The Economic Evolution of Wildfire Suppression Organizations

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Abstract
Wildfires are destructive events, costing billions of dollars each year in damage, suppression and recovery costs. Fires also have rather unusual characteristics that make their management and control rather complex and seemingly irrational. Their occurrence has great spatiotemporal variance and preparation and timeliness is crucial for effective fire suppression. Fires tend not to coincide with landownership boundaries, so that land tenure and land use characteristics affect both private and public agency incentives to fight fires. Fire suppression institutions vary substantially over time and environments, ranging from private individual and cooperative action to large scale centralized government intervention, military style organization, specialization, and pre-positioned investments. Building on economic theories of contracts and institutional design, this article examines the economic rationale for the structure of observed wildfire suppression institutions and examines implications of the model in relation to several dimensions of fire policy historically across the US and the world. We utilize a set of historical and cross-sectional case studies to test our hypotheses about the organization of suppression. Finally we consider the implications for contemporary wildfire management.

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Whether attacked by two smokechasers with hand tools or by dozens of organized crews with sophisticated equipment, every fire requires a certain degree of organization. Certain functions must be performed, and it is a truism that, in some form, all these functions must be done on all fires. Not only do fires require a division of labor, an organization by function; they need an integration of that division, an organization by complexity.

(Pyne 1984, p.372)

I. INTRODUCTION

Fire has always been a part of human life, and the control and suppression of fire is an inescapable part of human interaction with it. Uncontrolled wildland fire in particular is a widespread, dramatic and often catastrophically destructive phenomenon and an important force on six of the world's seven continents. In recent decades, an estimated 50 to 100 million acres (roughly 80 to 160 square miles) burn annually, and about 90% of these are due to human activities (Dolcemascolo 2004, Levine et al. 1999).

Suppression of and protection from wildfire are an integral part of human interaction with it. Failure to control and suppress fire can and often does lead to harm to people and their property. Responses can be as simple as individuals and families moving themselves and their assets in the face of an approaching fire, attempting to protect stationary assets such as homes and crops.by building fire breaks, or dousing flames with water. In contrast, the organization of modern wildfire suppression can also be stunningly complex. During active fire seasons, specialized fire crews and specialized firefighting machinery (e.g., vehicles and aircraft) owned or contracted by the U.S. federal government are moved from one active fire to another within and across fire management regions depending on the severity and relative risks. This broad scale resource coordination is managed through the National Interagency Fire Center (NIFC) in

Boise, Idaho.[1] On fires that have escaped "initial attack" and have developed into large complex fires, a large fire organization (LFO) system is followed, which resembles a military style hierarchical organization. As part of this structure a temporary encampment is usually set up near the fire, from which leaders and administrator coordinate and deploy fire fighters and equipment. The size of these temporary organizations can be staggering. For example, the Biscuit Fire in Oregon burned nearly a half a million acres 2004. It began on July 13 and at its zenith on July 31 there were over 2,000 firefighting personnel, 21 helicopters and 40 bulldozers assigned to the fire.

Wildfire suppression and its organization takes place within a broader economic, institutional, technological, and physical (environmental) setting which itself can be relatively simple or highly complex (Bradshaw and Lueck 2012). The ecological characteristics of fire-prone environments are complex and can vary immensely across space and time. These variations support substantial variation in wildfire behavior, and therefore call for variation in wildfire suppression responses. Analogously, the economic and social institutional environments within which wildfire occurs have important implications for wildfire suppression and themselves are immensely complex and variable as well. The system and pattern of land ownership, associated property and liability law, as well as environmental regulations and administrative institutions that in federal systems can span several nested and interrelated governmental jurisdictions, with variation across local jurisdictions existing under the umbrella of larger umbrella jurisdictions.

[1] See www.nifc.gov – NIFC was created from the original coordinating agency called the Boise Interagency Fire Center (BIFC). For more wildfire statistics see http://www.nifc.gov/fire_info/fire_stats.htm . For more extensive

In this article we examine the fundamental economic and institutional factors that affect the historical development of wildfire suppression institutions. We focus on three fundamental factors that drive the economic organization of wildfire suppression: property rights to assets in relation to wildfires, the emergency nature of wildfire response, and gains from specialization and technology. The interrelated variation and complexity of both the physical and institutional environments across space and time leads not surprisingly to substantial spatial and historical variation in the way in which wildfire suppression has been organized and carried out. In some parts of the world (e.g., Australia, South Africa) wildfire suppression is to a greater extent an undertaking of private landowners and private firms (Bennett 2012). In the United States, however, wildfire suppression has been primarily the domain of the federal and state government since the early 1900s (Davis 2001, Pyne et al.1996). But even within the US there is considerable variation across the country and there have been substantial changes over time as well (Davis 2001, Carle 2002, Stephens and Ruth 2005).[2]

The recognition that institutions (i.e., the structure of property rights) have important effects on economic outcomes has become an important part of modern economics.[3] Wildfire historian Stephen Pyne has noted how institutions have shaped wildfire management and the

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examination of U.S. Wildfire and suppression statistics, see U.S. Department of Interior (2012), Zybach et al. (2009), for example.

[2] Stephen Pyne, a leading fire historian, (2011) noted: "In 1960 the U.S. Forest Service enjoyed a virtual hegemony in fire; by 2010, it was but one large player in a complex field of institutions, practices, and ideas that had changed how Americans relate to wildland fire." Pyne also noted: "The past 40 years have witnessed remarkable changes in American fire policy, institutions, sciences, and practices."

[3] Building on the work of Coase (1988), Dixit (2009), North (1990), and Williamson (1985) there is now a substantial empirical literature that shows how institutions affect economic outcomes including studies of economic growth and development (e.g., Acemoglu, Simon, and Robinson 2001, 2002, 2005) as well as studies of institutions over land and natural resources (e.g, Libecap 1990, Libecap and Lueck 2011, Ostrom 1990).

relatively limited work in law and economics suggests that institutions are important (e.g., Yoder 2008, Bradshaw and Lueck 2012).

With the organizational complexity of modern wildfire suppression come complex incentives and a cursory examination of modern wildfire suppression suggests that inefficiencies and oddities abound. Indeed, there has been widespread criticism of the outcomes and incentives inherent in modern wildfire institutions (e.g., Arno and Allison-Bunnell 2002, Caulkin et al. 2005, Ingalsbee 2005). The most frequent critique is that there is too much suppression, especially by federal agencies. Many critics view the UFSF regime as leading to an overinvestment in suppression and under-investment on prescribed fire (e.g., Arno and Allison-Bunnell 2002). Consider this from Ingalsbee (2005, 223): "Every summer for a hundred years running, the U.S. government has made war in America's wildlands under the pretense of "fighting" fires. Under the command of the Forest Service and other federal land management agencies, tens of thousands of young people are sent into the forests of the West to suppress wildfires at a cost to taxpayers of more than a billion dollars a year. Organized with military structure and discipline, and supplemented with an armada of firefighting vehicles, heavy equipment, and aircraft, Uncle Sam's firefighting army is unrivaled in size and expense in the world."

Fire suppression crews have incentives to waste resources and extend the duration of fires, and even start fires. There is well documented evidence that fire suppression on large fires, especially when they are active, is often exceedingly ineffective (Gorte and Bracmort 2012, Reinhardt et al. 2008, Rogers 1982). Even when suppression of large fires may be effective there are many cases in which the suppression costs far exceed the value of the protected resources (Arno and Allison-Bunnell 2002). Federal suppression crews face minimal fiscal marginal costs

of additional effort. In addition, fire crews face no liability for trespass or damage to private property during the course of active suppression; indeed, they have near martial law authority (Merrill 2012). In addition it has been argued that there are built-in incentives for landowners to overdevelop or under-invest in risk mitigation in fire-prone areas given that they often do not face the costs of suppression (Kousky, Olmstead, and Sedjo 2012, Yoder 2012).

Our analysis illuminates the unusual structure of wildfire suppression organization and their incentives by incorporating essential and unique features of wildfire. Existing literature on the economic determinants of wildfire suppression institution structure is relatively sparse, and tends to ignore these features of fire and also provides little formal theoretical or empirical analysis of the relationship between institutional structure and wildfire outcomes. Much of the extant theoretical work is normative in focus, with the objective of improving perceived incentive structures and problems in suppression (e.g., Rideout, Wei, Kirsch, and Omi, 2008; Donovan, Brown, and Dale, 2008; Donovan and Brown, 2005). Empirical work on the topic of institutional drivers of fire suppression outcomes tends to be either analytically informal (e.g., Davis (2001)), or limited in scope (e.g., Gebert et al. 2007). Our approach is to draw from the literature on the economics of institutions and organization to examine the structure and effects of differences in institutions on wildfire outcomes (Lueck 2012 and Yoder 2008, 2012).

Section II provides a historical and geographical overview of wildfire suppression in the United States. In section III we provide an economic framework for optimal wildfire suppression in which suppression effort is allocated over time (i.e., the duration of the fire). The first-best baseline case assumes that the fire (or the land-based counterpart, the "fireshed") is owned by a single entity. The frameworks is then extended to consider the impact of divided landownership on the control and ownership of the fire. Further extensions include considering the gains from

specialized suppression and the impacts of other institutional factors including agency jurisdiction, policy and organization; legal regimes; and political jurisdiction. Section IV is an analysis of the implications of our model using historical case studies of suppression organizations. Section V summarizes our findings and examines implications for wildfire policy and wildfire research.

II. HISTORY AND GEOGRAPHY OF WILDFIRE SUPPRESSION

Fire suppression has often been a community effort and has also been coordinated by government for millennia. Emperor Augustus developed the first known organized firefighting organization for Rome as early as 24 B.C. (Hirst, 1884, Rainbird 1986). Urban firefighting organizations became commonplace thereafter in Europe, often in the form of volunteer firefighter organizations, whose structures evolved through the 18-19th centuries with the development of mobile firefighting technology such as water-carrying fire vehicles (McChesney 1986, Winer 2009).

Liability law and legal rules pertaining to wildfire suppression activities grew initially out of the common law to allow firefighters to enter and even destroy private property with immunity while there was an active fire (Merrill 2012). Indeed, liability law relating to lost control and/or failure to suppress fire and its consequences stretches back to no later than the Romans (Epstein 2012).

Early historical accounts of firefighting suggest that organized fire suppression began in urban areas. While there is a wealth of historical and archaeological accounts of active fire use by humans (Pyne 1983, Preece 2002, Keeley 2002), there is a relative dearth of historical description of organizations designed specifically for rural wildfire suppression before formal

government involvement. Anderson (2006) claims that Native Americans used fire to control and protect against catastrophic fire.[4] Pyne (1999) notes that in the colonial US there was widespread protective burning around settlements in the Northeastern United States to reduce risk of damage from native-set fires. Table 1 summarizes some major organizational, legal, and policy events, ranging from early urban firefighting to modern policy developments.

Table 1

Based on Belknaps' *History of New Hampshire,* Pyne (1999) describes suppression in the form of what came to be known as backfires, which were used to control the advance of escaped slash-burning fires in the northeastern United States during early periods of active logging. Arno and Allison-Bunnell (2002) contend that "There were no effective means of suppressing forest fires until well after 1910…", but technology may well have developed in response to a demand for fire suppression as land values increased.[5]

Nonetheless, organized firefighting activity developed in the form of formal or informal rural landowner associations prior to 1910, generally among private timber landowners (Southard 2011, CPTPA 2012).[6] Allen (1910) notes the importance of ten or so private forest cooperatives and their suppression activities during the 1910 fires of Idaho and Montana. These associations were made up of private timberland owners who paid prorated dues based on acreage, the funds from which were used for fire suppression. According to Allen (1910), the

[4] It is not clear from Anderson (2006) if he is referring to the use of backfires for controlling specific fires, or if he is referring to vegetation management for ex ante risk mitigation, but one might refer by his language that he is referring to both.

[5] Fernow (1907) provides accounts of the advent of law and regulation in the 1800s against fire and historically common burning in the plantations and Forests of Prussia and Europe, but does not provide any indication of active suppression or suppression organization among forest owners until the early 1900s.

State of Idaho became a dues-paying member of all associations in Idaho. Rural private cooperative fire management was more of less limited to timberland owners, both in the Eastern and Western United States, with limited indication of cooperative fire management among agricultural landowners.[7] By the turn of the century in the United States, about half of the states had developed state forestry organizations, and 16 of them had developed fire suppression programs (Southard 2011).

Major changes in suppression organization occurred in the first few decades of the 20th century.[8] In 1908 the so-called "blank check policy" of federal suppression funding emerged. With the Weeks Act of 1911 the Forest Service gained authority to buy forests in the southeast, which aided in the dramatic expansion of the national forest system from it early days in the late 1800s.[9] Prior to 1891 there were no national forests (or forest reserves) but by 1901 there were over 40 million acres. During Theodore Roosevelt's administration (1901-1990) more than 150 million acres were added to the national forest system and the US Forest Service was established.[10] In 1924 the Clarke-McNary Act created the cooperative fire control system, which linked Forest Service fire suppression to state and other organizations.[11] Blank check budgeting continued more or less unchecked until the 1980s when budgetary limits were imposed, but was re-established soon after the 1988 Yellowstone Fires and remains more or less intact today. The

[6] Bradshaw (2012) examines the historically dominant role forest landowner associations in cooperative firefighting activities.
[7] FAO 2001 (p. 67-68) indicates that farmers' associations are responsible for fire suppression in most of Namibia.
[8] This section discussion draws heavily from Lueck (2012).
[9] Egan (2010) discusses how the 1910 Burn became a focal point for political action and how the Forest Service and its supporters capitalized on it.
[10] See http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/12099/Est_and_Mod_of_Nat_For_Bou_and_Nat_Gra.pdf?sequence=1 for a list of national forests and their history and http://www.theodoreroosevelt.org/life/conNatlForests.htm for a history of Roosevelt's actions.
[11] All 50 states ultimately join this system.

national forest system itself grew during the early 20th century as well, as did the fire suppression organization within the Forest Service (Pyne, Andrews, and Laven 1996).

During the 1930s and 1940s specialized fire crews and smokejumpers emerged within the Forest Service. The "10 AM rule" was established in 1935 with the goal that all fires be suppressed by 10 AM of the day following detection.[12] There were also large programs to build roads, lay telephone lines, and establish fire lookouts throughout the National Forests. This effort was the beginning of the establishment of a vast network for fire control, from reporting fires to communications for resource management and coordination during suppression activities.

The highly structured, hierarchical, military-style suppression organization that exists today in the U.S. was well established by the 1960s. This current organizational regime began to emerge in the post WWII era and was influence by the Mann Gulch Fire. At Mann Gulch, an extreme fire event called a blowup killed 13 fighters including 12 members of the fledgling smokejumper unit based in Missoula, MT.[13] There was also the emergence of fire science within the USFS during this period which ultimately led to the establishment of the Missoula Fire Sciences Laboratory in Missoula, MT in 1960.

The structure of modern large fire suppression organizations (LFOs) is summarized in Lueck (2012) and Pyne (1999). Important changes during this period were increased use of aircraft and the establishment of 20-man 'hotshot' crews which were deployable throughout the

[12] The 10 AM rule was officially abolished in the USFS in 1978 in order to allow fires to burn under certain prescriptions but after the 1998 Yellowstone fires it once again became the norm if not the official policy. Johnston and Klick (2012) examine how this policy has impacted fire large fire frequency in the western states.

[13] Maclean (1992) made the story of Mann Gulch an American legend. Smokejumpers are organized differently from other fire crews in that they do not have a fixed group with a set leader but a loose hierarchy in which groups form from an initial random draw and then formed on the basis of the fire demand.

west.[14] The term 'fire boss' emerged early as the term for the person in charge of the fire with the authority to declare it contained and controlled and the authority to order resources. Every fire has a fire boss even if there are just two fire-fighters on the smallest initial attack fire.[15] The National Interagency Fire Center (NIFC) now coordinates wildfires suppression efforts throughout the U.S.[16]

The historical development of western suppression organizations differs in other parts of the country (Arno and Allison-Bunnell 2002). In the southeastern states, private forest protective associations never developed to the extent that they did in the West. In the Southeast, prescribed fires have been used for decades and even centuries by locals, and even in the national forests of the Southeast the USFS did not develop the same intensive fire suppression organization and approach. In the northeastern states, fire protective associations emerged in the late 1800s, as they did in the Pacific Northwest, and later state organization became involved but federal involvement was more limited. In the Midwest and Great Plains there was little organized wildfire suppression and it appears that rural fire department handle suppression of prairie fires (Pyne 1999).[17] Texas, which has very little federal land, has a system that relies

[14] Details of modern suppression organization and policy are in the *Fireline Handbook* -- http://www.nwcg.gov/pms/pubs/410-1/410-1.pdf shows it all and BLM *Fireline Control Notebook* .

[15] When fire suppression organization became integrated into the Incident Command System the fire boss became the incident commander (IC).

[16] NIFC coordinate the following resources: National Area Command Teams, Type 1 Incident Management Teams, Type 1 Interagency Hotshot Crews , Smokejumpers , Smokejumper Aircraft, Type 1 & 2 Helicopters, Airtankers ,Infrared Aircraft , Leadplane Aircraft , Large Transport Aircraft ,Modular Airborne Firefighting Systems (MAFFS) ,National Mobile Food Units, National Mobile Shower Units National Commissary Units, NIRSC Communication Components , Fire Weather RAWS Systems , Critical Cache Items. See http://www.nifc.gov/ accessed August 9, 2012.

[17] Pyne (1999, 90-95) also described the fire organization on the XIT Ranch in Texas which had over 3 million acres in the early 20th century.

largely on state and local organizations.[18] In California, the California Department of Forestry (now known as CalFire) became a co-dominant player with the Forest Service, basically having suppression jurisdiction over all non-federal lands (CDF 2005). Alaska, which has millions of acres of fire-prone lands had no systematic and organized suppression until statehood in 1958 when federal funds were directed to the BLM which was the largest federal landowner (Pyne 1999). By the mid-1960s the suppression organization in Alaska mimicked that in the lower 48 states with a relatively heavy emphasis on air attack (smokejumpers, helicopters, and retardant).

III. ECONOMIC FRAMEWORK

In this section we examine the determinants of optimal suppression effort and organization of suppression. Our baseline case examines the optimal suppression response to a wildfire wholly contained on a single plot of private land. We then consider fragmented landownership and large and heterogeneous landscapes that may contain many fires. In our analysis we focus on the structure of land ownership and the costs of organizing suppression for a landscape level wildfire. Our analysis also focuses on the typical characteristics of the observed set of suppression organizations in United States history.

Figure 1

Features of our framework are the concepts of the "fireshed" and the "firescape." The fireshed (Lueck 2012) is a well-defined area of land that will, on a regular basis, carry a natural fire.[19] Figure 1a shows the simplest scenario in which a single landowner has a plot of fire prone land that wholly contains a fireshed. The prototypical fireshed starts at an ignition point and then

[18] The Texas Forest Service is the primary agency; see http://en.wikipedia.org/wiki/Texas_Forest_Service.

expands as an ellipse, driven by prevailing winds on flat terrain. In more rugged terrain fire shape and size is more variable but is often likely to be a v-shape going up a drainage (on both sides) getting larger at the higher elevation. Over the course of a fire wind changes can create a fireshed that may have a very irregular perimeter[20]. A firescape is simply a larger landscape level area in which there are a multitude of firesheds, perhaps overlapping (Figure 1(c)).[21] For our purposes for understanding the economic problem of suppression and asset protection the firescape can be defined as an area appropriate for making integrated planning and preparedness decisions.

We assume a *wildfire is any uncontrolled fire occurring in vegetation in the countryside or a wilderness area, or otherwise outside an urban area.* This definition includes fires in the wildland-urban interface (WUI) but does not include prescribed (or controlled) fires unless they escape control. We do not include structural fires except when they are part of a wildfire. We also do not consider the effects of thinning or other pre-suppression land fuel management on wildfire.[22] We define *suppression* as the act of attempting to reduce the extent and/or the intensity of all or part of the wildfire, and *protection* as the act of protecting assets at risk of burning without attempting to extinguish the advancing fire limit the extent of the fire per se (Bayham and Yoder 2012). For some assets such as timber the distinction between suppression

[19] This term is not in the literature on fire ecology (Agee 1993) but some fire scientists use the term 'fireshed' and 'fire regime' to represent, more or less, the same idea. Watersheds , airsheds, viewsheds, and floodplains are similar concepts.

[20] There is a growing literature on how topography, wind and fuels can influence fire shapes (e.g., Clark et al. 1996)

[21] See literature on fire ecology for related discussion of fire regimes (e.g., ponderosa pine in the Northern Rockies, chaparral in Southern California).

[22] Yoder (2012) examines the relationship between the various aspects of fire management which include prevention (e.g., thinning), control (e.g., prescribed fire), and suppression.

and protection is blurred or even nonexistent, but for other assets (e.g., buildings) it is an important distinction for our analysis.

Our framework allows for cases in which a wildfire will not be suppressed at all as well for cases in which the fire will be fully suppressed or where high-valued areas/resources will be protected. In some cases the cost of suppression overwhelms the benefits from damage prevention, such as a remote area with low vegetation and fuel. In other cases the potential damages across a large landscape justify rapid and intense suppression. In yet other cases, pockets of high valued resources (e.g., homes, villages, and mining sites) make it optimal to protect only those assets and otherwise avoid suppression.[23]

We hypothesize several characteristics of wildfires and their landscapes to be important determinants of the structure and variation of suppression organization over time and space:

1) Ignition risk and fire behavior characteristics,
2) Land ownership characteristics in the fireshed and firescape,
3) Asset characteristics and distribution within the fireshed and firescape, and
4) Suppression technology characteristics.

The importance of each of these factors will become clearer below, but consider them briefly here. The location and timing of ignition or escape of what becomes a wildfire is usually unknown and highly uncertain. Once ignited, a fire can develop rapidly and violently so that suppression difficulty, complexity, and cost can increase dramatically if not suppressed early.

[23] It is also possible for fire to be both beneficial for vegetation management and even for mitigation of future wildfire risk, within a landscape with assets at risk requiring protection. This is often the case for example when prescribed fire is used. In fact, a prescribed (i.e., controlled) fire can be thought of as a sort of domesticated fireshed.

Preparedness, prepositioning, and rapid emergency response are often highly productive, so these characteristics of suppression as a response are often crucial.

Fireshed and firescapes tend not to coincide with landownership boundaries, so that land ownership patterns and land use characteristics affect both private and public agency incentives to fight fires, and to the extent that localized suppression leads to privately incurred costs but provides public benefits, incentives to invest in suppression are weak from an economic efficiency perspective.

Irrespective of land ownership patterns, the distribution and characteristics of economic assets across the landscape are important determinants of economically sound suppression tactics. It is possible, for example, that active fire management is not worth its cost. Alternatively, while suppression for the purpose of stopping the advance of a fire may make sense if it is approaching an interface with a large residential development, in an environment with isolated high-valued assets (e.g. one house on an otherwise economically desolate 10,000 acres) may call for point protection with no attempts to stop the advancement of the fire through that acreage.

Finally, the costs suppression and the relative effectiveness of any combination of suppression tactics and strategies depend on available technology, and developments in suppression technology have advanced substantially in the last century. Further, improvements in technology can be associated with gains from specialization.

As we shall see, the factors that affect the development of wildfire suppression institutions themselves vary substantially over history space, and the combination of these forces may lead to suppression responses and institutions ranging from relatively simple private point protection responses to massive and complicated public organizations for wildfire suppression.

Each of these type of suppression responses come with their own unique incentive structure, from strong private incentives to protect private property to complicated and often seemingly perverse incentives associated with ongoing coordination of numerous public and private economic entities for suppression.

The development of a fire is a highly dynamic process (Lueck 2012, Bayham and Yoder 2012). Depending on weather and fuel conditions, fires can either smolder and self-extinguish, or they can "blow up" into major intense conflagrations. Blow-ups can be thought of as thresholds, which after being reached often imply high damage and losses and lower marginal suppression productivity, and for many of the most destructive fires, these thresholds are reached quickly. As such, wildfire development and suppression can be described as a dynamic problem in which suppression resource allocation early in the fire can have profound consequences later in the fire's development.[24] Figure 2 shows the stylized path of a wildfire area burned over time, but this time-path can vary dramatically as per the discussion above due to both environmental/land conditions and suppression activity.

Figure 2

We develop our economic framework in several stages of increasing complexity. First we examine a case where a single landowner of a homogeneous fireshed, and then consider the added complexity of heterogeneous assets within the fireshed, and stochastic ignitions within firescapes. We then consider the economic implications of multiple owners within a fireshed and firescape, as well as the implications of technology development.

[24] Fire scientists have developed several models to predict fire growth and extent based on field conditions. For examples, see http://www.firemodels.org/ and Clark, Coen, and Latham (2004).

A. Property rights and economically optimal wildfire response

Because land ownership does not typically encompass the geographic expanse of a fireshed or a firescape, control or ownership of a wildfire becomes a contracting problem.[25] Our approach to the ownership and control of a wildfire, and the resulting incentives, is rooted in Coase's Nobel-winning work (1937, 1960) on economic organization and property rights. Our analysis based in this approach not only illuminates the history of wildfire suppression but also informs the debate about current management and policies.

Consider a case in which a single landowner owns and controls resources over the entire firescape and any given fireshed, and whose objective is to maximize the economic value of the landholding.[26] Suppose also that the landowner will bear all the damage (or benefit) from any fire occurrence, as well as the full costs of fire management. Under these conditions, a landowner will have the incentive to allocate fire suppression resources efficiently over the entire course of any given wildfire, and prepare (invest) in response to the risk of future fires. While we will not formally characterize a model in this article, an optimization model would imply several important necessary conditions for optimal suppression activity that we will discuss. These conditions represent tradeoffs at the margin between the costs and benefits of suppression decisions over the course of a fire. The complexity and variability of environmental, economic, and wildfire characteristics precludes a comprehensive examination of tradeoffs, but we will summarize the fundamental tradeoffs for suppression strategy and institutional organization.

[25] The study of wildlife ownership by Lueck (1989), and contracting work of Libecap (1990) are both relevant.
[26] It is important to make a distinction here between *economic value* and the more restrictive concept of *market value*. Economic value refers to the full value of a given asset or resource relative to the value of other assets as assessed by individuals. The economic value of environmental amenities is often are not fully reflected in market prices of goods. Market value is therefore not to be confused with economic value.

Suppression, point protection, and timing

Firefighting effort can be focused on the extensive margin --- limiting fire size --- which we call *suppression*, or the intensive margin --- protecting assets without substantively affecting spatial fire growth --- which we call *protection* (Bayham and Yoder 2012).[27]

Consider a very simple environment with economic assets spread homogeneously across a fireshed, where the asset is itself the fuel for the fire. Figure 1a without the blue box in the fireshed would represent this simplistic case, and it approximates an even-aged timber stand supporting a crown fire, in which a constant asset value is lost per acre burned. In this case, suppression is economically equivalent to protection: suppressing the extent of a fire is equivalent to protecting assets.

Consider the incentives for suppression in the case of homogeneous assets at risk. Because the fire is growing over time over the homogeneous asset, any investment in suppression has important implications for future fire growth and therefore future suppression costs, so when balancing the marginal costs of suppression with the marginal benefits, both current and future implications of current suppression must be considered. Further, because the leading edge of the fire – the burning fire perimeter – usually increases in length over time as the fire develops, suppression costs tend to increase rapidly, and stopping fire growth early provides high marginal benefits in terms of both future damage and future suppression costs over the course of a fire.

[27] The distinction between point protection and suppression are related to the concepts of "direct" and "spillover" damage mitigation from wildfire hazard mitigation discussed by Butry and Donovan (2008).

Now consider a case in which there is one concentrated high-valued asset in an otherwise valueless fireshed. This is illustrated by Figure 1a, where the blue box represents the asset, and the orange holds little or no value, but contains fuel to sustain a wildfire. If fire suppression is costly and the fire is not extinguished immediately after ignition, before the fire perimeter gets larger, then it is likely that the most economically efficient response would be to protect the concentrated asset and otherwise let the fire burn the entirety of the fireshed. In terms of the timing of wildfire response, initial response is of little import (except if a very early response is possible) except to prepare for and implement point protection of the concentrated asset. As a related example, consider valuable Ponderosa Pine timber stand under which a ground fire is burning (low value) understory. In the absence of ladder fuels, the risk of an economically damaging crown fire is low, and the cost of allowing the fire to run its course is low. It may be optimal in this case for the fire to burn over the entire fireshed without any management effort (or perhaps only effort to reduce any chance of the fire climbing into the canopy), especially if it reduces future wildfire risk by reducing ever-growing biological fuel loads. This economic approach is a different perspective on asset "protection." Thus, the spatial relationship between fuel and economic assets is an important determinant of how fires are optimally fought. While the dichotomy between suppression and pure point protection is instructive and will inform our discussion below, real economic and environmental landscapes are more complex, and a mix of suppression, point protection, and timing of each is likely to be the case.

Emergency preparedness and prepositioning for future fires.

The discussion about optimal timing of suppression versus point protection suggests that optimal timing of wildfire response depends on the characteristics of the assets to be protected.

Nonetheless, fires often develop fast, and rapid response to wildfire is usually valuable. In general, preparedness and prepositioning of assets for rapid response is economically justified to the point where the expected marginal benefit of preparedness investment equals the marginal opportunity cost of preparedness (Is purchasing a fire extinguisher canister to keep in a house worth the cost? How about a second canister or a third?).

Further, the spatial distribution of firefighting inputs in and around a fireshed should, perhaps obviously, be kept where their expected effectiveness at reducing damage is (jointly) highest. Consider the economic incentives at the firescape level, while still assuming a single landowner (Figure 1c). The uncertainty about the timing and location of ignition and the potential rapidity of fire growth imply benefits of preparation, planning, and prepositioning of firefighting assets prior to the occurrence of a fire. To the extent that such preparation is economically justified at all, optimal pre-positioning of firefighting capital would be such that the marginal value of firefighting input placement on the landscape would be approximately equal across space, where the marginal value of such placement would be dependent on the distribution of assets at risk and the relative risk of ignition across the firescape.[28] In Figure 1c, for example, if ignition risk is homogeneous across the firescape, optimal placement might be proximate to (and perhaps in the center of) the cluster of blue concentrated assets within the fireshed in the center-right of panel 1c, with perhaps a lower concentration of assets elsewhere. More generally, pre-positioned suppression resources would be added (and distributed) until the

[28] In a varied landscape with roads, distribution across space would likely depend a great deal on the spatial characteristics of roads in relation to fire "hotspots".

marginal expected benefits of these placements is equal to the marginal cost of supplying these suppression resources for fighting any and all fires in the firescape.[29]

These marginal tradeoffs will fully reflect all the cost and benefits with respect to wildfire impacts because the single landowner is assumed to bear all the costs and benefits of these actions in terms of opportunity costs and wildfire damage averted, and is the sole manager of wildfire risk. It will therefore induce economically optimal wildfire management decisions by the single agent.

The fireshed has been a useful focus for discussing issues of multiple resource owners, firefighting strategy and the benefits and costs of specialization focusing on a single fire of known origin. The broader concept of a firescape represents a set of possible future wildfires, the management of which can reasonably be conceptualized across a larger geographic and temporal scope than a fireshed, and represents the economic/geographic scope of potential deployment of suppression response. The problems of firefighting response and resource allocation discussed above in the context of firesheds generally apply, but are exacerbated in a firescape-level management problem.

We now examine how more realistic land ownership patterns as well as and labor and asset contracts can shape incentives for wildfire suppression.

B. Contracts and the economic organization of wildfire suppression

As Coase (1960) and a substantial literature following it suggests, in a hypothetical world with zero transaction costs and full information, efficient firefighting outcomes can result even if

[29] Although not a focus of this article, pre-fire risk mitigation in the form of fuel management or asset protection such as defensible space creation around homes or altering materials or location of assets for risk management

wildfire span multiple landholdings and asset owners contract among themselves and with others to manage wildfires. Indeed, in such a setting any contract structure among agents would suffice to reach an efficient outcome. However, transaction costs are a part of all human interactions and they play a central role in the structure of contacts and the incentives inherent in alternative contractual or organizational regimes (Coase 1937, 1960; Williamson 1985).

In this section we examine how different organizations would compare to this ideal outcome by considering such issues as divided landownership, firescapes, specialization and network gains, emergency effects, and political economy. In particular we consider the following few (of many possible) basic organizations:

a) the landowner is an unspecialized firefighter,

b) the landowner contracts with a specialized firefighting firm;

c) landowners cooperate in firefighting (and may hire specialists)

d) a specialized third-party administrative public agency provides suppression services.

Single landowners, private contracts, and specialization

To this point, we have been describing a setting in which a landowner is solely involved in suppression and preparedness. However, even in a simple setting when a landowner completely "owns" a complete firescape and therefore any fire that occurs on it, there can be economic gains from markets for specialized suppression services. First, fire ignitions are sporadic events whose time and place are difficult to predict by wildfire response organizations. To the extent that fire ignitions are relatively rare and evenly distributed over a fire season, and specialized assets (labor and capital) are mobile across numerous firescapes and/or firesheds, contract-based

purposes is also subject to the same fundamental economic tradeoffs.

suppression and even rental contracts for pre-positioning can develop. This arrangement can be thought of as a rental market for specialized suppression assets much like rental markets for seldom used construction or farming equipment. Rental contracts such as these can minimize down-time for suppression assets (which is costly to suppression resource owners) because these suppression resources can keep busy by moving from fire to fire and firescape to firescape as needed.

Specialization and rental contracts may not always work effectively for fire suppression, however. While fire ignitions are indeed sporadic, they tend to be concentrated in a "fire season", the part of the year with hot, dry weather. Much like farming, where all farmers in a region have a brief (and highly correlated) window for harvesting, suppression assets are often demanded for numerous fires simultaneously. As a result, in highly fire-prone areas there might be a strong incentive to hold and maintain personal (landowner-specific) assets, which in the absence of "ignition congestion" would seem like overcapitalization. This, again, is similar to farmer investment in assets such as combines, which are expensive, and in the absence of the harvest timing congestion would likely form the basis of a rental market for combines (Allen and Lueck 2003).

Private markets for specialized firefighting labor can also develop if efficiency gains accrue from specialization in suppression. Wildfire suppression is a complex, difficult, and dangerous job, and experience is undoubtedly an important factor in effective wildfire management. It is unlikely, however, for landowners to become specialists in fighting fires, and so contacts with firefighting specialists could form among private parties for firefighting services. Further, development of specialized technology for firefighting (as with other

activities) often leads to increasing returns to specialization. So as specialized firefighting technology develops, markets for specialized firefighting services are more likely to develop.

Note, however, that efficiency gains from a market for firefighting services will also generate transaction costs. While firefighters may be more productive, they are generally not the residual claimants of their firefighting activities; landowners are. This misalignment of incentives between resource owners and firefighter actions may lead to inefficient allocation of firefighting effort on a property much like, much like an hourly wage fails to strongly incentivize hard work and fails to direct effort toward the most important tasks at any point in time (though the threat of being fired for poor performance will help address these problems to some extent).

Land ownership and public benefits from suppression

In the simplest case in which a single landowner 'owns' the fire, the landowner would have the incentive to optimally suppress the fire in the manner of Coase's (1960) case of sole ownership. If there are no gains from specialization (Allen and Lueck 2003), then the single owner of the fireshed (or firescape) will have the incentive to account for all costs and benefits of suppression and generate the outcomes that maximizes the net value of the landholding at risk of fire through optimal fire management decisions (Yoder 2004). However, like many large scale natural resources (e.g., oil, wildlife populations), there are often large numbers of landowners that will have a stake in a single fireshed. In such a setting, private individuals acting independently will have weak incentives to account for the impacts of their own private action, or inaction, on neighbors (Shafran 2008, Butry and Donovan 2008).

Consider the right-hand side of Figure 1 (panels 1b and 1d), in which the blue lines represent property boundaries. In the top right panel with one fireshed divided across multiple

landholdings, the actions of one landowner may easily affect the others. The most obvious case is the owner of the ignition point in the lower left of panel 1b. If this individual stops a fire at the ignition point before it leaves the property as it moves northeast, it will save the property of all other landowners in the fireshed. Yet, without any interaction with neighbors, this landowner has little incentive to invest in suppression, especially if his valuable economic assets are not at risk (the blue cube); the loss from inaction by the landowner at ignition point are born primarily by others in the firescape, even though immediate dousing at the ignition point (and the preparation to do so) might be the most economically effective suppression strategy for the fireshed as a whole.

The economic losses that can result from independent action over economically interdependent activities provides an incentive to develop explicit or implicit contacts --- cooperate, trade, and otherwise interact --- to improve economic outcomes. Landowners to the northeast of the ignition point have an incentive to promote suppression at the ignition point, and so have an incentive to enter into a contract with that landowner to promote suppression there, if the costs of doing so are lower than the costs of acting alone. One could imagine, for example, that all landowners in the fireshed would have an incentive to keep an eye out for fires on the land of the others, to jointly invest in firefighting apparatus to keep on hand, and to cooperate in suppression activities. Downwind landowners may have to provide additional incentives to the ignition-point landowner to participate effectively, but they may well be willing to do so.

Nonetheless, the ability to develop productive contractual solutions that induce more optimal outcomes will depend on the costs of contracting and enforcing agreements among landowners (Lueck 1989, Libecap 1990), which in turn depend on the nature of the resource management problem itself, the number and heterogeneity of landowners, technology, and other

factors. For example, if the set of landowners with land within the fireshed in Figure 1b choose to jointly invest in firefighting equipment to be used for coordinated fire protection, they will need to agree on a cost distribution among them. Should this cost distribution be based on relative landholding size, or the share of economic assets at risk? While each of these might be valid cost-sharing metrics, each landowner would prefer to shift more of the costs on the others. This contractual complexity may be sufficient to cause a contractual failure, forcing a reversion to independent action and the suboptimal outcomes that ensue. Further, contractual failure is in general more likely with an increase in the number of stakeholders and their heterogeneity in terms of assets at risk and other factors (Libecap 1990).

One solution to private contractual failure among many landowners is to vest the responsibility for wildfire suppression in a public entity. An example of this would be the establishment of public water and wildlife management agencies (Lueck 1989, Lueck and Yoder 1997).[30] Public agency involvement in wildfire suppression itself can be hypothesized to have arisen to mitigate the costs of private contracts over wildfire management. Transferring the responsibility of wildfire suppression from a landowners to a public agency can in principle reduce the number of decision makers from many (all private landowners in a fireshed) to one (an agency), making the coordination problem simpler in this sense (this strategy applies in principle to wildland and urban fires alike). In emergency situations especially, having a single decision unit can be crucial for effective action, and it is certainly conceivable that such a single decision locus could be more effective at fighting fires over numerous landholdings than a large

[30] Oil and gas conservation agencies are also examples of administrative agencies that arise from private contractual failure to manage large-scale resources.

set of landowners who may be cooperating in principle but each with their own private assets and incentives that can act counter to the benefit of landowners as a whole.

Vesting suppression responsibilities in a public agency is not without its drawbacks, however. As in the case of private market contracts discussed above, the landowners face the risk of asset loss from the fire, but with a public wildfire authority they no longer have direct control over suppressing wildfire affecting their land. Importantly, as with private firefighting specialists, public firefighters do not bear the losses from a fire, nor do their bear the losses that vary in response to their firefighting decisions. As such, their incentives for allocating suppression effort effectively are often weak or skewed, leading to inefficient outcomes. In the case of public firefighting agencies, the other important factors come into play as well. If landowners do not pay the full cost of fire suppression, then they have weaker incentives to mitigate risk of wildfire or to reduce potential damage from fires. If agency firefighting personnel do not bear suppression costs themselves, nor the damage associated with incomplete fire suppression, their incentives can be weak or skewed to choose effort levels effectively or distribute effort across firefighting tasks in a cost-effective way.

Network effects and coordination

As noted above the presence of many firesheds in the firescape can generate economic gains from specialization that will create the incentive to create an organization with specialized human and physical capital to apply suppression effort. The more extensive is the firescape with similar firesheds the more are the gains from specialization. In addition to potential benefits from cooperation and contracting over wildfire management, there may also be network effects from coordination of firefighting activity, preparedness, and prepositioning within

firescapes. Suppression assets can be deployed more efficiently training, skills and equipment are similar. Network effects are present if the sum of suppression costs for independent suppression of multiple fires exceeds the costs of integrated resource allocation applied to those same fires. The presence of network effects provides additional economic gains from organizing suppression efforts at the firescape level instead of at the fireshed level.

C. Hypotheses about wildfire suppression organization

Thus far we considered how the wildfire characteristics and the distribution of assets over firesheds and firescapes, affect optimal wildfire response and organizational structure. We can now point to several hypotheses about the level of suppression and the organization of suppression. We discuss them generally to start and then examine them again in our historical case-studies below.[31]

1) *Suppression and/or point protection is more likely when there are higher values at risk and/or when damage reduction is less costly.*
2) *Point protection is more likely when assets values in a fireshed are more heterogeneous; Suppression is more likely when assets are more homogeneous.*
3) *Suppression is less likely and point protection more likely in fuel environments with rapidly growing fire risk.*
4) *Smaller landholdings relative to a fireshed size lead to less private suppression and more private point protection relative to private suppression.*
5) *Cooperative (or public [third-party]) suppression is more likely with homogeneous assets and divided land ownership.* Corollary: *Public [third-party] suppression is more likely over private cooperative as landholding sizes decline relative the size of the fireshed.*
6) *Public suppression is more likely on (or in areas with more) publicly owned land.*

[31] These hypotheses are to be interpreted in *ceteris paribus* terms.

7) *Larger gains from specialization lead to larger firefighting organization scale.*
8) *Larger network economies lead to larger firefighting organization scale and complexity.*

Hypothesis 1 is perhaps patently obvious, but we include it to emphasize that it may be optimal to not actively manage a wildfire. On or beyond a frontier where the economic value of assets at risk of burning are low because the economic returns on their use are low, or if wildfire management is costly due to difficult terrain, long distances, or weather factors (among other things), wildfires may not actively suppressed, and assets may not be protected. Indeed, historically speaking wildfires have often been left to burn due to low expected losses or high expected management costs. Such a basic outcome can help understand general patterns of historic response to wildfire.

Hypothesis 2 follows from the discussion about point protection and timing. When the fuel itself is relatively low value and economic value is concentrated within a fireshed, it may be more efficient to focus on protecting specific assets in a fireshed instead of reducing the final fire size and/or duration.

Hypothesis 3 follows from the fact that suppression reduces fuel consumption today, leaving it for future ignitions to burn. If fuel loads are growing fast, more intense fires will tend to occur sooner, meaning that the present value of savings (in expected value terms) from suppressing a fire are lower than if fuel growth is slow or nil. In such an environment, point protection of assets (allowing fuel to burn) becomes more economically beneficial.

Hypothesis 4 emerges because for a given fireshed, smaller landholdings lead to a higher ratio of public/private benefits from private suppression. Thus, with smaller

landholdings, private returns to private suppression are lower for a given distribution of values at risk in a fireshed, leading to less (and inefficiently low) private suppression. Incentives for private protection remain strong, however, because the benefits are retained privately.[32]

Hypothesis 5 follows from hypothesis 4, in the sense that smaller landholdings skews private incentives and leads to lower private-action welfare, making cooperative fire management potentially more valuable. The corollary follows from an underlying hypothesis that transaction costs grow with the number (and diversity) of landowners in a fireshed, and so further economic loss may be avoided by reducing the number of decision makers by vesting firefighting decisions in a third-party manager, though at the cost of severing management from asset ownership.

Hypothesis 6 is based on the recognition that economic incentives for effective management are relatively stronger when asset management and asset ownership are in the same hands. Hypothesis 5 and "large numbers costs" notwithstanding, management incentives tend to be better aligned with asset values if the manager is a residual claimant of asset values.

Hypotheses 7 and 8 recognize the relationship between specialization and network gains and organizational (coordinative) scale as discussed above. We will show that changes in specialization and network potential driven in historically important ways by changes in technology over time.

[32]Further, because private suppression incentives are weak, suppression effort will be low. Consequently, private protection efforts in response to wildfires may be higher (inefficiently high) due to weak suppression incentives.

We now turn to a qualitative empirical examination of the history of wildfire response. In doing so we provide evidence for several of these hypotheses listed above.

IV. CASE STUDIES -- EMPIRICAL COMPARISONS

We examine the economic history of wildfire suppression by creating several discrete sections. We begin with a discussion of evidence for the structure of early fire use and protection, the advent of firefighting organizations, geographic variations in wildfire response, and then examine the development of federal wildfire policy in the United States.

A. The historical emergence of organized wildfire suppression

The distinction between asset protection from and suppression of wildfires is an important one in the historical development of wildfire suppression organization as it exists today. In this section we look at the historical development of fire in the U.S., up until and then during the emergence of the federal wildfire suppression infrastructure development.

Human use and response to fire: Fire use and asset protection

As discussed in Section 2, humans have long used broadcast burning for managing vegetation, facilitating game hunting, and for other reasons. The application of organized active suppression for the purpose of extinguishing out-of control fires, however, shows up in the historical record first in an urban setting around two thousand years ago. It is not until the mid to late 1800s that the active fire suppression of wildland fires is adopted. There is some limited historical evidence of the obvious impacts of wildfire: namely the destruction of human life and property from both natural and human-caused fires (Keeley 2002). Other limited accounts of early prehistorical wildfire and history well into the 1800s suggest that protection of local assets,

and not suppression of fires generally, was the standard response in rural settings in North America (Morton 1637, Stephens and Sugihara 2006).

Our analysis suggests that when broadcast fires provide general positive value (or zero, or only small negative value) at the extensive margin for landscape management (Hypothesis 1), and when human values at risk are concentrated in a fireshed, that protection of local assets rather than fire suppression is more often the most economical response (Hypothesis 2). A response to a threatening wildland fire would more likely be the protection of private living quarters or villages/towns. Under these circumstances, when human assets within a landscape are relatively diffuse, but local protection rather than suppression is optimal, protection essentially becomes a private matter (Figure 1b). As Pyne (1983) notes, "Free-burning fires belonged with the flaming front of colonizers and pioneers." One economic definition of a frontier is that margin beyond which development had not yet been worth pursuing. As such, natural resource values tend to be low except due to increases in value from the application of labor and development --- the most valuable and stationary of which tend to be housing. Thus, local protection, and not suppression, would tend to be the chosen strategy on a sparsely populated frontier (Hypothesis 2).

Protection of sparse personal or family assets provides little incentive for coordinated or organized action beyond the household level. When households with divided ownership are densely situated within a fireshed, then asset protection rather than suppression may still be optimal, but coordinated protection is likely to arise (Hypothesis 5). Limited evidence suggests that this was the response to wildfire risk by early European settlers of North America: In response to risk from Native American broadcast burning, Native Americans themselves almost certainly self-protected their valuable fixed assets (Anderson 2006), settlers cleared vegetation

around settlements via the use of backfires and perhaps controlled fires prior to individual fire threats (Morton,1637, Pyne 1999, Stephens and Sugihara 2006).

The advent of organized suppression: from urban to rural

Just as there is an incentive for coordination of protection among settlers in localized settlements within a fire-prone fireshed, urban fires call for coordinated action as well. In an urban setting, however, valuable assets are concentrated but more spatially homogeneous within the urban fireshed.[33] As such, suppression is likely to be a more economically effective response to a wildfire than individual private protective responses (Hypothesis 2). Indeed, since at least Ceasar Augustus in Rome two millennia ago, organized fire suppression organizations have existed and persisted in various forms in urban environments (Hirst 1884, Winer 2009, McChesney 1986).

The first evidence of persistent rural suppression effort and suppression organizations that we have found dates to the late 1800s in the United States with two parallel developments. In 1885 and 1886, wildfire control programs were developed for the Adirondacks Reserve in New York and Yellowstone National Park, respectively (Chambers 1987). Around the turn of the century, private forest protection associations began to develop: first in Northeastern Forests, and very shortly after, in Northwestern states (table 2). Typically members paid dues based on the forest acreage within the jurisdiction governed by the association. These dues were used to purchase firefighting equipment (water trucks, etc), build fire lookouts, and pay labor for fire scouts and firefighters (Allen 1910, CPTPA 2012, Bradshaw 2012). By 1910, the State of Idaho

[33] Indeed, when wood was the primary construction material you can think of a city as a dense, dry old growth forest, ready to burn. Every lantern was a potential "lightning strike" or ignition source.

had become a member of all of the approximately 10 fire protection associations in the State in order to facilitate protection of state forest land (Allen 1910). In 1905, the State of Maine in cooperation with forest protection associations instituted fire control districts over unincorporated townships, and a fire lookout system. Also in that year, the California State Forester was granted authority to maintain forest fire patrols, an event that can be interpreted as the creation of CAL FIRE (CDF 2005, Thornton 2005), which has developed into one of the most extensive state fire management and suppression organizations in the United States.[34] State involvement in fire suppression generally increased in the Northeast and Northwest during this time period.

In the context of our model, forests harvested for timber can be viewed as having relatively homogenous value across a fireshed. Forest fires are often categorized in *regimes* of severity and frequency (FRCC 2012).[35] Some forest types tend to have high frequency, low intensity ground fires, and some have a natural tendency to occur in the form of crown fires, such that a primary fuel for the fire were the marketable trees themselves. As such, asset protection is functionally equivalent to suppression: If protection is economically viable at all, the way to protect timber assets is to suppress crown fires (Hypothesis 2). In terms of more recent land use, the substantial growth in the Wildland-Urban Interface (WUI) is at least in part driven by the value people place on a natural environment surrounding homes. As housing values become dependent on environmental assets from aesthetics, then protecting a house is not sufficient to protect value --- the entire environment becomes important, and to the extent that burned-over

[34] See http://www.fire.ca.gov/ accessed March 28, 2013. CALFIRE has a responsibility area of more than 30 million acres.
[35] See also a map of U.S. fire regimes: http://www.landfire.gov/geoareasmaps/CONUS/CONUS_FRG_c00.jpg

property is less aesthetically appealing, suppression becomes relatively more preferred over point (home) protection.

When firesheds tend to span numerous landholdings, suppression efforts on one landholding affect that extinguish or reduce the extent of a fire will tend to reduce damage to assets and suppression costs on neighboring landholdings, so in contrast to the "local protection" regime discussed above, the incentives for cooperative suppression activity and/or third-party (public) fire suppression become stronger (Hypothesis 5). Our model is therefore consistent with the advent of cooperative private timber associations that developed in the Northeast, Northwestern United States in the late 1800s and early 1900s as timberland became privatized and timber production was near its zenith (Fernow 1907).

B. Geographic variations: from the Northeast to Southeast to West.

While some of the most fire-prone habitats in North America occur in the southeastern and southwestern states (Fowler and Konopic 2007), organized suppression did not seem to develop in the South as early or extensively as it did in the northern states until the Federal government became actively involved in aggressive suppression (discussed below). For example, while numerous timber protection associations had developed in the Northeast and Northwestern U.S. by around 1910, the Florida Analogue, the Florida Forestry Association, did not form until 1923, which is late in comparison to those in the North. We argue that this was due in part because of the nature of the vegetation itself.[36] Fire return intervals in southern US

[36] A counterexample is the Georgia Forestry Association, which formed in 1907 (GFA 2012). As Pyne (1999) noted : "The very concept of cooperative fire protection may be the Northwest's most enduring legacy. For this program the almost simultaneous arrival of industrial logging, the forest reserve system, and a timely series of holocausts may take the credit."

tend to be shorter in general, not the least due to active human burning (FRCC 2012 and link in footnote 34). The consequence is that frequent burning would more often tend to burn understory, leaving the standing timber unharmed (FRCC 2012). "Light burning", the application of low intensity fires for vegetation management had been an integral part of these southeastern firescapes since prehistory, and continued well beyond initial European Settlement (Fowler and Konopik 2007, Shea 1940, Pyne 1999). According to Eldredge (1911), "…It is only by chance that any area of unenclosed land [in North Florida] escapes burning at least once in two years." (quoted and cited in Wade et al. 2000). These low intensity fires were not as often destructive of timber value, so the economic risk of fire is lower than when high-valued vegetation (timber) is at higher risk of burning (in crown fires, for example). As a result, either no firefighting response, or local protection rather than suppression, was more likely the economically viable response (hypotheses 1 and 2).[37]

There is also some evidence that in the highly fire-prone environments of Florida and the Southeast generally. In this region the consequences for increasingly intense fires due to fire exclusion was more obvious and the effects more immediate than in the Northern climates where fire risk growth was slower. Wade (2000) argues that it was widely believed in the South that light burning was crucial for managing risks of high intensity fire in Southern Pine forests. Shea (1940) provides some interesting anecdotal evidence in support of this perspective. Fire suppression in this type of environment not only is less likely to have substantive benefits in terms of current asset value (value of timber in the current year), but also may have detrimental

[37] This is certainly context dependent. See Fowler and Konopick (2007) for a description of the changes to forest (and therefore fire) regimes from the 1890s through the early 1900s in which they suggest that catastrophic fire became more common in areas that had been heavily logged.

effects on future timber value because fire exclusion by suppression increases fire intensity and the risk of crown fires in future years. Under these conditions, local protection of assets (and, for that matter active fuel management like broadcast burning) should dominate suppression as a response to wildfire (Hypothesis 3).

Similarly, we have found little or no evidence to date of early organizations developed for rural fire suppression in the Great Plains. Although natural and anthropogenic fire has been an integral part of the ecology of the Great Plains, fires tend to be less severe than forest fires, and grassland ecosystems recover faster and may even respond by increasing biomass growth rates. While grass fires can spread rapidly and therefore become large quickly, fires in the prehistoric record of the Northern Great Plains tended to last no more than a day (Seig 1995). Thus, while Pyne (1999) provides some limited evidence of organized wildfire suppression in Texas, it appears that broad scale private and state-level cooperative fire suppression was driven from development of timber production in the Northern United States, while the Southern states and the Great Plains were apparently less active and lagged in the development of suppression organizations. In fact, within the last couple of decades, the first organized prescribed fire cooperatives developed in West Texas and numerous others have developed since (Taylor 2005). Again, these developments are consistent with a setting in which suppression has low or perhaps negative net present value (hypotheses 1 and 3).

C. Origins and evolution of federal wildfire suppression.

The U.S. Forest Service and national forest lands developed under a series of legislative acts between 1891 through 1911, with the charge of managing forests in the public domain (U.S. Forest Service 2012). The Creative Act of 1891 (also known as the Forest Reserve Act)

authorized the President to reserve "public land bearing forests — whether of commercial value or not, as public reservations," (Act of March 3, 1891, ch. 561, 26 Stat. 1095, 1103; quoted in Snider 2009) and the Organic Administration Act of 1897, provided direction for the forest reserves to use the national forest reserves for timber production, among other things. (16 U.S.C. 475; Snider 2009).

Federal forest reserves (not including National Parks) went from zero to 175 million acres, an area roughly the size of Texas, between 1894 and 1906 (Fernow 1907). At this point these reserves were exclusively in the western 13 states. By this time period, a number of large fires in the Northern United States and Canada devastated towns and killed people in large numbers. Table 2 shows some of the largest and most important of these wildfires in US history.

Table 2

Direct federal involvement by the federal government began in 1886 with U.S. Army fire patrols in Yellowstone (Chambers 1987, Agee 1974). In 1908, the Forest Fires Emergency Act authorized the Forest Service to spend whatever available funds necessary to combat wildfires and fire prevention and control programs in National Forests (Forest History Society 2012a).[38]

The Great Burn of 1910 in Idaho and Montana was large and devastating – 3 million acres, 85 lives and destruction of buildings and towns, yet of the same scale as the 19th century fires. While the large fires in the Northeast and Great Lakes states provided some impetus for the development of private and State-level suppression organizations, the 1910 Burn was the

[38] This is the "The "Blank Check" policy of 1908" referred to in Lueck (2012) and elsewhere.

spark for political action that dramatically increased Federal involvement in wildfire suppression, and changed public land management policy throughout the 20th century.[39]

In the wake of the 1910 fires, the Weeks Law of 1911 the Clarke-McNary Act of 1924 became the basis for the development of Federal-State cooperative funding for wildfire suppression and management (Forest History Society 2012). Importantly, as described in numerous historical accounts (e.g. Pyne 1999), the U.S. Forest Service promoted an aggressive fire policy focused almost entirely on fire suppression during this time period, funded under the Forest Fires Emergency Act and subsequent acts.

In simple terms, the U.S. Government had become a large owner/manager of forest land, had been given the authority and the funds to suppress wildfires aggressively, and the 1910 fires occurred largely on Federal National Forest land. [40] Our model would suggest that this is the type of economic environment from which a policy of suppression would more likely arise: the owner/manager of large tracts of forest land is more likely to approach wildfire risk and damage mitigation by extinguishing fires at the extensive margin rather than focusing on point protection (Hypothesis 2). Indeed, the approach had been pursued by organized private timber associations in Northern States in the years preceding these federal land developments, and the federal government adopted the Northwest Timber owner's strategy of active suppression.[41] It is noteworthy that the Big Burn happened in a region where private timber associations had already

[39] There is a vast literature on the Big Burn and its relationship to Federal wildfire suppression policy. We rely on Egan (2009), Pyne (2008), and Forest History Society 2012b.

[40] We will discuss the apparent motivations for transfer/purchase of private forest lands in the West and East to public management.

[41] The agency nor any of its employees or managers were the residual claimants of either the values at risk (timber values), nor the costs of suppression. Berry (2007) argues that the Forest Fires Emergency Act of 1908 --- the blank

been actively pursuing suppression, and not in the South, where light burning was much more heavily pursued, and forest owner associations seemed to be less active (especially in terms of fire suppression).

The U.S. Forest Service, however, is not a private landowner. Much has been written about the apparent inefficiencies of Forest Service wildfire suppression activity, and some has been written on the nature of the incentives (See Ingalsbee 2010, Berry 2007, Davis 2001, Busenburg 2004, Stephens and Ruth 2005, Pyne 1999, O'toole 2002). We will examine these incentives shortly, but first consider the basic reasons why the U.S. Forest Service *is* involved the way it is in the context of the most fundamental land ownership characteristics. As noted above, the Forest Service is a large owner/manager of forest land. As such, it is at least in a proximate sense the residual claimant of the assets at risk to fire on federal land. As such, it's employees have among the strongest incentives to protect those assets of anyone, at least to the extent that they are held accountable for these assets. Therefore, public suppression and protection (as opposed to private protection) is likely to develop on publicly-owned land, if it develops at all (Hypothesis 6).

There are other reasons beyond public land ownerships that the public sector might become involved in suppression and protection. Even though Forest Service landholdings tend to be large, fires often span borders among federal, state, and private lands. Multiple-landowner incentive and coordination problems exist, but now in the context of a militaristic government bureaucracy. Furthermore, the Forest Service has developed an infrastructure and capital that,

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check policy ---- provided little incentive for the Forest Service to make the kind of marginal cost/benefit analysis that a private forest owner would, and promotes the strong focus on suppression.

due to the spatiotemporal variability and unpredictability of fire ignition, is highly mobile. From a physical perspective it can be mobilized to non-Forest Service land, and in fact it often is. The Forest Service has formal and informal agreements with all States for cooperative suppression and cost-sharing. It is not, however, generally responsible for initial attack when a fire ignites on other federal lands, or on state or private lands. Both the Bureau of Land Management (BLM) and the National Park Service (NPS) are landowning agencies within the Department of Interior and they also have responsibility for initial attack on their lands. In the case of state lands, the state itself is responsible (most/all states have firefighting programs, often managed through departments of natural resources or forestry). In the case of fires ignited on private lands, initial attack is often the responsibilities of municipal and/or county firefighting organizations.[42]

In addition to cross-boundary effects, the characteristics of fire ignition lend itself to large, complex response structures, particularly when specialized, mobile technology is available for deployment. Fire is an explosive force whose ignition is both diffuse and unpredictable across a firescape. If fire suppression is the optimal response to a fire, there is value in preparedness and rapid deployment of mobile capital in the form of firefighting machinery and labor (Hypotheses 7 and 8). The organizational structure that arises in emergency settings such as this is often similar to military or rule-based organizations. Indeed, the Forest Service

[42] However, there are often formal or informal agreements between the Forest Service and local/State administrations that stipulate Forest Service initial attack responsibility when local deployment infrastructure is more suited to such an arrangement (David Calkin, U.S.F.S. Rocky Mountain Research Station in Missoula, Montana, personal communication.)

developed an infrastructure for attacking fires in such a firescape on Forest Service lands that operates much like military organizations.[43]

In broad strokes, we have a setting in which landowners (or their local public agents) have responsibility for the crucial initial attack period of wildfire suppression, but the firefighting assets of largest public land managers are brought to bear via cooperative arrangements with smaller landholders and jurisdictions. To the extent that landowners are the residual claimants of the resources at risk from wildfire, this basic organization makes sense in the context of our model. Even if all landowners were private entities, however, cross-boundary effects of fire and suppression would lead tend to second-best cooperative or non-cooperative solutions. Given the fact that public agencies are major landowners, and that at a local scale firefighting organizations tend to be non-landowning quasi-public, incentives and therefore wildfire outcomes can be extremely complex and economically disjoint, with firefighting incentives structures much more complex, and in some ways preposterous incentives.

V. SUMMARY AND CONCLUSIONS

The organization of wildfire suppression is complicated, varied, and seemingly without economic logic. We examine the economic rationale for the structure of observed wildfire suppression organization and examined implications or our framework against data from throughout the U.S. and over time. The theoretical framework incorporates the unique features

[43] Federal ownership, management, and use of firefighting capital leads directly to questions about the economics of organizations as discussed in the theory section. When would/should the forest service as a forest land manager contract with private firms to manage fire suppression, or contract with private parties for the use of capital and operations? The pert answer is that they often do, and fire suppression preparedness and attack is usually a complex mix of contractual relationships. We will be examining this contractual environment in the future.

of wildfires that make them complicate assets to manage: fires are spatiotemporally sparse events; fire suppression timeliness is severe; and landownership patterns tend not to align with fireshed boundaries.

We find that the existing structure of wildfire suppression institutions - specialized crews, large scale government intervention, military style organization, pre-positioned investments – are largely a rational response to the unique features of wildfire in the modern environment, and their historical development over time follows some important developments in land use and land ownership. Our empirical evidence is comprised of historical case studies. We illustrate the economic foundations for the advent of suppression in an urban setting and the later development of suppression in settings with high value but relatively homogeneous timber asset, while simultaneously failing to develop in the south where the nature of the vegetation itself reduces the value of suppression, and in fact, the value of regular fire return. Public involvement in fire suppression may have developed in part due to its ability to reduce coordination costs, but in the Western United States, it seems clear that the fact that the federal government became a large timberland owner had much to do with an escalation in aggressive wildfire suppression. Given further development of specialized mobile firefighting technology and spatially complex land ownership patterns, the largest landowner in the part of the country with the most destructive wildfires --- the U.S. Forest Service has become the dominant firefighting organization, utilizing a militaristic management structure as a way to address the emergency characteristic of firefighting.

As has been pointed out by many, the current wildland fire suppression institutional arrangement provides complex incentives that can promote inefficiently high suppression costs and wildfire damage, but in broad strokes it is not inconsistent with the basic hypothesis that

modern firefighting organization has evolved to approximately maximize the net value of land assets subject to transaction costs and the idiosyncrasies of wildfire.

This is not to say that these institutions should be accepted as optimal or static from a policy perspective. Substantial increases in wildfire suppression costs over the last decade indicate underlying structural changes in wildland fire management problem, with some evidence of contributions from increasing economic complexity at the wildland-urban interface, changing fuel loads, and climate change. With these changes come important opportunities for restructuring incentives for more efficient management of wildland fire and the lessons of economic history become relevant.

VI. REFERENCES

Agee, J. K. 1974. Fire management in the National Parks. *Western Wildlands* 1:27–33.

Allen, E.T. 1910. "What Protective Co-Operation Did." *American Forestry*, vol. 16 (November): 641-643. http://www.foresthistory.org/ASPNET/Policy/Fire/FamousFires/Allen_Cooperation.pdf

Allen, D.W. and Lueck, D. 2003.*The Nature of the Farm* (MIT Press).

Anderson, M. Kat. 2006. The use of fire by Native Americans in California. Chapter 17 in Fire in California's Ecosystems, edited by Neil G. Sugihara, Jan W. van Wagtendonk, Kevin E. Shaffer, JoAnn Fites-Kaufman, Andrea E. Thode. University of California Press.

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

Berry, Allison. 2007. Forest Policy Up in Smoke: Fire Suppression in the United States. Property and the Environment Research Center. http://www.perc.org/articles/article1004.php

Bayham, Jude, and Jonathan Yoder. 2012. Wildfire Hazards: A model of disaster response. Washington State University School of Economic Sciences Working paper 2012-9. http://faculty.ses.wsu.edu/WorkingPapers/Yoder/wp2012-9.pdf

Bradshaw, Karen M. and Dean Lueck eds. 2012.*Wildfire Policy: Law and Economics Perspectives.* Washington D.C.: Resources for the Future.

Butry, David, Marcia Gumpertz, and Marc Genton. 2008. "The production of large and small wildfires." Chapter 5 in *The Economics of Forest Disturbances*, Holmes, T., Prestemon, J., and Abt, K., Eds. Springer.

Butry, David and Geoffrey Donovan. 2008. Protect Thy Neighbor: Investigating the Spatial Externalities of Community Wildfire Hazard Mitigation. *Forest Science*, Volume 54, Number 4, August 2008 , pp. 417-428(12).

California Department of Forestry and Fire Protection. 2005. *100 Years of CDF* Nashville: Turner Publishing.

Cardille, Jeffrey, Stephen Ventura, and Monica Turner. 2001. "Environmental and social factors influencing wildfires in the upper Midwest, United States."*Ecological Applications* 11(1):111-127.

Carle, David. 2002. *Burning Questions: America's Fight with Nature's Fire*. Praeger Publishers, Westport CT.

Calkin, David , Krista Gebert, Greg Jones, and Ronald Nelson. 2005. "Forest Service Large Fire Area Burned and Suppression Expenditure Trends, 1970-2002 "*Journal of Forestry*.179-183.

Chambers, John. 1987. "The Evolution of Wildland Fire Management and Policy."*Fire Management Notes* 48(2):5-8. U.S. Department of Agriculture Forest Service.

Clark TL, Coen J, Latham D (2004) Description of a coupled atmosphere–fire model. *International Journal of Wildland Fire* **13**, 49–63. http://dx.doi.org/10.1071/WF03043.

Clark, Terry, Mary Ann Jenkins, Janice Coen, and David Packman. 1996. A coupled atmosphere fire model: convective feedback on fireline dynamics. *Journal of Applied Meteorology*35(6):875-901.

Coase, Ronald H. 1937. "The Nature of the Firm" *Economica* 386-405.

Coase, Ronald H. 1960. "The Problem of Social Cost," *Journal of Law and Economics.*3:1-44.

CPTPA. 2012. Clearwater-Potlatch Timber Protective History. http://www.cptpa.com /history/history.htm. Last accessed August 5 2012.

Dixit, Avenish. 2009. "Governance Institutions and Economic Activity." *American Economic Review,* 99(1), March 2009, 5-24.

Dolcemascolo, Glenn P. 2004. Burning issues: Control of fire management In central kalimantan, Indonesia. Ph.D. Dissertation, department of Anthropology, University of Hawaii.

Donovan, Geoffrey, Thomas Brown, andLisaDale .2008."Incentives and wildfire management in the United States." Chapter 16 in *The Economics of Forest Disturbances*, Holmes, T., Prestemon, J., and Abt, K., Eds. Springer.

Donovan, Geoffrey H., Douglas B. Rideout, and Philip N. Omi. 1999. The Economic Efficiency of the National Fire Management Analysis System and FIREPRO. USDA Forest Service Gen. Tech. Rep. PSW-GTR-173.

Enright, Neal J. and Thomas, Ian. 2008. Pre-European Fire Regimes in Australian Ecosystems. Geography Compass 2(4):1749-8198.

Epstein, Richard. 2012. "Common Law Liability for Fire: A Conceptual, Historical, and Economic Analysis," in Bradshaw and Lueck eds. *Wildfire Policy: Law and Economics Perspectives* Resources for the Future Press.

Fernow, Bernhard, E. 1907. *A brief history of forestry in Europe, the United States and other Countries.* University Press, Tortonto, Canada.

Florida Forestry Association. 2012. *Who We Are: History*.
http://www.floridaforest.org/history.php

Forest History Society. 2012a. U.S. Forest Service Fire Prevention and Control.
http://www.foresthistory.org/ASPNET/Policy/Fire/Prevention/Prevention.aspx

Forest History Society. 2012b. The1910 Fires.
http://www.foresthistory.org/ASPNET/Policy/Fire/FamousFires/1910Fires.aspx

Fowler, Cynthia and Evelyn Konopik. 2007. The History of Fire in the Southern United States. *Human Ecology Review* 14(2):165-176.

FRCC. 2012. Fire Regime Condition Class. http://www.frames.gov/partner-sites/frcc/frcc-home/ . Last accessed November 10 2012.

Gebert, Krista, David Calkin, and Jonathan Yoder. 2007. "Estimating suppression expenditures for individual large wildland fires."*Western Journal of Applied Forestry* 22(3): 188-196.

Georgia Forestry Association. 2012. Georgia Forestry Association: Our history.
http://www.gfagrow.org/displaycommon.cfm?an=1&subarticlenbr=5

Gorte, Ross W. and Kelsi Bracmort. 2012. *Wildfire Protection in the Wildland-Urban Interface*. Congressional Research Service report 7-5700, RS21880.

Hirst, Joseph. 1884. *On the methods used by the ancient Romans for extinguishing conflagrations.* Exeter: London.

Holmes, Thomas, Jeffrey Prestemon, and Karen Abt, eds. *The Economics of Forest Disturbances*, Holmes, T., Prestemon, J., and Abt, K., Springer.

Ingalsbee, Timothy. 2005. “The War on Wildfire.” In *Wildfire: A Century of Failed Forest Policy* George Wuerthner ed. Island Press.

Keeley, Jon E. Native American impacts on fire regimes of the California coastal ranges. Journal of Biogeography, 29, 303–320

Levine, J.S., Bobbe, T., Ray, N., Witt, R.G. and Singh, A. 1999. Wildland Fires and the Environment: A Global Synthesis. Nairobi, Kenya: Division of Environmental Information, Assessment and Early Warning (DEIA&EW), United Nations Environment Program (UNEP).

Libecap, Gary D. 1989. *Contracting for Property Rights*. Cambridge: Cambridge University Press.

Lueck, Dean. 1989. “The Economic Nature of Wildfire Law.” *Journal of Legal Studies.* 18:291-324.

Lueck, Dean. 2012. "Economics of Wildfire Suppression Organization,” in Bradshaw and Lueck eds. *Wildfire Policy: Law and Economics Perspectives* Resources for the Future Press.

Lueck, Dean and Jonathan Yoder. XXXX. “Federalism and Wildlife Conservation in the West.” In Anderson, Terry and Peter J. Hill, Eds, *Environmental Federalism.*Rowman and Littlefield, Lanham, MD.

Libecap, Gary D. 1990. *Contracting for PropertyRights*.Cambridge: Cambridge University Press.

Libecap, Gary D. and Dean Lueck, 2011. “Land Demarcation and the Role of Coordinating Institutions,” *Journal of Political Economy* 119:426-467.

McChesney, Fred. 1986. “Prohibitions on Volunteer Fire-Fighting in Nineteenth Century America: A Property Rights Perspective,” *Journal of Legal Studies* 15:69-xxx.

Merrill, Thomas. 2012. "Property and Fire," Chapter 2 in Bradshaw and Lueck eds. *Wildfire Policy: Law and Economics Perspectives* Resources for the Future Press.

Morton, Thomas. 1637. *New English Canaan: or New Canaan*. New York: Arno Press.

National Interagency Fire Center. 2012. http://www.nifc.gov/fireInfo/fireInfo_stats_lightng.html

North, Douglass C. 1990. *Institutions, Institutional Change and Economic Performance*. New York: Cambridge University Press.

Ostrom, Elinor. 1990. Governing the Commons: The Evolution of Institutions for Collective Action.Cambridge University Press.

O'toole, Randal. 2002. Money to Burn? *Regulation* 25:16-20.

Rainbird, J. S.1986. The Fire Stations of Imperial Rome. *Papers of the British School at Rome* 54:147-169

Peece, Noel. 2002. Aboriginal fires in monsoonal Australia from historical accounts. *Journal of Biogeography*, 29, 321–336

Pyne, Stephen J. 1983. Forged in Fire: History, land, and anthropogenic fire. Chapter 4 in *Advances in Historical Geography*, William Balee, Ed. Columbia University Press, NY.

Pyne, Stephen J., Patricia L. Andrews, and Richard D. Laven. 1996. *Introduction to Wildland Fire*, 2nd Edition. John Wiley & Sons, New York.

Pyne, Stephen J. 1991. *Burning Bush: A Fire History of Australia*. New York: Henry Holt.

Pyne, Stephen J. 1999. *Fire in America: A cultural history of wildland and rural fire.* 2nd ed. University of Washington Press. Seattle.

Pyne, Stephen. 2011. *Between Two Fires*. http://firehistory.asu.edu/between-two-fires/. Accessed Dec. 22, 2011.

Reinhardt, Elizabeth D., Robert E. Keane, David E. Calkin, Jack D. Cohen
Objectives and considerations for wildland fuel treatment in forested
ecosystems of the interior western United States. *Forest Ecology and Management* 256:1997-2006.

Rogers, Michael J. 1982. Fire Management in Southern California. Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems, June 22-26. General Technical Report GTR-PSW-058.

Schindler, Ludwig. 1998. The 1997 Wildfire Season and the Impact of Fire Management Projects in Indonesia. *International Forest Fire News* (IFFN) 18:37-39. January. http://www.fire.uni-freiburg.de/iffn/country/id/id_12.htm .

Aric P. Shafran, Risk externalities and the problem of wildfire risk, Journal of Urban Economics, Volume 64, Issue 2, September 2008, Pages 488-495, ISSN 0094-1190, 10.1016/j.jue.2008.05.001. (http://www.sciencedirect.com/ science/article/pii/ S0094119008000399)

Shea, John P. 1940. “Our Pappies burned the woods.” American Forests April:159-174.

Stephens, Scott and Lawrence Ruth. 2005.“Federal forest-fire policy in the United States.” *Ecological Applications* 15(2):532-542.

Stephens, Scott L. and Neil G. Sugihara. 2006. Fire Management and Policy Since European Settlement . Chapter 18 in Fire in California’s Ecosystems, edited by Neil G. Sugihara, Jan W. van Wagtendonk, Kevin E. Shaffer, JoAnn Fites-Kaufman, Andrea E. Thode.

Stewart, O.C. 1956. Fire as the first great force employed by man. In W.L. Thomas Jr. (Ed.), Man's Role in Changing the Face of the Earth, University of Chicago Press, Chicago, IL (1956), pp. 115–133

Southard, Lewis F. 2011. The history of cooperative forest fire control and the Weeks Act. *Forest History Today* Spring/Fall:17-20.

Stearns, Forest W. 1997. History of the Lake States Forests: Natural and human impacts. In: Vasievich, J. Michael; Webster, Henry H., eds. Lake States Regional Forest Resources Assessment: Technical Papers. Gen. Tech. Rep. NC-189. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 8-29. http://www.ncrs.fs.fed.us/gla/reports/history.htm

Taylor, Charles A. Jr. (2005) Prescribed Burning Cooperatives: Empowering and Equipping Ranchers to Manage Rangelands. Rangelands: February 2005, Vol. 27, No. 1, pp. 18-23.

Thornton, Mark V. 2005. General History of CAL FIRE. http://www.fire.ca.gov/about/about_calfire_history.php. Last accessed November 10 2012.

U.S. Forest Service. 2012. Founding Legislation and History of the Forest Service's Traditional Role. http://www.fs.fed.us/plan/par/2003/final/html/fs_glance/founding_legislation.shtml

van Wagtendonk, Jan W. 2007. The history and evolution of wildland fire use. *Fire Ecology* Special Issue 3(2):3-17.

Wiitala, Marc R. and Andy E. Wilson. 2004. Wildfire Initial Response Assessment System: A Tool for Fire Preparedness Planning. Proceedings of the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.Williamson, Oliver E. 1985. *The Economic Institutions of Capitalism: Firms, Markets and Relational Contracts*. New York: Free Press.

Winer, Daniel H. 2009. The development and meaning of firefighting, 1650-1850. Doctoral Dissertation, University of Delaware, 2009. http://gradworks.umi.com/33/60/3360270.html

Yoder, Jonathan K. 2008. "Liability, regulation, and endogenous risk: the incidence and severity of escaped prescribed fires in the United States."*Journal of Law & Economics* 51: 297-325

Yoder, Jonathan K. 2012. "Fuel for the Fire: Liability and the economics of wildfire risk."in Bradshaw and Lueck eds. *Wildfire Policy: Law and Economics Perspectives* (Resources for the Future Press.

Table 1: History of wildfire institutions and organizations

Date – Location- Description

Prehistory onward	worldwide	Fire used for native land/vegetation modification, land clearing, hunting, other.
25 BC 6 AD	Rome	Ceasar Augustus creates the first organized firefighting squad
1650-1850	London, Amsterdam, Boston, Salem	Municipal firefighting
1600s	New Hampshire	Vegetation burning around European settlements to protect from frequent broadcast burning by Native Americans.
Pre-1500s on	North America, California	Native Americans use fires to reduce wildfire risk, and possibly backfire use.
1700-1800s	United States	Use of backfires for fire suppression in/around timberlands in Northeast, Protection of human structures by miners during the California Gold Rush era.
1866 -1891 and beyond	California/ United States	U.S. Army used to patrol for Wildfire in Yosemite/ Mariposa, then Yellowstone, Sequoia, Grants national parks
1891	United States	U.S. Forest Reserve Act Allowed president to reserve forests from public domain.
late 1800s, early 1900s	Northeast, Northwestern, Lake States	Private forest owner associations.
present day	Namibia	Farmer associations responsible for fire suppression
1905	Maine	Fire Control District, over unincorporated townships, fire lookout systems. Maine state government in cooperation with logging industry.
1905	California	State Forester has authority to maintain forest patrols --- Advent of CAL Fire
1905	United States	Transfer Act; Forest reserves moved to Bureau of Forestry (later USFS).
1907	United States	Midnight reserves 16M acres added to NF system.
1909	New York State	State Fire protection program for state lands.
1908	Forest Fire Emergency Act	Created ‘blank check’ policy for suppression.
1910	northeast	Fire lookout system in Vermont, state fire organizations strengthened during this period, and private timber companies formed private fire protection associations.
Pre-1911	US wide	26 of 48 states had state forest departments. 16 of them had suppression organizations. Details unknown.
1911	United States	Weeks Act; USFS gets authority to buy forests in south and east.
1913	Oregon	Compulsory fire patrol law, compulsory fire protection dues or protection provision by timber companies.

1924	United States	Clarke-McNary Act; Created cooperative fire control system, USFS at center.
1934	United States	National Fire Danger Rating System.
1935	United States	10 AM Rule; Emphasis on initial attack.
1940	United States	Smokejumpers established in USFS; Emphasis on initial attack.
1944	United States	Smokey Bear born in New Mexico; National anti-fire campaign launched.
1960	United States	Specialized (IR) crews established; Creation of a suppression network.
1964	United States	Wilderness Act; Limited fire suppression.
1965	United States	Boise Interagency Fire Center (BIFC) created; USFS loses authority to coordinating agency.
1978	United States	USFS Manual eliminates 10 AM rule for suppression; Allows fires to burn under some prescriptions.
1995	United States	1995 Federal Wildland Fire Management Policy rules; Reinforces suppression and increases budget authority.

Sources: see text.

Table 2: Important and large wildfires in the United States

Date	Name	Location	Acres	Impact
1825	Miramichi and Maine Fires	New Brunswick and Maine	3,000,000	160 lives lost
1871	Peshtigo	Wisconsin and Michigan	3,780,000	1,500 lives lost in Wisconsin
1881	Lower Michigan	Michigan	2,500,000	169 lives lost 3,000 structures destroyed
1898	Series of South Carolina fires	South Carolina	3,000,000	Unconfirmed reports indicate 14 lives lost and numerous structures and sawmills destroyed
1902	Yacoult	Washington and Oregon	1,000,000 +	38 lives lost
1903	Adirondack	New York	637,000	
1910	Great Idaho	Idaho and Montana	3,000,000	85 lives lost
1918	Cloquet-Moose Lake	Minnesota	1,200,000	450 lives lost, 38 communities destroyed
1933	Tillamook	Oregon	311,000	1 life lost; area burned again in 1939
1947	Maine	Maine	205,678	16 lives lost
1949	Mann Gulch	Montana	4,339	13 smokejumpers killed - fire safety rules developed
1953	Rattlesnake	California		15 lives lost
1970	Laguna	California	175,425	382 structures destroyed
1988	Yellowstone	Montana and Idaho	1,585,000	Large amount of acreage burned - limited 'let burn' policies.
1994	South Canyon	Colorado	1,856	14 lives lost
2000	Cerro Grande	New Mexico	47,650	Escaped prescribed fire, 235 structures destroyed and Los Alamos National Laboratory damaged
2002	Biscuit	Oregon	500,000	100,000 + acres in backfire-burnout
2006	East Amarillo Complex	Texas	907,245	80 structures destroyed, 12 lives lost, largest fire during 2006 fire season
2009	Station	California	160,000	2 killed, 89 homes destroyed just outside LA

Source: http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html accessed April 30, 2013.

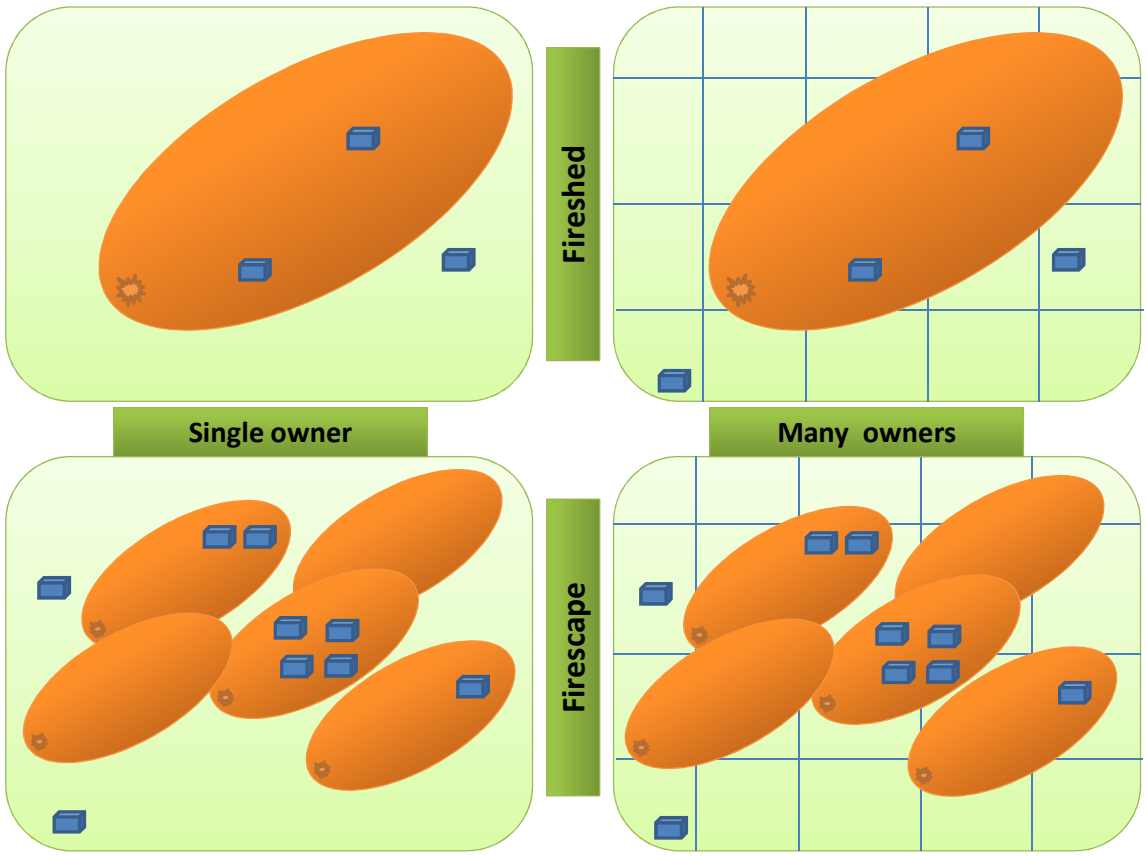

Figure 1: Firesheds, firescapes and landownership
(a) Upper Left. Fireshed with a single owner, with diffuse asset values (orange) and concentrated asset values (blue).
(b) Upper Right. Fireshed with multiple owners (blue lines are property boundaries).
(c) Lower left. Firescape with multiple firesheds and a single owner,
(d) Lower Right. Firescape with multiple firesheds and multiple owners.

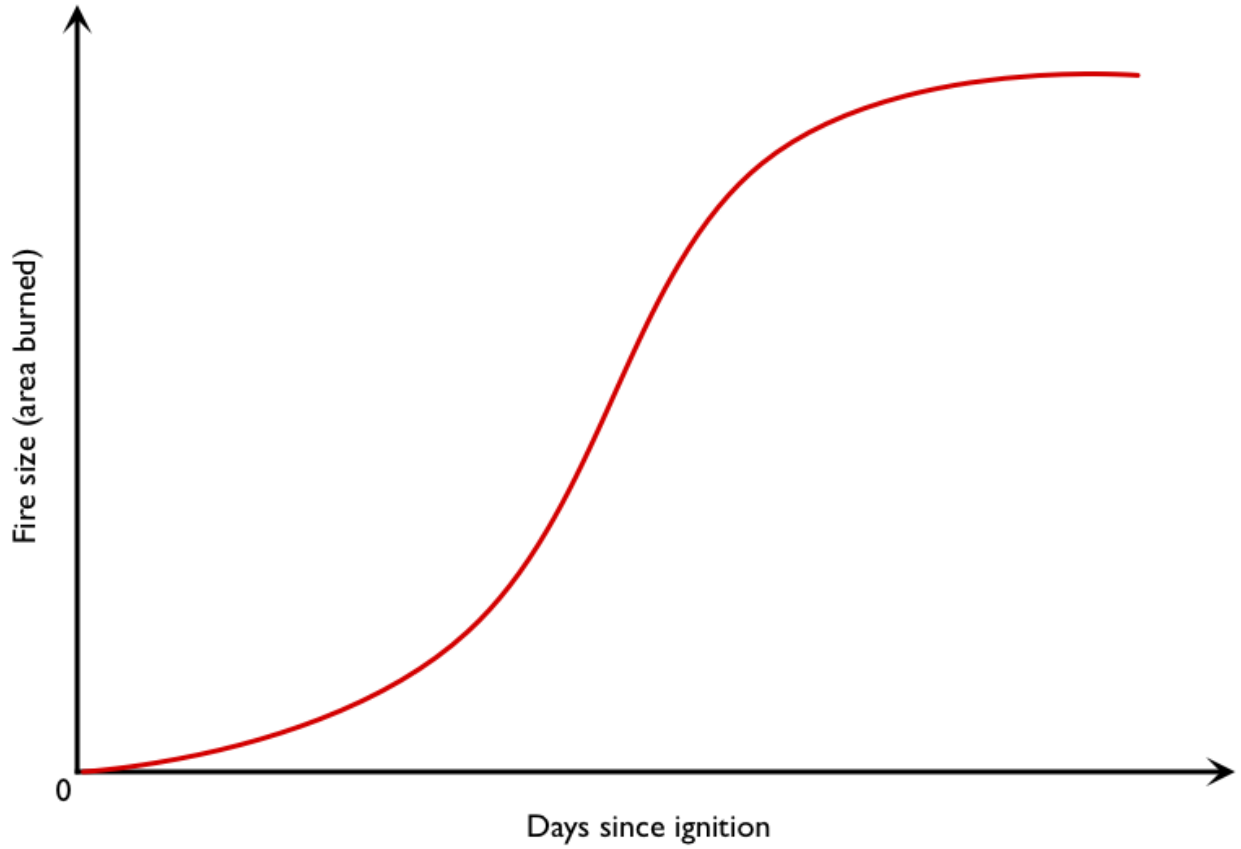

Figure 2: Time path of a wildfire.