for fire regime class 5 is: χ_2 (3) = 6.49, and Pr > χ_2 = 0.0902.

[20] In the test of joint significance for *firemgt*, *nearfed*firemgt*, and *fireregime2*nearfed*firemgt*, χ_2 (3) = 0.72, and Pr > χ_2 = 0.8685.

barren land. This is not as restrictive as the term "barren" might seem to indicate; for example, this includes significant portions of the desert Southwest. However, the amount of land in this category in our sample is small (about three percent, or 30 out of 860 parcels). All of the joint significance tests for the fire regime interactions are hampered by this fact.

6. Conclusions

We use panel data on land-use change in the western United States between 1970 and 2000 to test the hypothesis that federal fire suppression policy has influenced land development in areas at risk for damage from wildland fires.   The econometric analysis identifies the effects of federal fire suppression efforts on development by exploiting a natural experiment – a major but temporary policy shift toward increased suppression that took place as a result of the catastrophic Yellowstone fires during summer and fall 1988 – as well as other sources of spatial and temporal variation in the benefits and costs of fire suppression. Models control for underlying trends in development over time and across states. We find that the shift away from "fire management" policies (which allow some natural fires to burn, and use some prescribed burns to manage forested and other ecosystems in which fire plays a critical role) that followed the Yellowstone event may, in fact, have induced some land development on private land near federal land affected by fire suppression efforts. The magnitude of this effect seems to vary depending on how frequently fire can be expected to occur and the typical severity of fire on a particular parcel of land.

Economists have drawn significant attention to the ability of public policies to induce land development in risky locations through subsidies of various kinds (including subsidized insurance, the construction of infrastructure meant to reduce risk, direct payment for damages in the aftermath of catastrophic events, and other mechanisms), but the literature offers scant empirical evidence to support these claims. Our empirical test is one of only a handful in the economics literature that quantifies the impact of such policies on development, and the first to focus on the increasingly severe and expensive problem of wildland fires spreading into and through neighborhoods in the exurbs and suburbs of the American West. The costs of induced development in this case include human morbidity and mortality (both firefighters and civilians), as well as the destruction of homes and other assets. Climate change has already been linked in the natural science literature to an increase in the incidence of large wildland fires in the U.S. West. We provide evidence that federal policy may inadvertently have increased the population in harm's way of such fires. Our results are directly relevant to ongoing debates over preparedness for and response to hurricanes, droughts, floods, and other events that become natural disasters when they occur in highly populated areas, and that may be expected to occur with increasing frequency in a changing global climate.

References

Alig, Ralph J., and Andrew J. Plantinga. 2004. Future forestland area: impacts from population growth and other factors that affect land values. *Journal of Forestry*. 102: 19-24.

Biswell, H. 1989. *Prescribed burning in California wildland vegetation management*. Berkeley: University of California Press.

Butry, David T., D. Evan Mercer, Jeffrey P. Prestemon, John M. Pye, and Thomas P. Holmes. 2001. What is the price of catastrophic wildfire? *Journal of Forestry*. 99: 9-17.

California Fire Alliance. 2001 Characterizing the fire threat to wildland-urban interface areas in California. Sacramento: California Fire Alliance.

Calkin, David E., Krista M. Gebert, J. Greg Jones, and Ronald P. Neilson. 2005. Forest service large fire area burned and suppression expenditure trends, 1970-2002. *Journal of Forestry*. 103: 179-183.

Cardille, Jeffrey A., Stephen J. Ventura, and Monica G. Turner. 2001. Environmental and social factors influencing wildfires in the upper Midwest, United States. *Ecological Applications*. 11: 111-127.

Carle, David. 2002. *Burning questions: America's fight with nature's fire*. Westport, CT: Praeger.

Chapman, H. H. 1932. Some further relations of fire to longleaf pine. *Journal of Forestry*. 30: 602-604.

Cordes, J. J., and A. M. J. Yezer. 1998. In harm's way: does federal spending on beach enhancement and protection induce excessive development in coastal areas? *Land Economics.* 74: 128-145.

Cross, J. A. 1989. Flood insurance and coastal development. *The Florida Geographer.* 23: 22-45.

Elfring, Chris. 1989. Yellowstone: fire storm over fire management. *Bioscience*. 39: 667-672.

Gill, A. Malcolm, and Scott L. Stephens. 2009. Scientific and social challenges for the management of fire-prone wildland–urban interfaces. *Environmental Research Letters*. doi:10.1088/1748-9326/4/3/034014.

Goodwin, Barry K., Monte L. Vandeveer, and John L. Deal. 2004. An empirical analysis of acreage effects of participation in the Federal crop insurance program. *American Journal of Agricultural Economics*. 86: 1058-1077.

Gorte, Ross W. 2006. Forest fire/wildfire protection. CRS Report for Congress RL30755. U.S. Congressional Research Service, Library of Congress, Washington, DC.

Hann, W., A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, J. Jones, M. Levesque. 2008. Interagency fire regime condition class guidebook. Available at: http://www.frcc.gov/.

Hardy, Colin C., Kirsten M. Schmidt, James P. Menakis, and R. Neil Sampson. 2001. Spatial data for national fire planning and fuel management. *International Journal of Wildland Fire*. 10: 353–372.

Johnston, Jason Scott, Jonathan Klick, and Dean Leuck. 2009. Climate change and western wildfires: the danger in inferring causality from correlation. Working paper, University of Pennsylvania Law School, Philadelphia, PA.

Kennedy, Patricia L., and Joseph B. Fontaine. 2009. Synthesis of knowledge on the effects of fire and fire surrogates on wildlife in U.S. dry forests. Oregon State University Agricultural Experiment Station, Special Report 1096. September.

Krutilla, J. V. 1966. An economic approach to coping with flood damage. *Water Resources Research*. 2: 183-190.

Loveland, T.R., Sohl, T.L., Sayler, K., Gallant, A., Dwyer, J., Vogelmann, J.E., and Zylstra,G.J., 1999, Land cover trends: rates, causes, and consequences of late-twentieth century U.S. land cover change: EPA Report.

Mercer, D. Evan, Jeffrey P. Prestemon, David T. Butry, and John M. Pye. 2007. Evaluating alternative prescribed burning policies to reduce net economic damages from wildfire. *American Journal of Agricultural Economics*. 89: 63-77.

Prestemon, Jeffrey P., D. Evan Mercer, John M. Pye, David T. Butry, Thomas P. Holmes, and Karen L. Abt. 2001. Economically optimal wildfire intervention regimes. Paper presented at the American Agricultural Economics Association Annual Meeting, Chicago, IL.

Prestemon, Jeffrey P., John M. Pye, David T. Butry, Thomas P. Holmes, and D. Evan Mercer. 2002. Understanding broadscale wildfire risks in a human-dominated landscape. *Forest Science*. 48: 684-693.

Pringle, Paul. 2009. Before the Station fire, a cost-cutting memo. *Los Angeles Times*. 2 October.

Stavins, Robert N., and Adam B. Jaffe. 1990. Unintended impacts of public investments on private decisions: the depletion of forested wetlands. *American Economic Review*. 80: 337-352.

Theobald, David M., and William H. Romme. 2007. Expansion of the US wildland-urban interface. *Landscape and Urban Planning*. 83: 340-354.

U.S. Department of Agriculture, Office of the Inspector General, Western Region. 2006. Audit Report: Forest Service Large Fire Suppression Costs. Report No. 08601-44-SF. November.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science*. doi: 10.1126/science.1128834.

Wu, Junjie. 1999. Crop insurance, acreage decisions, and nonpoint source pollution. *American Journal of Agricultural Economics*. 81: 305-320.

Yoder, Jonathan. 2004. Playing with fire: endogenous risk in resource management. *American Journal of Agricultural Economics*. 86: 933-948.

Table 1. Fire regime classes

Fire regime	Fire frequency	Fire severity	Notes
1	0-35 years	Low	Generally replaces less than 25% of the dominant vegetation; can include mixed-severity fires that replace up to 75% of aboveground vegetation. Primarily occurs on forested land.
2	0-35 years	Stand replacement	High-severity fires replace more than 75% of the dominant aboveground vegetation. Primarily occurs on grassland & shrubland.
3	35-100 years	Mixed	May either cause selective mortality in the dominant vegetation, depending on plants' susceptibility to fire (having a relatively consistent, intermediate effect), or generate a spatial mosaic of low-severity and stand replacement fire. Occurs on forested land, grassland & shrubland.
4	35-100 years	Stand replacement	High-severity fires replace more than 75% of the dominant aboveground vegetation. Occurs on forested land, grassland & shrubland.
5	200+ years	Stand replacement	High-severity fires replace more than 75% of the dominant aboveground vegetation. Can also include low- and mixed-severity fires of this long interval, though less common. Occurs on forested land, grassland & shrubland.
6	None	N/A	Barren land – does not burn.
7	None	N/A	Water – does not burn.

Notes: Sources are Hardy *et al*. (2001, 1998) and Hann *et al*. (2008). Fire regimes represent typical pre-European-settlement, historical fire processes, including any use of fire by Native Americans before modern mechanical intervention.

Table 2. Summary statistics

Variable	Definition	N	Mean	Std dev	Min	Max
D_{it}	average acres/year developed from all other land cover since *t*-1	3440	7.22	33.83	0	787.43
D_{it}_fireprone	average acres/year developed from fire-prone land cover since *t*-1	3440	4.42	22.89	0	770.67
near_fed	within 2.4 km of federal land	3440	0.79	0.40	0	1
near_USFS	within 2.4 km of USFS land	3440	0.44	0.50	0	1
near_NPS	within 2.4 km of NPS land	3440	0.08	0.28	0	1
near_BLM	within 2.4 km of BLM land	3440	0.51	0.50	0	1
fire_mgt	federal fire management policy in place	3440	0.75	0.43	0	1
fireregime1	fire regime class 1	3440	0.22	0.41	0	1
fireregime2	fire regime class 2	3440	0.19	0.39	0	1
fireregime3	fire regime class 3	3440	0.37	0.48	0	1
fireregime4	fire regime class 4	3440	0.13	0.33	0	1
fireregime5	fire regime class 5	3440	0.06	0.24	0	1
fireregime6	fire regime class 6	3440	0.03	0.18	0	1
fireregime7	fire regime class 7	3440	0.00	0.00	0	1
all_in_fed	completely within federal land	3872	0.11	0.31	0	1

Table 3. Distribution of U.S. states in the sample

State	I	number	%
Arizona	860	54	6.28
California	860	207	24.07
Colorado	860	38	4.42
Idaho	860	73	8.49
Montana	860	41	4.77
Nevada	860	37	4.30
New Mexico	860	49	5.70
Oregon	860	135	15.70
South Dakota	860	1	0.12
Texas	860	19	2.21
Utah	860	51	5.93
Washington	860	110	12.79
Wyoming	860	45	5.23

Table 4. Effects of federal fire policy changes on conversion to developed land using "fire management" dummy

Variable	**Conversion to "developed" Panel FE (1)**	**Conversion to "developed" Panel RE (2)**	**Conversion to "developed" Tobit RE (3)**
nearfed		-8.00***	-30.57***
		(2.83)	(8.55)
firemgt	-1.25	-1.39	-3.32
	(1.29)	(1.30)	(4.40)
nearfed*firemgt	-0.34	-0.16	-7.40
	(1.67)	(1.67)	(5.48)
year	0.04	0.04*	0.10
	(0.06)	(0.02)	(0.60)
constant	-82.92*	-76.57*	-232.29
	(47.44)	(47.97)	(1192.21)
state fixed effects	no	no	yes
state fixed effects*year	yes	yes	yes
R^2 within	0.01	0.00	
between	0.06	0.10	
overall	0.04	0.07	
Number of observations (N)	3440	3440	3440
Number of parcels (I)	860	860	860

Notes: Dependent variable is number of acres per year converted to "developed" since the last period from forest, grassland, shrubland, and mechanically and nonmechanically disturbed land (D_{it}*_fireprone* - $D_{i(t-1)}$*_fireprone*). Each parcel (*i*) is 24,809 acres. Standard errors reported in parentheses are robust and clustered by parcel in columns (1) and (2). ***indicates significance at 0.01, ** at 0.05, and * at 0.10. Models drop 108 parcels completely within federal land. In the Tobit model in column 3, N includes 2826 left-censored and 614 uncensored observations**.**

Table 5. Effects of federal fire policy changes on conversion to "developed" land using year dummies

Variable	**Conversion to "developed" Panel FE (1)**	**Conversion to "developed" Panel RE (2)**	**Conversion to "developed" Tobit RE (3)**
nearfed		-7.18***	-28.25***
		(2.53)	(7.94)
nearfed*1973-1980	-0.94	-0.43	-8.92
	(1.69)	(1.65)	(5.66)
nearfed*1980-1986	-1.17	-0.92	-11.37**
	(1.12)	(1.10)	(4.60)
nearfed*1992-2000	-2.13*	-2.47*	-11.18**
	(1.28)	(1.35)	(4.77)
year	0.10	0.13	0.18
	(0.10)	(0.10)	(0.69)
constant	-185.16	-246.64	-407.15
	(188.09)	(197.50)	(1372.81)
state fixed effects	no	no	yes
state fixed effects*year	yes	yes	yes
R^2 within	0.01	0.00	
between	0.06	0.10	
overall	0.04	0.07	
Number of observations (N)	3440	3440	3440
Number of parcels (I)	860	860	860

Notes: Dependent variable is number of acres per year converted to "developed" since the last period from forest, grassland, shrubland, and mechanically and nonmechanically disturbed land (D_{it}*_fireprone* - $D_{i(t-1)}$*_fireprone*). Each parcel (*i*) is 24,809 acres. Standard errors reported in parentheses are robust and clustered by parcel in columns (1) and (2). ***indicates significance at 0.01, ** at 0.05, and * at 0.10. Models drop 108 parcels completely within federal land. In the Tobit model in column 3, N includes 2826 left-censored and 614 uncensored observations**.**

Table 6. Effects of federal fire policy changes on conversion to "developed" land, controlling for fire regime classification

Variable	Panel FE (1)	Panel RE (2)	Tobit RE (3)
nearfed		-16.28***	-54.78***
		(4.25)	(10.85)
firemgt	-1.76	-1.98	-2.68
	(1.83)	(1.82)	(5.27)
nearfed*firemgt	3.86*	3.19	11.17
	(2.36)	(2.86)	(18.46)
fireregime1*nearfed*firemgt	-2.74	-2.41	-26.44
	(1.71)	(2.17)	(19.10)
fireregime2*nearfed*firemgt	-2.11	-2.38	-13.50
	(1.58)	(2.17)	(20.43)
fireregime3*nearfed*firemgt	-2.96**	-2.53	-13.10
	(1.65)	(2.17)	(18.36)
fireregime4*nearfed*firemgt	-15.85**	-9.10*	-33.92*
	(8.55)	(4.97)	(19.32)
fireregime5*nearfed*firemgt	-1.61	-4.22**	-59.05**
	(1.52)	(2.18)	(27.04)
year	0.03	0.04	0.07
	(0.05)	(0.04)	(0.78)
cons	-81.82	-68.89	-195.11
	(78.05)	(78.47)	(1543.64)
state dummies	no	no	yes
state dummies*year	yes	yes	yes
R^2 within	0.01	0.01	
between	0.03	0.10	
overall	0.02	0.07	
Number of observations (N)	3440	3440	3440
Number of parcels (I)	860	860	860

Notes: Dependent variable is number of acres per year converted to "developed" since the last period (D_{it}-$D_{i(t-1)}$) from all other uses. Each parcel (*i*) is 24,809 acres. Standard errors reported in parentheses are robust and clustered by parcel in columns (1) and (2). ***indicates significance at 0.01, ** at 0.05, and * at 0.10. Models drop 108 parcels completely within federal land. In column 3, N includes 2724 left-censored and 716 uncensored obs**.**

Figure 1. U.S. Federal Lands and Indian Reservations

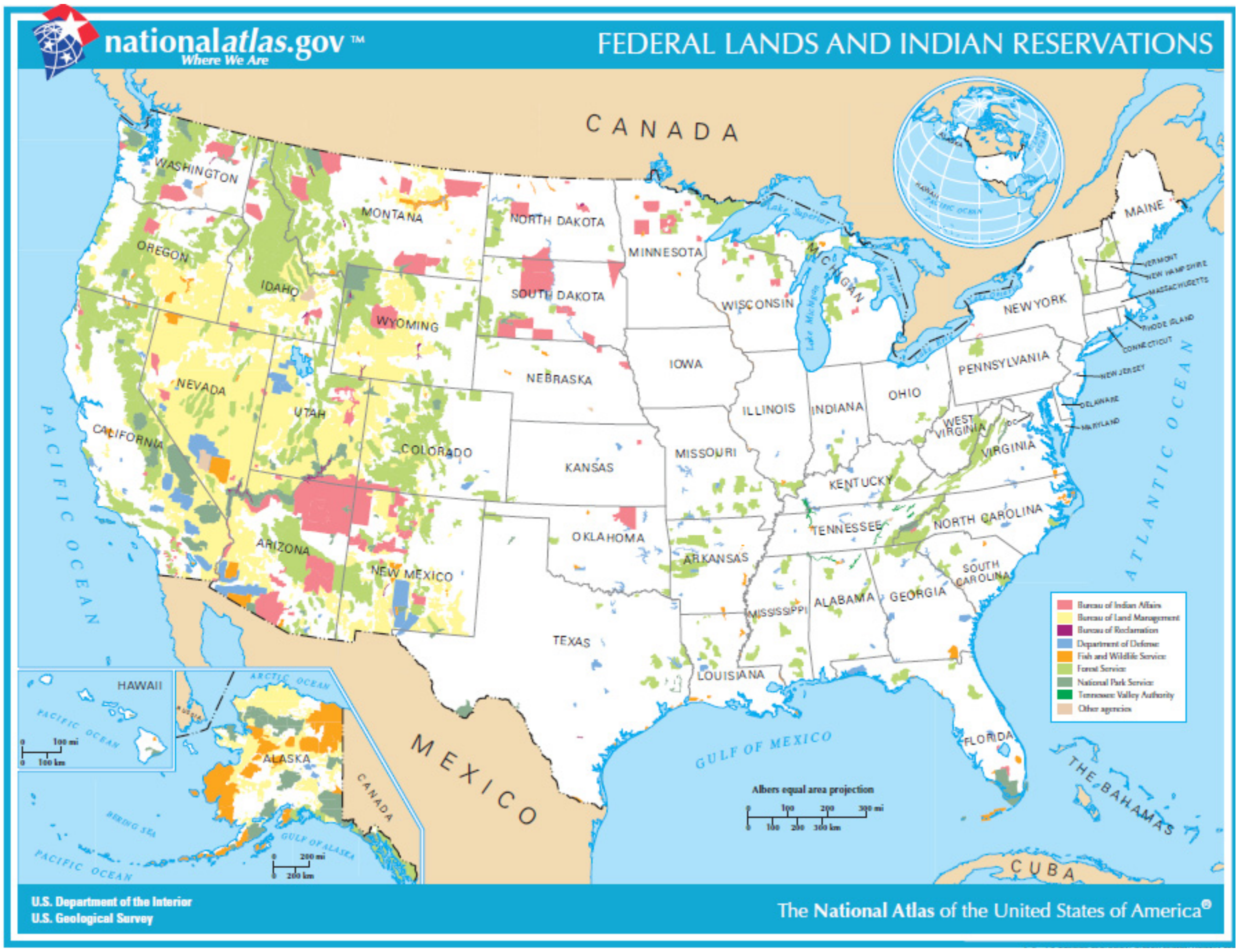

Figure 2. Sample parcels and selected federal lands in the Western United States

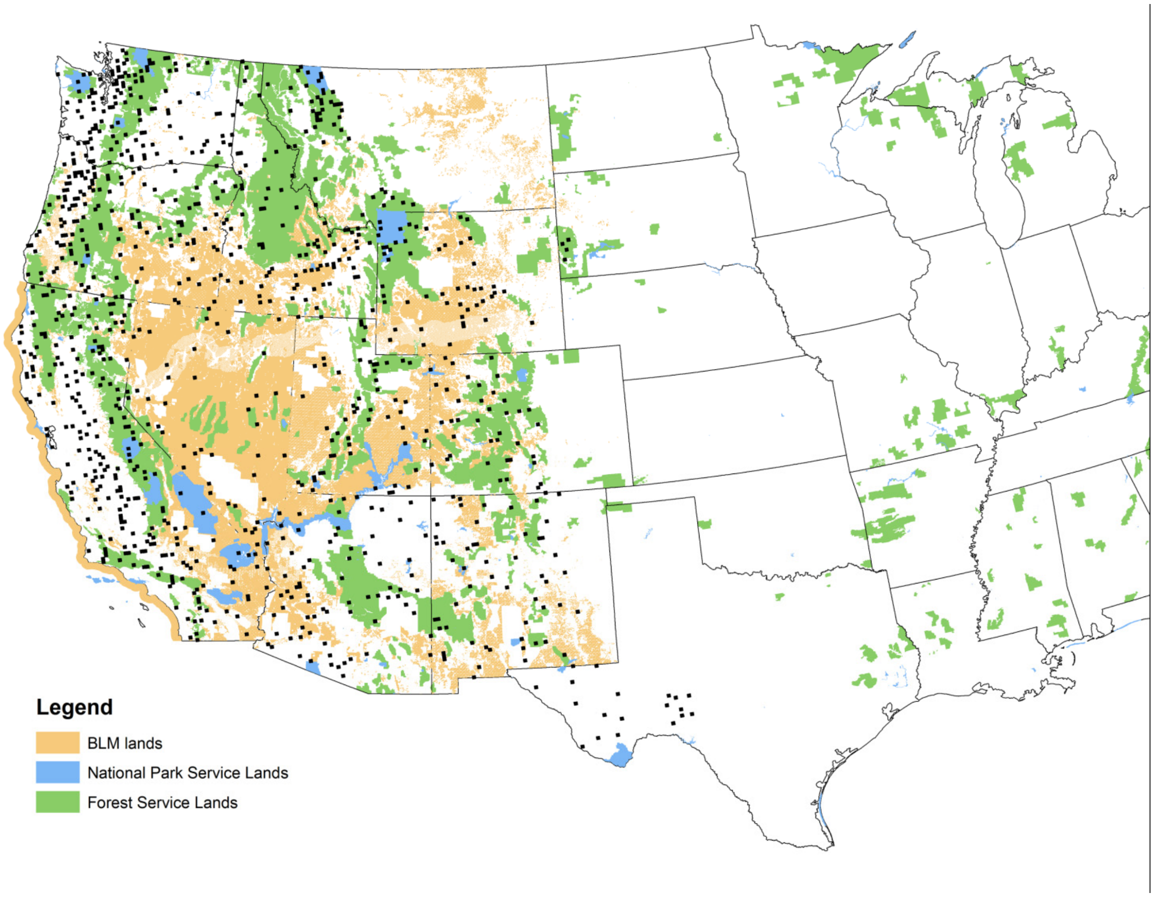

Figure 3. Timeline of land-cover observations and federal fire suppression policy shifts