The Effect of Wildfire Agency Differences on the Size and Duration of Wildfire in Northern California.

By Mike Dehn

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I dedicate this thesis to my parents.

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona.

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Abstract

This thesis explores how institutional differences between wildfire suppression agencies impact the size and duration of wildfire in Northern California. Previous literature has discussed theoretical implications of how different wildfire suppression organizations, values at risk, and ownership of the fire shed impact wildfire. However these theories of wildfire economics have not been tested empirically. The United States Forest Service (USFS) acts as a land management agency; it owns the majority of the area it has been assigned to protect and can more or less dictates how the land is used. California's state wildfire suppression agency, CALFIRE, on the other hand essentially acts as a rural fire department for its protection areas. CALFIRE owns very little of the area it is assigned to protect and essentially is a suppression only agency. In testing the impact of the differences between these agencies on wildfire size and duration, this thesis will attempt to empirically examine theoretical wildfire economics literature. An economic frame work is developed with predictions to test the extent that agency organization influences wildfire. A study of Northern California wildfire and the impact of institutional differences among wildfire agencies is conducted using wildfire data on over 30,000 wildfires from multiple sources spanning from 2001 to 2011. This data were then incorporated into a single dataset using GIS. Variables controlling all exogenous parameters of the fire shed such as elevation and vegetation are also included in the estimates. It is found that wildfire agency structures do indeed have an impact upon wildfire size and duration. The nature of the exact differences, such as what can be attributed to positioning of wildfire suppression resources or organization of suppression efforts is not made evident in this study.

Chapter 1: Introduction and Research Motivation

1.1 Introduction

The purpose of this thesis is to investigate the wildfire economics behind how the organization of wildfire suppression agencies affects the size and duration of wildfire. By comparing the wildfire outcomes of the USFS to that of CALFIRE while simultaneously controlling for exogenous variables the impact of organizational differences on wildfire size and duration will be made evident.

The state of California presents a unique challenge to wildfire policy managers. The state spans a large geographic area and is heterogeneous in terms of its climate, topography, and vegetation cover. The state itself is also one of the largest economies in the world with many resources and assets located in areas that are prone to destructive wildfires. Wildfires in such areas can be a significant threat to property, recreation and timber stumpage, and watershed and top soils that are vital to California agriculture. To confront the threat of wildfire, Northern California is predominantly protected by two separate wildfire management agencies. The United States Forest Service (USFS), which is a branch of the United States Department of Agriculture, and CALFIRE, which is part of the California Department of Forestry, a state agency charged with managing natural resources within the state. While the mission of both of these agencies is concurrent, circumstances make it such that their incentives and constraints are quite different. CALFIRE is primarily concerned with small privately held parcels of land that are within State Responsibility Areas (SRA) where the state of California is responsible for wildfire. On the other hand the USFS is tasked with wildfire policy namely on federal land which it manages. In this sense CALFIRE acts as a large scale rural fire department while the USFS acts as a land management agency. Within Northern California the responsibility areas of CALFIRE and the USFS often boarder each other, and each agency is responsible for determining wild fire policy in similar areas. The close proximity of these two agencies presents the potential for a natural experiment to examine how their differences affect wild fire policy.

There is scarce economic literature with regards to how institutions shape and implement wildfire policy. A more complete economic analysis must consider land ownership, the uncertainty of wildfire, and how the political economy influences agency rules and incentives Wildfire is a very peculiar item for economic study; it can potentially provide both value and damage to the land it burns and is also unrestrained by the boundaries of property (Lueck 2012). A single owner of a fire shed will allocate their fire suppression efforts to maximize the benefits of wildfire while minimizing its costs. The divided ownership of a fire shed however creates an incentive to free ride and often results in coordinated fire policy either between the landowners themselves or through government organizations (Lueck 2012). The political economy of the fire shed can also influence how agencies carry out their wildfire policies.

1.2 Research Question

The purpose of this thesis is to examine how the institutional differences between CALFIRE and the USFS effect wildfire severity in terms of acres burned and the duration of wildfires. In doing so I will control for exogenous parameters of the fire shed such as vegetation and land values in order to capture only the agency effects. I have limited this study to the USFS and CALFIRE because unlike other wildfire suppression agencies in Northern California, these two agencies often border each other along similar eco-zones and topography.

An economic frame work is developed to explore how institutional differences affect wildfire severity and wildfire duration. Variables are included to measure the effects of land ownership and incentives of the political economy on each agency. Specific variables are also included for naturally occurring aspects of fire regimes to control for uncertainty across the multiple fire sheds each agency has jurisdiction over. The empirical analysis uses fire shed and agency data from 2001 to 2011.

The area of focus for this study will be 26 counties of Northern California. The study area exhibits a large variety in terms of topography, climate, fire regime, fuel load, vegetation, land ownership, Wildlife Urban Interface (WUI), and agencies responsible for wildfire suspension. The selected area stretches from North to South starting on the border of Oregon and California and ending at the latitude of the San Francisco Bay, and stretches from East to West starting with the Sierra Mountains and ending at the Pacific Ocean as depicted in Figure 1.1

Figure 1.1 Selected Study Area of Northern California.
Source USFS, CA: State and County, 2011.

Using the size and duration of wildfire as dependent variables I empirically examine the impacts of agency organization, economic assets at risk, and organization of land ownership while controlling for naturally occurring parameters within the fire shed such as vegetation, elevation, county, and year to better compare these two agencies. A fire shed is defined simply as an area of land at risk of wildfire ignition and spread (Lueck 2011).

1.3 Organization of Chapters

This thesis is organized as follows. In chapter 2 the descriptive statistics of the entire study area are discussed alongside a brief history of the USFS and CALFIRE in Northern California. The chapter concludes with an analytical comparison of the two agencies responsibility areas and policy constraints and incentives. In chapter 3 an economic framework is developed for differences between agencies and their effects on wildfire size. In chapter 4 I describe the empirical study using the relevant data for both the entire selected study area of Northern California, and several subsamples. Chapter 5 summarizes the results and addresses any remaining questions for future research.

Chapter 2: History of Wildfire in Northern California

As long as humans have settled within Northern California they have interacted with the wildfires that frequently lay claim to the landscape. Newly Arriving Europeans took note of the extensive brush and wildfires they witnessed during periods of dry and windy weather. The French observer Deflot de Mofras wrote of California wildfire in his journal during his frequent travels between Santa Cruz and Santa Clara during 1841;

> *Occasionally the traveler is amazed to observe the sky covered with black and copper colored clouds, to experience a stifling heat, and to see a fine cloud of ashes fall. Such extraordinary spectacles are caused by prairie or forest fires started by careless Indians or white men who, after lighting camp fires, forget to extinguish them upon departure…These in fact often seriously handicap travelers who are overtaken by fires out on the plains where the grass is nine or ten feet or in the forests where the trails have not yet been broken.* (Clar 1959)

The northern portion of the state represents an interesting laboratory for wildfire due to its extreme variation in climate, vegetation, topography, interactions between people and wild lands, and institutions dedicated to carrying out wildfire policy.

2.1 Description of Study Area

The area of focus for this study will be 26 counties of Northern California. The study area exhibits a large variety in terms of topography, climate, fire regime, fuel load, vegetation, land ownership, wildlife urban interface (WUI), and agencies responsible for wildfire suspension.

This land area of 26 California counties contains an area of 28,152,225 acres. The counties vary in terms of acreage; the largest counties are mostly situated in the Northern part of the study area with county size decreasing towards the southern region of the study area. The counties of the study area have an average size of 5.3 million acres with a standard deviation of 970,000 acres, which is five times the size of Rhode Island.

Very little information is available concerning how natives to the territory known as Alta California viewed wildfire. Written documents exist from the Spanish authorities who administrated the territories through missions until the Mexican Revolution in 1822. These show that the California natives did employ deliberate burnings as a source of agriculture. These burnings often took place in scrub and grasslands to drive small game to desirable locations. However such burnings were limited to grasslands. Forest land was source of the acorn crop which was an essential component of native agriculture, thus forest fires were often the result of escaped burnings from the grasslands(Clar 1959). The first regulations with regards to wildfire were issued by the Spanish Governor of Alta California in 1793 with a decree that banned the free range burning as employed by the native Californians (Clar 1959). This banning of the "Indian Way" of employing wildfire would become a common theme of wildfire regulations in California and the United States as well. The Indian method of prescribed burnings was often considered, untamed, barbaric, and a purely destructive force to be reckoned with(Pyne 1982). Prior to the California Gold Rush of the 1840s the Alta California territory held very little population and the institutions of the Spaniards and Mexicans were not capable of developing nor enforcing specific wildfire mitigation or suppression policies and wildfire intuitions would not develop until the turn of the twentieth century.

The topography of the study area features large variations in elevation from county to county. A number of mountain ranges, basins, and valleys populate the landscape. The Klamath Mountains and the Cascade Mountain ranges stretch through the North; with the Klamath towards the North Western counties and the Cascades towards the North Eastern counties. These mountain ranges surround much of the California Central Valley, which features some of the most productive agriculture in the United States that is fed by rivers and watersheds from the surrounding mountains. In the Northeast extreme of the study area is the Modoc Plateau, which also extends into Nevada and Oregon. The plateau was formed by extensive lava flows and is nestled between the Cascade Mountains to the West and the Warner

Mountains to the East. The Sierra Nevada Mountain range runs north to south for 400 miles through the eastern counties of the study area. The Sierra is also home to the giant sequoia, the largest trees found on earth. The Basin and Range of the Western United States extends from Nevada into the Eastern part of the study area. Similar to most of the Great Basin the landscape of the study area this is primarily barren (Sawyer 2006).

As one moves away from the Central Valley and into the surrounding mountains, the severity of wildfire increases with elevation. The northern most counties of the study area exhibit the greatest frequency and severity (acres burned) of wildfires recorded from 1900 to present day. These counties include Siskiyou, Del Norte, Lassen, Modoc, Humboldt, Trinity, and Shasta. These seven counties alone account for over 50 percent of all historic fire occurrences in the 26 California county study area. The Klamath Mountains cross through Del Norte and Humboldt and the parts of the Cascade Mountains cross through Siskiyou, Lassen, Modoc, and Shasta counties. Moving down the mountain ranges that surround the central valley, the frequency of wildfire diminishes. Moving into the counties of the central valley the threat of wildfire occurrence becomes increasingly negligible. The counties that contain the Sierra Nevada Mountain range east of the Central Valley are Plumas, Sierra, Nevada, Placer, Amador, Calaveras and El Dorado. The eastern parts of Butte and Yuba counties also have the Sierra Nevada pass through them. These counties represent approximately 30 percent of the fire occurrences within the study area over the last century. The remaining counties of the Central Valley and the Costal mountain ranges to the West represent the areas of most infrequent wildfire. These remaining 11 counties of the study area represent approximately 20 percent of wildfire occurrences. Across the entire study the area the average number of wildfires per county from 1900 to 2011 is approximately 240, with Siskiyou representing the maximum of 845 fires and Sutter representing the minimum with only 7 recorded wildfires.

When considering the severity or wildfire from 1900 to 2011 in terms of total recorded acres burned, the counties with the greatest fire frequency generally have the largest wildfires. There are two exceptions to this case where counties with above average wildfire occurrence. Del Norte County in the northwest extreme of the study area exhibits moderate wildfire frequency with relatively small wildfires. El Dorado County in the southern part of the Sierra Nevada range exhibits high fire frequency, but mild to moderate wildfire severity. The average acreage burned over the last century is approximately 26,000 acres. Siskiyou again represent the max of the study group with 1,186,331 total acres burned and Amador the min with only 458 acres burned. In 2011 the United States saw approximately 70,000 individual wildfires with a little less than 9 million acres burned. In 2011 the entire state of California saw approximately 8,000 wildfires with 128,000 acres burned (National Interagency Fire Center).

2.2 History of the United State Forest Service in California

In 1897 President Grover Cleveland proclaimed 13 new forest reserves known as the Washington's Birthday Reserves. Two of these large reserves were located in Northern California and would eventually be split into the 14 National Forests that are administered by the USFS today. From 1907 to 1973 the former forest reserves were frequently re-organized and renamed, but have remained static in terms of both name and boundary since. Prior to 1905 the USFS (which was the Division of Forestry at the time) had primarily conducted forestry research within California; afterwards it acted as a land management agency. The vast majority of the National Forests are located along the Sierra Nevada Mountain range and the Northern counties of the study area along with Klamath and Cascade mountain ranges. (Steen 1976)

The United States Forest Service (USFS) first appeared in the state of California as a result of the 1905 Transfer Act. This moved jurisdiction over the National Forests from the BLM to the USFS. In 1905 approximately 2 million acres of forest land came under the jurisdiction of the USFS from the Lassen and Tahoe National Forests. (Steen 1976) By 1907 approximately 7.5 million acres of forest reserves under the BLM had been re-organized in National Forests within the selected study area. As the Rouge River-Siskiyou was added in 1906, followed by the Humboldt, Mendocino, Modoc, Plumas, and Stanislaus National Forests in 1907. In the following decades slightly less than 4 million acres would also be added. The modern USFS currently manages 14 national forests within the study area. Some of these are these are entirely within the state of California while others extend into Oregon and Nevada. The name of each National Forest as well as its size and establishment year can be found in Table 2.1 below.

Table 2.1 National Forests Within the Selected Study Area.

Forest Name	Acres	Year Established
El Dorado	579,568	1910
Fremont-Winema	6	1961
Humboldt-Toiyabe	29,606	1907
Klamath	1,523,293	1905
Lake Tahoe Basin	111,070	1973
Lassen	1,198,341	1905
Mendocino	853,004	1907
Modoc	1,654,392	1907
Plumas	1,142,485	1907
Rogue River-Siskiyou	78,815	1906
Shasta Trinity	2,193,973	1954
Six Rivers	880,778	1947
Stanislaus	114,899	1907
Tahoe National	934,794	1905

Source: USFS, Automated Lands Program; Administrative Forest Geodatabase. 2011

From its inception the USFS began a gradual shift towards to policy of all out suppression. This choice of wildfire policy was influenced by a number of political and economic factors. In 1908 the Forest Fire Emergency Fund Act was passed which allowed the USFS to engage in deficit spending to cover costs incurred during fire suppression. The first test of this policy came during the Great Burn of 1910, where over three million acres of forest land were burned in Northeast Washington state, Northern Idaho, and Western Montana (Pyne 1981). Congress sustained the act which allowed the USFS to engage in unlimited spending during fire suppression (Pyne 1981). Such unlimited funding was only available for actively suppressing wildfires. Prescribed burnings, decisions to let burn, and other means of fire mitigation were not covered under the Forest Fire Emergency Fund Act. These financial incentives to only engage in active wildfire suppression along with the propensity of public bureaucracy to seek additional funding and prestige (Rogers 1973) resulted in the adaptation of a wildfire suppression only policy beginning the in the 1930's. These policies began to change gradually in the 1960s with a complete abandonment of the 10 AM policy in the mid to late 1970s (Pyne 1982).

As a wildfire agency in California the USFS adopted a strategy of systematic fire protection. In 1914 Coert duBois, an associate district forester in District 5 of the USFS published *Systematic Fire Protection in the California Forests*, this work which would eventually be adopted as USFS's national wildfire policy. duBois advocated a suppression only policy with an emphasis on a speedy attack of seasonal and volunteer firefighters and efficient communication between the fire line and forest rangers. Fire prevention was to be achieved through outreach campaigns to make the general public more aware of wildfire risk. Great emphasis is placed on the cost effectiveness of large local volunteer forces under the command of USFS personal. The fire suppression capital of this era was primitive at best with most firemen wielding axes and other hand tools and wildfire sites were approached on horseback or simply on foot. Speed of attack was considered critical as very little manpower could prevent a negligent campfire from transforming into a blowup (duBois 1914).

While the Forest Service's decision to pursue a suppression only policy occurred in the first two decades of the twentieth century, the means of carrying out such policies actually became available during the government stimulus programs of the Great Depression and massive defense spending of World War II. The employment programs enacted during the Great Depression however provided a large labor pool for the Forest Service to employ in wildfire suppression. The Civilian Conservation Corps (CCC) originated in 1933 from the New Deal programs and allowed for the Forest Service to construct a network of trails, road, fuel breaks, communication lines, and observation lines throughout national forest land, thus providing the fixed capital necessary to engage in extensive wildfire suppression (Busenberg 2004). Many of these projects took place in California National Forests.

Beginning in the mid 1930's the USFS began to restructure its organization from one of large volunteer labor pools to a highly structured military model style of organization. In 1935 the 10 A.M Rule was enacted, which stated that Forest Service policy was to have every wildfire extinguished or contained by 10 A.M. the day after the wildfire was initially reported(Pyne 1981). Emphasis on speed of attack and efficient communication remained, but the USFS introduced smoke jumpers to attack small backcountry fires and the 40-man "shock troops" crew for use against large fires(Pyne 2009). This force also became increasingly hierarchical and mechanized as bulldozers and aircraft became common sights on the fire line. The firebombing of Japan and Germany during World War II had convinced the military that the next war would be a fire war. The success of the Soviet Union in detonating an atomic bomb made it all the more imperative to understand the physics of large fires. Beginning in the early years of the Cold War wildfire suppression became integrated with national defense (Pyne 1981).

In 1970, despite two decades of extensive fire research, development of equipment and generous financing, wildfires in California and Washington State burned more acres of national forest in any year since the 1910 Great Burn (Pyne 1982). There came a growing recognition that the lightning strike fires in wilderness areas were essential to native ecology, and that tolerating such fires or introducing prescribed burns may be a necessity to maintain the ecological health of these areas. Also many years of aggressive wildfire suppression had resulted in large buildups of fuels in many national forest lands. As a result the Forest Service amended the 10 A.M policy to allow for let burn and prescribed burns (Pyne 1981). The USFS of the 21st century is still organized as a military style organization. A large emphasis is placed on the initial attack of the wildfire, but unlike the suppression only approach of the past, fuels management is now taken into account (Lueck 2012).

2.3 History of CALFIRE

California was admitted to the Union in 1850, but no significant wildfire laws were enacted until the late 19th century. Many early attempts at creating public wildfire legislation and agencies were quickly repealed through lobbies on the behalf of forest land owners. Legislation allowing for counties and communities to collect taxes and establish institutions for the purpose of rural wildfire suppression was passed in 1881. Within two years forest land owners successfully lobbied to reform the law, limiting the ability of rural fire officials to raise taxes beyond populated areas for the purpose of fire protection (Clar 1959). The blueprints for state wildfire institutions in California would be laid down in 1885 and then truly conferred in 1905. In 1885 the Board of Forestry was created to investigate, collect, and disseminated information about forest lands in the state. In 1887 the power of enforcement was granted to the California Board of Forestry to ensure compliance in what few forestry laws were in existence at the time (Clar 1959). At the turn of the twentieth century a number of loosely organized groups including logging companies had taken steps to bring wildfire protection to the scattered properties which were not included in the Federal Forest Reserves. The largest and best organized private groups were the Stockmen's Protective Association and Redwood Fire and Protective Association, organized in 1904 and 1909 respectively. (Clar 1959) These industrial guilds were successful in coercing individual firms into contributing to fire suppression and also enforced a number of nuisance laws with respect to fuels (Clar 1959).

The 1905 Act granted the state forester the right to appoint local fire wardens and to maintain fire patrols during times of fire emergency. The emergency fire patrols however were to be funded by the county in which suppression took place. The state of California budgeted no money to maintain these wildfire protection forces (California Department of Forestry Historical Society and Museum 2005). In 1931 thirty-one counties had entered into cooperative fire suppression agreements with the state. While the state and the USFS had appropriated funds for salaries, very little assistance was available for physical improvements such as lookouts, fuel breaks, and communication lines. Almost all equipment and physical improvements were provided by the cooperating country. To provide state funding to the wildfire activities of the Division of Forestry the state enacted the Sanford Plan in 1931 proposing the that funds be appropriated to each county based ranger station with the weighted value of protected areas in mind. Areas that contained watersheds vital to Northern California agriculture were given the highest priority at the time. The weighted value of a protected area was determined in a similar manner employed by the USFS; whereas timber, watershed, and recreation were considered in tandem. Under this plan the state was divided into three classes; class one designated areas of high value, class two indicated of low value areas from which wildfire could spread to class one areas, and class three areas were left to local authorities to protect (California Department of Forestry Historical Society and Museum 2005).

In 1943 Governor Earl Warren enacted the Clar Plan, which extended fire protection to the delineated state and privately owned timber and watersheds. Whenever necessary the state would pay for such firefighting costs as deemed proper. Another development in the mid-1940s added to the Division of Forestry fire suppression labor pool; the use of state inmates. This practice now referred to as conservation camps organizations still continues today to provide labor for fire mitigation work(Clar 1959).

The California Legislatures actions in the 1970s mirrored that of the federal National Forest Management Act (NFMA) of 1976 on the national scene, though the state forestry laws with regards to logging were far less restrictive. The 1973 California Forest Practices Act simply required a review of all commercial and state logging activities through the Division of Forestry to ensure they complied with already existing laws protecting wildlife and watersheds. The Division of Forestry also began to move to toward a mixed policy of prescribed fire, let burn, and wildfire suppression similar to that of the USFS in the mid to late 1970s. In 1980 the state legislature approved SB 1704 (Chaparral Vegetation Management Program). The program allowed CALFIRE to enter into contracts with landowners for prescribed burning to prevent high-intensity wild land fires, manage watersheds, rangeland, vegetation, forests, and wildlife habitat. Under SB 1704 the state could assume up to 90% of the costs of conducting a prescribed burn, assume liability, and suppress escaped fires. In contrast to the USFS, CALFIRE would have to contract with land owners within its protection area in order to do this. The wildfire policies of CALFIRE have changed relatively little since the 1980s, with the Fire Plan changing in the mid-1990s to allow for a public comment for major Board of Forestry decisions. As of 2004 the Division of Forestry consisted of 146 cooperative fire agreements and protection agreements in 35 of the state's 58 counties, and 31 fire districts(California Department of Forestry Historical Society and Museum 2005).

2.4 Cooperative Efforts Between the USFS and CALFIRE

Since the inception of these two agencies in California, both have shared resources, policies, and joint cooperation that continue to this day. The Weeks Law of 1911 initiated the cooperation between the USFS and CALFIRE. This legislation was passed in response to the Great Burn of 1910, and allowed for federal agencies expand beyond their assigned public domain by purchasing lands in watersheds or navigable streams from both public and private entities. The Weeks Law also created a matching grant system between the USFS and state foresters for the protection of certain watersheds from wildfire (Steen 1976). In 1924 Congress passed the Clarke-McNary Act, which further expanded the Weeks Act. The Clarke-McNary Act greatly encouraged the creation of state forestry organizations and the cooperation between these organizations and the USFS. This cooperation between the USFS and state agencies such as CALFIRE spread the federal wildfire policies across the nation further than acquiring additional forest lands ever could(Pyne 1981). This early cooperation between the USFS and CALFIRE allowed for the sharing of policy goals from the former agency to the latter. The funding available through cooperative efforts with the USFS on non-federal lands allowed for CALFIRE to hire suppression personal, purchase fire suppression equipment and conduct fire patrols in counties who contributed very little to CALFIRE officials they partnered with (Pyne 1981). In 1921 the Mather Field Conference took place near Sacramento California. This conference assembled in California the best minds in forestry of the USFS to review and standardize fire policy. In 1923 a special panel created by the California Board of Forestry which governed CALFIRE officially condemned light burning and moved towards suppression dominated policy. In 1935 the USFS would adopt the 10 AM Rule (Pyne 1981).

The years of the Great Depression had similar effects upon both the USFS and CALFIRE. The Civilian Conservation Corps (CCC) originated in 1933 from the New Deal programs and allowed for the UAFS and CALFIRE to construct a network of trails, road, fuel breaks, communication lines, and observation lines throughout national forest land, thus providing the fixed capital necessary to engage in extensive wildfire suppression activities in accordance with the 10 AM Rule (Busenberg 2004), (Clar 1959). In the post-World War II era the USFS as well as CALFIRE would also become an increasingly mechanized force. Both agencies found their mission defined more along the parameters of national defense rather than management and preservation of natural resources. The firebombing of Japan and Germany during World War II had convinced the military that the next war would be a fire war. The success of the Soviet Union in detonating an atomic bomb made it all the more imperative to understand the physics of large fire storms. Beginning in the early years of the Cold War fire control became integrated with national defense at both the federal and state level. Between 1950 and 1954 under the direction of the Office of Civil Defense, the USFS assumed responsibility for directing fire defense for both rural areas and wild lands. The basis for this expansion was the Clarke-McNary Program, which included all fifty states by 1966 (Pyne 1981). From these wartime contracts with Civil Defense the USFS was given priority access to federal surplus equipment program, allowing the USFS to incorporate massive amounts of mostly mechanized military equipment into its fire suppression efforts. In 1956 both helicopters and air tankers became regular features on the fire line. CALFIRE would acquire much of its mechanized fire suppression equipment through its cooperation with the USFS through the Clarke-McNary Program (Pyne 1981).

Cooperation between the USFS and CALFIRE declined in the 1970s. In the early 1970s there began a growing movement toward a more natural approach to wildfire policy. There came a growing recognition that the lightning strike fires in wilderness areas were essential to native ecology, and that tolerating such fires or introducing prescribed burns may be a necessity to maintain these areas. Many decades of aggressive wildfire suppression had resulted in large buildups of fuels in many California forest lands. The issue of focus for wildfire policy in the United States shifted from one of all out suppression to a more balanced approach that simultaneously pursued fuel reduction, and suppression of damaging high intensity wildfires. The 1978 Cooperative Forestry Act began to remove the federal contribution to state forestry and wildfire agencies with Congress specifying that such substantial subsidies were no longer necessary(Pyne 1984). It was also at this time that the 10 AM was abandoned by the USFS as official policy (Pyne 1982). While large amounts of wildfire funding is no longer granted to state agencies via the USFS, cooperative agreements still exist between the two agencies.

Both the USFS and CALFIRE are members of the California Wildfire Coordinating Group (CWCG) which determines rules and regulations for mutual assistance between agencies. A part of the CWCG both agencies have agreed to a number of shared policies and procedures which are outlined in the California Master Cooperative Wildfire and Fire Management and Stafford Act Response Agreement (CWFM). Through this CALFIRE and the USFS have agreed to the “closest forces concept” with respect to initial attack. Should a wildfire occur in one agencies responsibility area, the other is authorized to make the initial attack should its forces be in closer proximity. Once the initial attack has been made the responsible agency takes command of the incident. (CWFM 2011) Administrators from both CALFIRE and the USFS are required to outline plans for monetary re-imbursement when assistance is provided from one agency to another. (CWFM 2011) Should a wildfire occur on the border of responsibility areas a cooperative incident command is formed between both agencies. Under this agreement the agency with suppression resources closest to the wildfire ignition is responsible for the initial attack as agreed upon by agencies with bordering responsibility zones. This “Mutual Aid” between agencies is of no cost to the recipient agency, but is only good for a maximum of 24 hours (CWFM 2011). Should 24 hours elapse and the protecting agency still require interagency assistance it must contract with the supporting agency via Reimbursable Cooperative Fire Protection or what is better known as “Assistance by Hire”. Under this method of interagency protection the protecting agency will reimburse the supporting agency for resources specified by the protecting agency. Should the supporting agency provide resources beyond those requested by the protecting agency this is considered to be a voluntary contribution, and will not be reimbursed (CWFM 2011) . Agencies are also free to exchange wildfire suppression duties with other agencies and contract with other agencies to provide wildfire protection (CWFM 2011). The ability for agencies to exchange and contract for wildfire protection is the explanation behind why wildfires within one agencies jurisdiction areas, are sometimes suppressed by an entirely different agency (CWFM 2011). This scenario occasionally appears within the data set I use for empirical analysis, and will be discussed in Chapter 4. In the event a wildfire occurs on the boarder of responsibility zones each agency is to assume that its neighbor is completely unaware of the wildfire and engage in initial attack.

As the many fire sheds within the study area are not homogeneous the contracting between boarding agencies through Annual Operating Plans (AOP) and Local Operating Plans (LOP) presents many different economic and institutional scenarios. While agencies may contract and negotiate over suppression resources their responsibility areas are generally fixed, though a process does exist for adjusting them in the long term. The many fire sheds within the study area are not homogenous, which may present difficulty for an agency seeking the optimal level of suppression. An agency with jurisdiction over a wildfire prone area will have to contract with a neighbor that can spare resources in times of emergency. This will have to be an agency with resources in reasonable proximity with jurisdiction over an area less prone to wildfire. In providing support an agency accepts the risk that wildfire may ignite and spread within their own responsibility area while their suppression resources are away. Each agency has more or less of a blank check policy for emergency suppression spending, which may create a large demand for Assistance by Hire. The risk of wildfire within a supporting agencies responsibility area may result in an insufficient supply of available supporting resources. The most likely scenario will be agencies with high risk fire sheds with valuable assets contracting with agencies responsible for low risk fire sheds with few assets in harm’s way.

2.5 Description of Agency Jurisdiction Area

Of the total selected study area, the USFS and CALFIRE are responsible for a combined 80 percent of the land area. 15 percent of the study area is administered by local fire organizations and the remaining amount is administered by a variety of federal land management agencies. Some counties are almost entirely administered by the USFS while others are almost entirely administered by CALFIRE.

Table 2.2 Agency Jurisdiction by Percentage of Acres in Study Area by County

County Area	CALFIRE	USFS	BLM	NPS	Local
Total Area	**43.93%**	**38.16%**	**5.39%**	**0.96%**	**14.96%**
Max Area[1]	94.02%	95.44%	41.41%	4.45%	99.11%
Min Area	0%	0%	0%	0%	0%
Mean Area	44.81%	32.12%	1.98%	0.45%	19.75%
STD	27.07	29.64	8.27	1.06	26.77

SOURCE: USFS, Direct Protection Areas, 2011

Figure 2.2 depicts the jurisdiction areas of CALFIRE and the USFS within the study area with respect to county borders. As one of the original missions of the USFS was to protect headwaters and watersheds in western states many of the responsibility areas of the agency are found along the three major mountain ranges cross from north to south within the study area. The responsibility areas for CALFIRE often borders on the USFS responsibility area. The only major gaps in jurisdiction for these two agencies are the Modoc Plateau within Modoc and Lassen Counties administered by the Bureau of

[1] Max and Min areas refer to the largest and smallest percentages of agency jurisdiction per county area of the 26 county study area.

Land Management, and the California Central Valley which is administered by a patchwork of local fire authorities. The smaller gaps surrounded by CALFIRE and USFS jurisdiction are either the few national parks found within the study area or areas reserved for the Department of Defense.

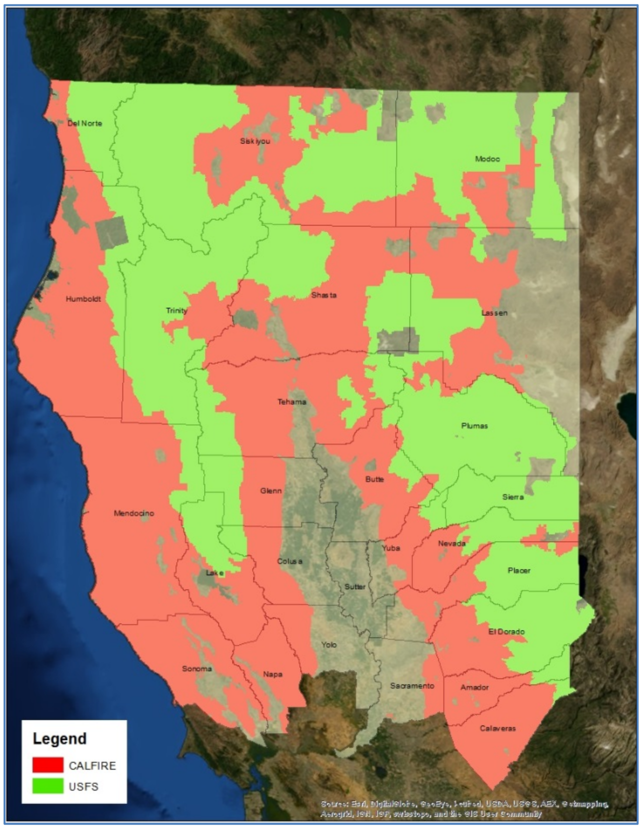

Figure 2.2: Map of Agency Protection Areas by County
Source: See Data Generating Process

The reasonability area of the USFS exists primarily on the federal lands that it was given jurisdiction over following the 1905 Transfer Act with approximately 82 percent of its responsibility area existing on federal land. CALFIRE on the other hand has the same percentage of its responsibility areas occurring on private lands. This indicates that the USFS function primarily as a land management agency, as it is able to determine what can and cannot take place on the land it controls. CALFIRE on the other hand must approach wildfire as it occurs on privately held lands and thus its ability to dictate wildfire policy is more limited in comparison to the USFS. CALFIRE is responsible for a handful of state forests but the majority of its area originated from the Clar and Standford plans which added large amounts of privately held land into CALFIRE's responsibility areas (California Department of Forestry Historical Society and Museum 2005).

The Wildland-Urban-Interface (WUI) is measurement of development in areas of heavy vegetation which is most often prone to wildfire. Not only do these two agencies experience differing land uses on the areas they are responsible for, they experience different population densities among different types of fuel loads of vegetation cover. The combined measurement of development density and heavy loads of vegetation generate an index of the risk to property from wildfire. Highly dense areas of housing in close proximity or intermixed with heavy vegetation present a high risk of large monetary damages from wildfire occurrence. Areas with sparse wildfire prone vegetation and little or no development pose little threat to property. As CALFIRE and the USFS have agreed to place protection of property as second only to firefighter safety (CWFM 2011), development alongside fire prone areas will play an important role in wildfire policy for both agencies. Table 2.3 exhibits nine categories of WUI which is explained further in the paragraph below. A No-Veg designates areas with less than 50 percent vegetation cover, Intermix designates areas with 50 percent or greater vegetation, and Interface represents areas with greater than 50 vegetation cover within approximately 2.5 kilometers of areas with 75 percent or greater vegetation. Of these three categories, the large fuel load of the Interface category represents the greatest risk of large wildfire flare ups. High, medium, and low density of housing represents the density of development within 2.5 kilometers. In this sense a High Density Interface is at great risk of monetary losses from wildfire, while a Low Density No-Veg area is at relatively low risk.

Table 2.3 Wildland-Urban-Interface Definitions

WUI Term	Housing Density	Vegetation
High Density Interface	> = 741.3162	Vegetation <= 50%, within 2.414 km of 75% or Greater Vegetation
High Density Intermix	> = 741.3162	> 50%
High Density No Veg	> = 741.3162	<= 50%
Med Density Interface	>= 49.42108 and < 741.3162	Vegetation <= 50%, within 2.414 km 75% or Greater Vegetation
Med Density Intermix	>= 49.42108 and < 741.3162	> 50%
Med Density No Veg	>= 49.42108 and < 741.3162	<= 50%
Low Density Interface	< 49.42108	Vegetation <= 50%, within 2.414 km of 75% or Greater Vegetation
Low Density Intermix	< 49.42108	> 50%
Low Density No Veg	< 49.42108	<= 50%

Source: SILVIS Lab, 2000

Because development in wildland areas often increases the risk of wildfire (Pyne 1984) CALFIRE and the USFS are often obligated to protect property within their responsibility area; WUI indices are useful in measuring the extent that development influences wildfire risk. Table 2.4 depicts which WUI's occur most frequently within each agency's area of responsibility.

Table 2.4 Occurrence of WUI's for CALFIRE and USFS

WUI Term	CALFIRE	USFS
High Density Interface	0.02%	0.01%
High Density Intermix	0.00%	0.00%
High Density No Veg	0.00%	0.00%
Med Density Interface	0.37%	0.08%
Med Density Intermix	1.63%	0.26%
Med Density No Veg	0.00%	0.00%
Low Density Interface	0.44%	0.08%
Low Density Intermix	12.52%	1.24%
Low Density No Veg	12.52%	0.00%
Other	72.49%	98.34%

Source: SILVIS Lab, 2000

From Table 2.4, the majority of both agencies responsibility area lies in the "Other" category. The "Other" category includes areas with very little or no housing densities present regardless of vegetation cover; these present little risk of extensive damage from wildfires. However it is worth noting that over 25 percent of CALFIREs area contains some form of WUI while the USFS area contains almost none. Approximately 12 percent of CALFIRE's jurisdiction features Low Density Intermixed WUI, and CALFIRE has greater percentages of its area in all WUI categories than the USFS. This indicates that CALFIRE must face the additional challenge of permanent populations bordering and interacting with fire prone vegetation while pursuing its wildfire policy. This is due to the fact CALFIRE is tasked with protecting private property from wildfire. The USFS on the other hand does not face such difficultly with respect to its wildfire policy decisions.

As far as which agency's responsibility area is more prone to wildfire CALFIRE experiences almost twice as many wildfires than the USFS. The USFS has responded to 7732 reported while CALFIRE has responded to 15,122 from 2001 to 2011. Figure 2.4 shows how many wildfires each agency has responded to during this time span. 2001, 2002, and 2008 are the most severe years in terms of wildfire occurrences for both agencies.

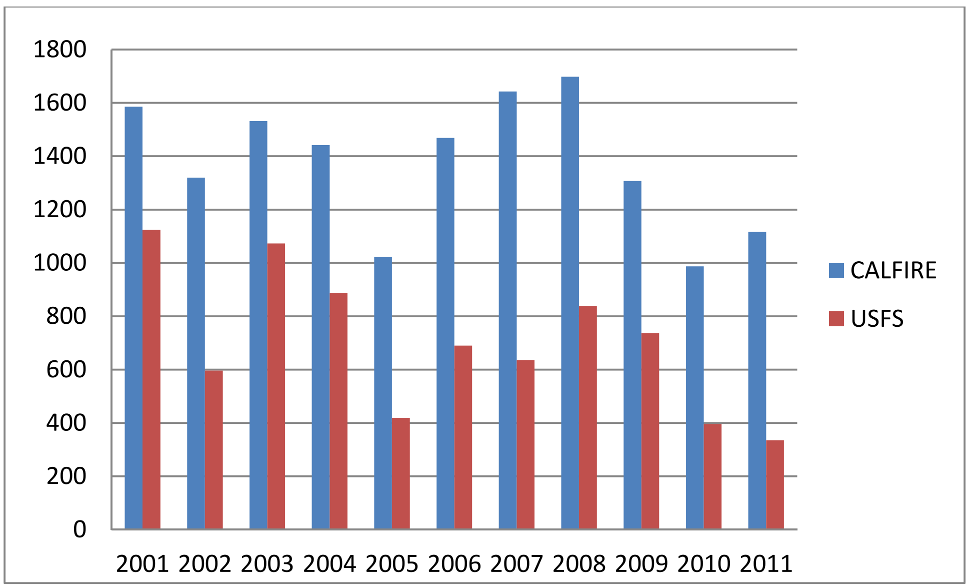

Figure 2.3 Fire Frequencies by Agency Responsibility
Source: CALFIRE, Wildfires of Study Area, 2011

In terms of wildfire severity in terms of acres burned there is a mirror image of what is depicted in Figure 2.4. The average wildfire size when the wildfire is declared controlled is depicted in Figure 2.5. On average the USFS responds to much larger wildfire sizes than that of CALFIRE. 2006 and 2008 represent the most serve years in terms of acres burned for both agencies.

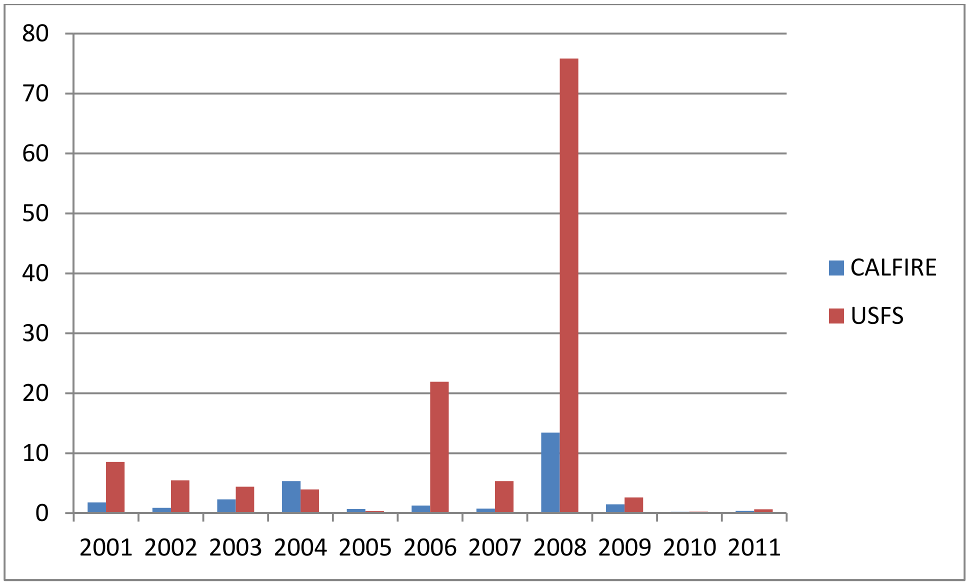

Figure 2.4 Average Fire Severity by Agency Responsibility
Source: CALFIRE Wildfires of Study Area 2011

2.6 Agency Constraints and Incentives

The activities of each agency are directed by a number of laws and regulations. The USFS is primary concerned with laws and regulations at the federal level while CALFIRE is primarily concerned with rules and regulations issued by the California Board of Forestry or passed into law by the state legislature and governor, although CALFIRE must also abide by a number of federal laws as well such as the Endangered Species Act. Table 2.5 details a brief history of law and policies that have affected the USFS and CALFIRE over the past century. I have already discussed the influence of regulations on wildfire policy for the USFS and CALFIRE up until the 1940, to avoid redundancy I will focus namely on laws and policies after the 1940's in this sections.

Table 2.5 History of Significant Laws and Policies for the USFS and CALFIRE

USFS			CALFIRE		
Date	Law or Policy	Impact	Date	Law or Policy	
1905	Transfer Act	Transferred National Forests to USFS Jurisdiction	1905	Act of 1905	Permitted CALFIRE to organize fire patrols and fire lines
1911	Weeks Law	Allowed USFS to purchase additional areas for National Forests			
1924	Clarke-McNary Act	Cooperative wildfire system with states			
			1931	Standford Plan	Appropriated funding to CALFIRE from the California state government
1935	10 AM Rule	Emphasis on Initial Attack			
			1943	State Emergency Wildfire Funding	Extended CALFIRE wildfire suppression to privately held woodlands
1960	Multiple Use Act	USFS to also consider wildfire and recreational uses in policy decisions			
1964	Wilderness Act	Placed limits on use of fire suppression			
1970	National Environmental Policy Act	Limited prescribed burns and mitigation			
1973	Endangered Species Act	Limited prescribed burns and mitigation	1973	California Forest Practice Act	Required all commercial timber activities to report to CALFIRE and allow for a public comment period
			1980	SB 1704	Allowed CALFIRE to contract with landholders for prescribed burns and other mitigation activities
1995	1995 Federal Fire Policy	Reinforces suppression as primary wildfire tool			
2003	Healthy Forests Restoration Act	Provided greater funding for wildfire mitigation through thinning vegetation			

Source: Steen, 1976, California Department of Forestry Historical Society and Museum, 2005.

The 1940's and the 1950's saw great expansion of the suppression of wildfire as greater resources for this task we're available to both the USFS and state wildfire agencies. Starting in the mid 1960's legislation such as the Wilderness Act began to erode away at the suppression only policy and attempted to introduce prescribed burns as a means of wildfire mitigation, though suppression has remained the primary tool of wildfire agencies.

Both the USFS and CALFIRE are authorized to conduct prescribed burns, and each agency faces a number of similar constraints in doing so. The National Environmental Policy Act (NEPA)[2] and the Endangered Species Act[3] limit where and to what extent both CALFIRE and the USFS can apply prescribed burns. NEPA regulates the smoke generated from prescribed fire. States are required to adhere to certain pollute emission standards and some states, including California, have implemented smoke management programs. All prescribed burns in California are regulated by Title 17 of the California Administrative Code which contains strict meteorological guidelines for days prescribed burns can take place and cannot take place without a permit(Engel and Reeves 2012). The Endangered Species Act places restrictions on where prescribed fire can be used and the act requires that the habitats of listed species remain undisturbed. Therefore, setting a prescribed fire within the habitat of an endangered species is out of the question regardless of fuel accumulation.

Several policy differences with respect to prescribed fire exist between the two agencies. As CALFIRE's responsibility area is primarily private property it can contract with individual land owners to conduct prescribed burns. SB 1704 (Chaparral Vegetation Management Program) which governors prescribed burning for CALFIRE allows for the state to assume up to 90 percent of the costs of conducting a prescribed burn and requires CALFIRE to assume liability for any escaped fires to stray onto others properties. However such action requires the consent of the land owner. The USFS has its own rules for prescribed burning, however little funding is allocated for prescribed burns and liability laws regarding prescribed burning provide little incentive and great risk for the USFS to engage in such activity. The USFS however is not liable for damages incurred while suppressing wildfires(Bradshaw

[2] National Environmental Policy Act of 1969 § 102, 42 U.S.C. § 4332
[3] Endangered Species Act of 1973 § 136, 16 U.S.C § 1531

2011). In addition to this, the USFS is forbidden from using its suppression resources for the purpose of resource benefits. Any suppression undertaken must mitigate danger to personel and damage to property (Forest Service Manual).

Similar to the case of prescribed fire, both the USFS and CALFIRE face differing policies with respect to fire mitigation. In this paper fire mitigation practices refer to the removal of fuel build ups by hand or by machine. As is the case with prescribed burning the Endangered Species Act restricts where fire mitigation can take place for both agencies. CALFIRE's mitigation efforts are primarily conducted by the private landholders contracting with the state agency. In order to remove forest products from lands within CALFIRE's responsibility area land owners must submit a Timber Harvesting Plan (THP) in accordance with the 1973 California Forest Practice Act (CFPA). The CFPA limits the harvest of brush and small vegetation that may harm watersheds but will make an exception for a THP be that can validated by a professional forester as a means of reducing fuel load and wildfire risk. Similar to prescribed fires land owners can contract with CALFIRE where up to 90 percent of the costs may be covered. Mitigation activities on the part of the USFS are conducted within the guidelines of the 2003 Healthy Forests Restoration Act. Funding for such mitigation is only provided in certain circumstances; in cases where there are substantial WUI's or areas where historical fire regimes have been significantly altered by human activities and excessive wildfire suppression. The law also allows for mitigation to take place in endangered species habitats provided the USFS can demonstrate that such action will not adversely affect habitats.

Differences between the two agencies in terms of crew organization also exist as well. The USFS employs an extended attack organization as illustrated in the nationwide fire policy that was developed in 1995. Similar to CALFIRE, the USFS places great emphasis on the initial attack of wildfire to contain its further spread. The organization of initial attack is similar across agencies, but in terms of extended attack CALFIRE organizes its suppression forces at the battalion level. Typically a battalion of 12 to 40 firemen of seasonal firemen are present at a fire station alongside several fire engines, two captains and apparatus engineers, and one heavy equipment operator that are assigned to their stations year round. Each battalion is commanded by a battalion chief. There is often more than one battalion present within a CALFIRE unit. The entire unit is commanded by the Unit Chief (CALFIRE Unit and County Fire Plans). CALFIRE also relies on many local and rural fire departments in the initial detection and attack of wildfires. The extended attack organization of the USFS is of a much greater scale than that of CALFIRE, as illustrated in Figure 2.6

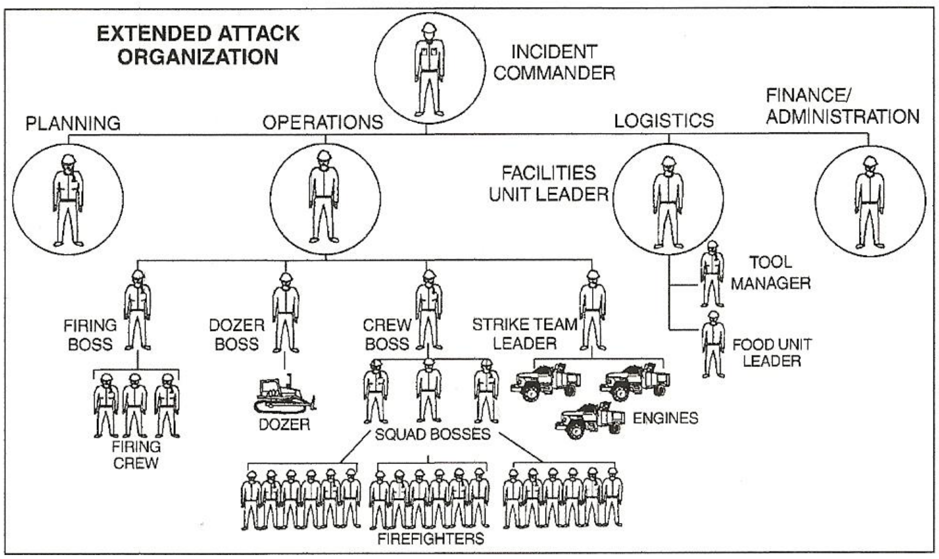

Figure 2.5 Large Crew Organization of the USFS
Source: Forest Service Manual 2011

Figure 2.6 highlights the key difference between CALFIRE and the USFS in terms of extended attack; CALFIRE is organized on the basis of smaller antonymous battalions while the USFS relies much more on large hierarchical forces for its fire suppression organization. In addition to this CALFIRE has also placed a greater number of small fire stations throughout the study area than the USFS. This fact will be discussed further in Chapter 4.

2.7 Summary and Conclusions

From the previous sections of this chapter it becomes apparent that our selected study area does not necessarily provide a natural experiment to observe how institutions and organization affects the wildfire incentives and policies of fire suppression for individual agencies. Both CALFIRE and the USFS responsibility areas border each other in locations with similar vegetation and topography which can potentially allow controlling for the uncertainty of the fire shed itself. As long as sub-sections of wildfires can be prudently selected from within the study area there is potential for a preferable natural experiment.

In addition to shared borders these two agencies have also agreed to the same priorities in where to apply wildfire suppression. Both agencies put human life at top priority, followed by the protection of assets in the fire shed. While these agencies share common goals they also face differing incentives and constraints in the pursuit of said goals, as different laws and regulations apply to each agency. In addition to this these agencies also have differences in the way their fire suppression crews are organized. In the next chapter the theoretical motivation of this study will be discussed.

Chapter 3: Economic Analysis of Wildfire Suppression

In this chapter I develop an economic model that incorporates suppression effort as well as agency constraints and incentives. This model will show how factors such spatial distance of suppression resources, ecological parameters of the fire shed, and institutional structures influence the differing decisions to suppress between CALFIRE and the USFS. I will begin with a review of previous wildfire economics literature and then develop my own model.

Previous literature provides a baseline frame work for developing a model of optimal wildfire suppression effort within a fire shed. While this previous literature considers the impact of assets at risk within the fire shed, the cost of wildfire suppression, and efforts to mitigate future wildfire, they fail to acknowledge differences between wildfire suppression agencies and the dynamic nature of wildfire. The model that I construct will take these factors into account as well as the costs and benefits of optimal wildfire suppression.

3.1 Previous Models of Wildfire Suppression

Until the late 1970's very little research was conducted on the topic of wildfire economics. In general economic models of wildfire fall into three categories: minimum damage, adequate protection, and minimum sum of costs and losses. I will briefly describe each of these models. The minimum damage theory proposed that wildfire damages should be held to a minimum, and placed a strong emphasis on the initial attack and prevention of large wildfires (Kotok and Show 1923) . DuBois (1914) was a large proponent of this theory, and at its core it is the basis of the 10 AM Rule as discussed in Chapter 2. The Least Cost Plus Losses (LCPL) models attempts to incorporate the costs and benefits of suppression into an economic context. This model has sought to identify the point at which investment in both pre-suppression and suppression would minimize economic losses due to wildfire. In his analysis Sparhawk (1925) only considered the value of timber when calculating the potential value of losses. He also failed to consider the temporal effects of mitigation, instead modeling his theory on suppression within a single frame of time (Sparhawk 1925). The adequate protection theory argues that wildfire suppression should act as a replacement for fire insurance.

The baseline LCPL has remained largely unchanged over the decades with a number of additions to better reflect the benefits and costs of wildfire. Many economists have contributed to this model such as Gonzalez-Caban and McKetta (1984), and Gorte and Gorte (1979). A modern version of the LCPL theory has been developed by Brown and Donovan (2005). This model considers the relationship between suppression, pre-suppression, fire damage, and fire benefits in tandem. The present value of all wildfire-related damages minus the present value of all wildfire related benefits is called the Net Value Change (NVC). The optimal amount of suppression minimizes the sum of all fire related costs (C) and NVC. The problem is;

$$\frac{Min}{P,S} : NVC + C = W^p P + W^s S + NVC(P,S) \tag{3.1}$$

where *P* denotes pre-suppression effort, *S* denotes suppression effort, W^p denotes the wage of pre-suppression effort, and W^s denotes the wage of suppression effort. The amounts of investment in these activities on the part of the fire shed owner are the choice variables in this case. Differentiating with respect to *P* and then *S* gives the following first order necessary conditions;

$$W^p + \frac{\partial NVC}{\partial P} = 0 \tag{3.2}$$

$$W^s + \frac{\partial NVC}{\partial S} = 0 \tag{3.3}$$

Rearranging the term yields;

$$-\frac{\partial NVC}{\partial S} = W^s \text{ and } -\frac{\partial NVC}{\partial P} = W^p \tag{3.4}$$

From the above first order conditions the optimal solution is where the marginal benefit of suppression equals the wage of a unit of suppression effort. Figure 3.4 below depicts the optimal solution for this version of the LCPL model. *A represents the lowest cost of suppress effort plus the losses of wildfire and *S represents the optimal amount of suppression effort. Once again note that the optimal amount of suppression does not reduce all damages, but rather to find equilibrium between wildfire damages and suppression costs.

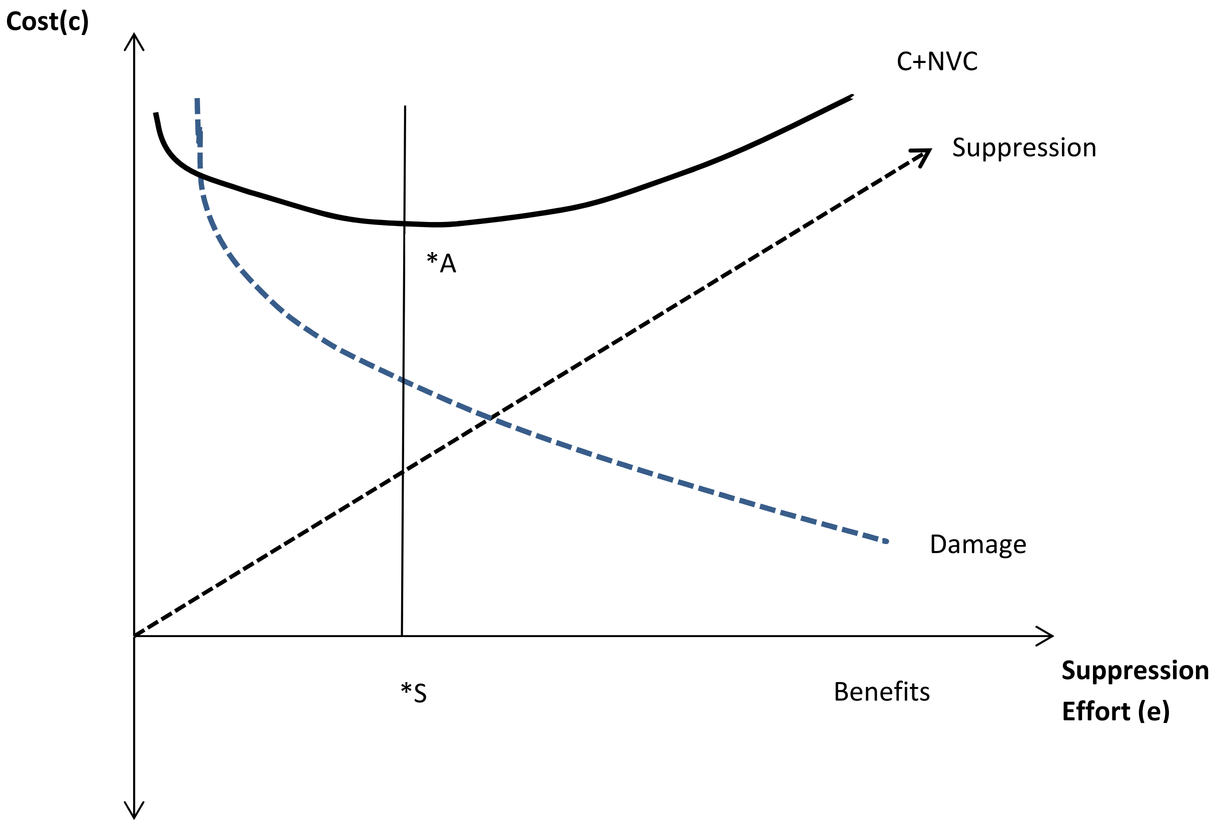

Figure 3.1: Optimal Solution of Wildfire Suppression Effort

3.2 Limitations of Previous Wildfire Models

The LCPL model as augmented by Brown and Donovan introduces fire mitigation as a choice in the model, however it does not consider the impact of heterogeneous ownership or the impact of institutions on the fire shed. A property owner in the fire shed will take the risk of wildfire spread from neighbor to their own land into consideration when making decisions. If a landowner has many assets which are at risk from wildfire they are more likely to exert greater effort towards wildfire mitigation or suppression. However the mitigation and suppression efforts of neighbors within the fire shed will be included in a land holder's decision making process. Consider the table below that describes how the organization and financing of wildfire suppression will evolve under different ownership regimes.

	Single Land Holder on Fire Shed	Multiple Land Owners on Fire Shed
Individual Landholder	A single owner that reaps the benefits and bears the costs of fire will engage in an optimal amount of fire suppression efforts.	Among a patchwork of landowners each individual is responsible for wildfire suppression on their property. The entire fire shed must to homogenous in order to prevent free riders in this regime.
Private Organization	This does away with the assumption that the single land owner possesses that complete knowledge of the fire shed, along with the ability and capital to cost effectively suppress wildfire. In this instance a private firm is contracted to supply fire suppression and is assumed to possess the capital and specialization to do so effectively.	In this more realistic scenario the collective landowners of the fire shed lack the ability and capital to effectively suppress wildfire. Thus, they contract a private firm that possesses the ability and capital to effectively engage in fire suppression. In this case the suppression firm can help to alleviate the free rider problem by charging greater amounts to properties at greater risk from wildfire.
Government Organization	Though a handful of private fire suppression firms do exist in the United States, it unlikely that a profit maximizing firm would possess the economy of scale to effectively engage in fire suppression efforts within an entire fire shed.	It is unlikely the previous assumptions will hold in an empirical manner. Perfect fire shed knowledge amongst landholders, homogenous parcels of land, strict liability on the part of landholders, and divided land ownership in general all combine to constitute the need for bureaucratic government structure to take responsibility for the suppression activities within the fire shed.

Figure 3.2:Conceptual Ownership and the Organization of Fire Suppression within a Fire Shed
Source: Lueck, 2011

Figure 3.2 depicts responsibility for wildfire prevention and mitigation becoming increasingly difficult to coordinate in a fire shed that is populated by multiple land owners. In such a situation where a government organization is not responsible response for mitigation land owners must decide how much to effort to expend mitigating their holdings against wildfire. In the simplest scenario an individual land owners would be responsible for wildfire suppression. This single landowner will reap the benefits of their holdings while also bearing the cost of wildfire and must determine how much suppression effort is optimal to reduce and prevent damages from wildfire (Coase 1960). For the most part a single landowner does not own the entire fire shed; typically the fire shed contains a patchwork of landholders whose holdings border each other. Wildfire will spread across the fire shed regardless of property lines, so a landholder will also consider the effort expended by neighboring landholders; as demonstrated in the upper right cell of Figure 3.2. This creates a free rider problem, where those with wildfire prone landholdings benefit from the suppression efforts of their neighbors at no cost. Ownership of the fire shed is also an important factor. A land owner charged with suppressing wildfire within their own holdings will have greater knowledge of the fire shed that would aid in the detection and suppression strategy of the wildfire. In addition, this ownership of the fire shed also provides greater incentive to not engage in activities that increase the risk of wildfire, such as open camp fires or burning of refuse. The economy of scale and expertise for effective wildfire suppression however, often makes suppression by the individual land owner impossible. In this case an outside individual or agency with the required wildfire suppression expertise and capital would need to contract on the behalf of the landowners. While a private wildfire firm could potentially be contracted to suppress wildfire a number of factors would make profit maximization difficult; determining the price of private wildfire suppression services and coverage would be difficult to determine, and the frequency and severity of wildfire is difficult to predict. Due to this a public wildfire agency is most likely to be organized and contracted to provide wildfire suppression to the landholders within the fire shed (Ahlbrandt 1973).

The previous model also fails to consider the dynamic nature of wildfire, if suppression resources do not arrive at the wildfire in a timely manner following the ignition there is very little additional suppression effort can do to reduce the size and damages of the wildfire None of these potential factors are considered in the modern iteration of the LCPL model. To put this in perspective recall the most obvious difference between the two agencies; the USFS in charged with protecting public lands that it for the most part owns. CALFIRE on the other hand defends many heterogeneous parcels of privately held land from wildfires. As outlined in Figure 3.2 these differences in ownership regime relative to suppression agency structure can have a significant influence as to how wildfire policy and outcomes are generated.

I will now build on the LCPL model with the addition of the dynamics of wildfire. Assume a homogenous fire shed with a single owner and no variation in elevation. In a flat landscape fire will tend to burn in an ellipse as illustrated in Panel A of Figure 3.3 (Lueck 2011). In more rugged terrain the size and shape is more unpredictable but is typically V shaped as it moves upward, increasing in size towards higher evaluations. A natural wildfire as depicted in Panel B of Figure 3.3 with no suppression effort will be of size $F(T^F) = F^F$ and have duration of T^F, where F is the size of wildfire in burned acres and *T* is the duration of wildfire in days. The total size of a natural wildfire is a function of fire duration and the natural parameters of the fire shed and can be defined as $F(t) = \int_0^T f(t)dt$ where *f(t)* is the rate of growth in acres (Lueck and Yoder 2012). The graph in Panel B of Figure 3.3 depicts the dynamics of a natural fire over time.

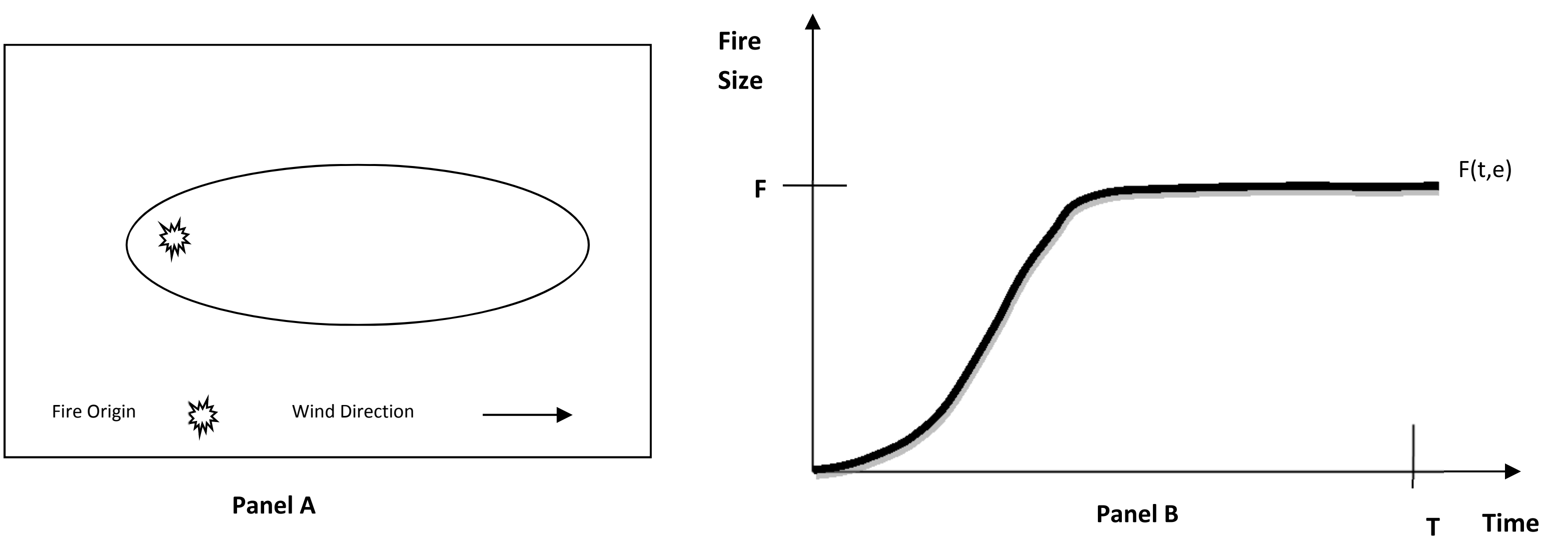

Figure 3.3 Dynamics of a Natural Wildfire
Source: Lueck and Yoder 2012

With the introduction of suppression effort *s(t)* on the part of the fire shed owner it is assumed that wildfire size is also a function of suppression in addition to duration and fire shed ecology. The wildfire size function is now $F(t) = \int_0^T f\big(t, s(t)\big)dt$. It is also assumed that the addition of suppression effort will reduce the duration and size of wildfire such that that $F^s \leq F^F$ and $T^s \leq T^f$.In this framework there are several possible outcomes which are shown in Figure 3.4. If suppression efforts begin shortly after ignition then the suppressed wildfire size is much smaller than if it was simply left to burn. This scenario is depicted in Panel A of Figure 3.4. If suppression does not arrive in a time manner or ecological factors such as dense fuel loads result in a large blow up, then suppression efforts are almost futile against such infernos. This scenario is depicted in Panel B of Figure 3.4

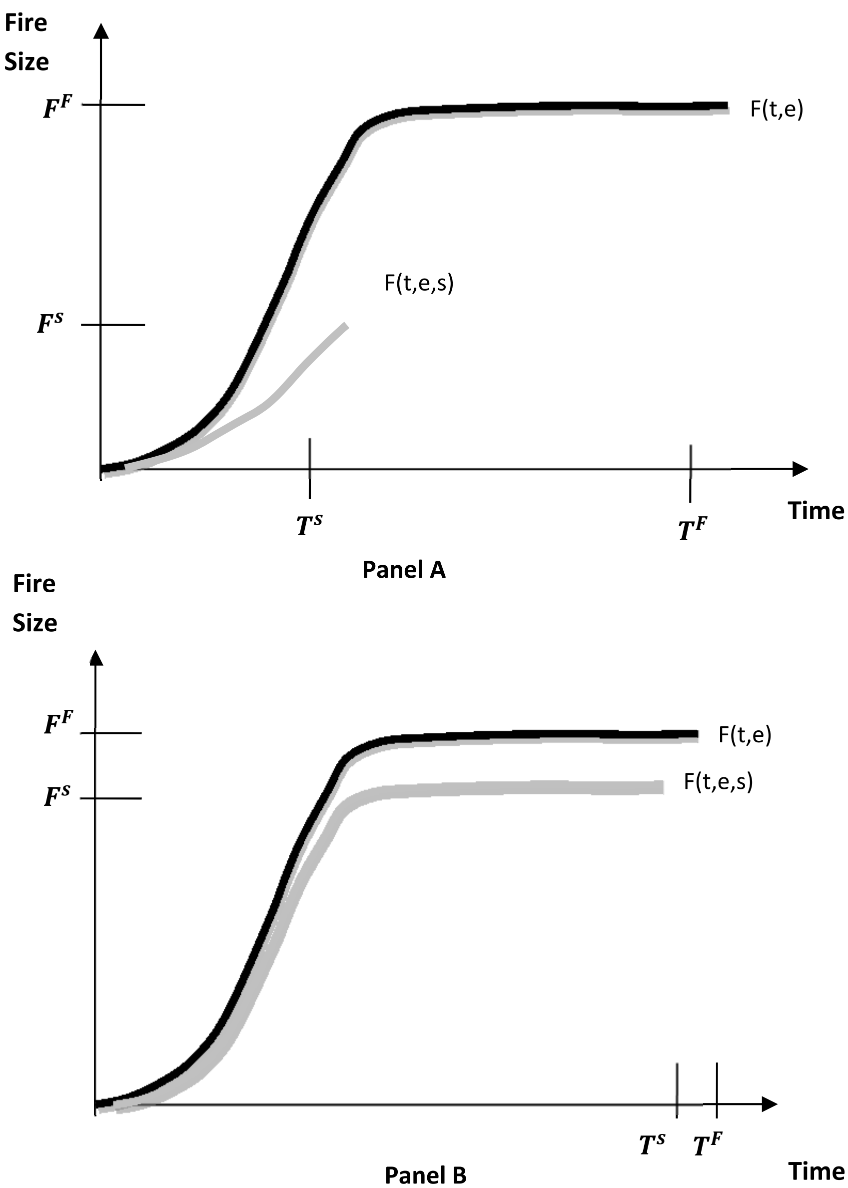

Figure 3.4 Comparison of Natural and Suppressed Wildfire Dynamics
Source: Lueck and Yoder 2012

These dynamics can have a large impact on wildfire size and wildfire duration. An agency with many suppression facilities such as fire stations, work camps, and air fields in close proximity to wildfire ignition points can quickly move suppression resources to wildfires. With this in mind an agency must choose the location of its suppression resources to achieve an efficient outcome. While placing many facilities throughout the protection area would greatly reduce wildfire size and duration, the costs of doing so would be prohibitive. A wildfire agency must consider the potential loss of assets to wildfire in tandem with the costs of placing suppression facilities and deploying suppression resources. This relationship between the dynamics of wildfire and how a wildfire agency has chosen to organize itself and its resources have been ignored in previous models. Notice that both functions of wildfire are only concerned with the current time period and ignore any previous suppression or wildfire prevention actions taken by the land owner in past wildfire seasons. While such actions may have an effect on land owner suppression efforts I have selected to set them aside in favor of modeling how institutional differences between CALFIRE and the USFS effect wildfire size and suppression effort.

3.3 Agency Model of Wildfire Suppression

Wildfire can have both positive and negative effects upon the fire shed. Positive effects are primarily ecological, as they can reduce fuel loads and therefore wildfire severity in future time periods. A number of plant species also require wildfire in order for their seeds to germinate (Agee 1990) (Kauffman 1990). The negative effects of wildfire include destruction of property, timber, and recreational areas. These effects are highly dependent on whether the fire propagates from its ignition point and the direction of the fire path.

Consider the case of a fire shed with a single owner and a homogenous fire shed. The owner will maximize the net benefits of wildfire function *NB,* which in turn is a function of benefits resulting from wildfire as well as the costs. The net benefits of wildfire are determined by the benefits that accrue to the owner from the occurrence of wildfire. In this case the benefits of wildfire are the potential damage from wildfire averted due to the application of suppression. The wages of suppression represent the cost portion of the wildfire net benefits function. The function of net benefits for wildfire is illustrated in equation 3.7 below.

$$\frac{Max}{S} : NB = D(s) - C(s) \tag{3.7}$$

D represents the monetary damage resulting from the wildfire in dollars. D is determined by the monetary per acre value of assets within the fire shed *(d)*, and *F(s),* the cumulative size of the wildfire in acres such that *D=dF(s)*. The monetary damages caused by the wildfire is subject to the size of the wildfire Once again consider Figure 3.4 in the case where no suppression effort is applied to the wildfire, in this case *s=0* and therefore $D = dF^t$. In contrast if the wildfire is completely suppressed then *F=0*, and *D=0* as well. The size of the wildfire is determined by the amount of suppression effort applied s, as well as the effectiveness of the suppression effort r. Mathematically this is expressed as $\Delta F = sr$. By multiplying the acreage change in wildfire size *sr* by d, the per acre value of assets within the fire shed, I find the reduction in damages. This is expressed as $R = dsr$ where *R* is the reduction in damages in dollars. This represents the benefit side of the Equation 3.7, and *D(S)* can be then be expressed as *D(S)=dsr*. *C(s)* represents the per acre dollar cost of suppression effort. Essentially *R* represents the vertical distance between F^T and F^S in Panel A and Panel B of Figure 3.4. As the suppression effort increases the per acre dollar cost will increase as a convex function. With this in mind I will calculate the optimal amount of wildfire suppression and generate comparative statics in the following section.

3.4 Maximization of Wildfire Net Benefits and Comparative Statics

The efficient wildfire agency will maximize the net benefits of wildfire from Equation 3.7 to solve for *S* in partial equilibrium. The first order necessary condition is;

$$\frac{\partial(NB)}{\partial S} = dr - C'(s) = 0 \tag{3.8}$$

From the first order conditions of Equation 3.8 *dr* represents the marginal benefit of suppression effort, in terms of reduced damage from wildfire, while *C'(s)* represents the marginal cost of suppression effort.

The second order sufficient condition follows as;

$$\frac{\partial^2(NB)}{\partial S^2} = -C''(x) \leq 0 \qquad (3.9)$$

With this in mind consider the following comparative statics. The explicit choice function is found by solving Equation 3.8 for the choice variable in terms of the land value parameter *d;*

$$s = s^*(d) \qquad (3.10)$$

Essentially this shows how much suppression effort will be put forth at any given land value of *d*. In this case I will consider *r* to be homogenous regardless of the agency, therefore *r=1.* Now by substituting Equation 3.10 back into Equation 3.8 the following results;

$$d - C'(s^*(d)) = 0 \qquad (3.11)$$

By taking the derivative with respect to *d* the comparative statics for land value per acre can be obtained. By using the chain rule to following is obtained;

$$\frac{\partial d}{\partial d} - \frac{\partial C'(S)}{\partial S}\frac{\partial S^*}{\partial d} \equiv 0 \qquad (3.12)$$

This can be rearranged as;

$$-C''(S)\frac{\partial S^*}{\partial d} = -1 \qquad (3.13)$$

Therefore because there is a cost associated with suppression effort *C'>0*;

$$\frac{\partial S^*}{\partial d} = \frac{1}{C''(x)} > 0 \qquad (3.14)$$

According to Equation 3.14 as the per acre land value within the fire shed increases, the suppression effort on the part of the wildfire agency will increase as well. The comparative static with respect to this parameter will assist in generating several predictions.

3.5 Predictions

Prediction 1: *As assets at risk within the fire shed increase, the size and duration of the wildfire will decrease.*

As discussed in Chapter 2 wildfire agencies in California place a high priority to defend property from wildfire damage. Therefore a fire shed with valuable assets at risk from wildfire presents a greater incentive for the agency to expend greater suppression effort to extinguish the wildfire as quickly as possible. The potential damages to assets within the fire shed justify the increased suppression costs as shown in Equation 3.7, and expanded upon in the comparative static in Equation 3.14.

Prediction 2: *An agency organized in similar manner to CALFIRE rather than the USFS will reduce the duration and size of wildfire.*

On average areas where CALFIRE is responsible for wildfire suppression have greater land values than that of the USFS, which provides greater incentive for CAFLFIRE to put forth greater suppression effort. As discussed in chapter 2, CALFIRE organizes extended attack using smaller more fluid battalions than that of the USFS, CALFIRE's protection areas often have suppression facilities closer to the ignition point as depicted in Table 3.1. According to comparative statics of Equation 3.16, the fact that CALFIRE suppression facilities are generally much closer to the wildfire ignition point will result in smaller wildfires of shorter duration than those that are suppressed by the USFS.

Chapter 4: Empirical Analysis

In this chapter the theoretical predictions described in Chapter 3 are tested against data from over 30,000 wildfires from 2001-2011. I first describe the final dataset used for the analysis. This is then followed by the empirical strategy adopted and an analysis of the empirical results. Using this data I will test the follow predictions; greater assets at risk within the fire shed will reduce the size and duration of wildfire, ownership of the fire shed on the part of the suppressing agency will reduce the size and duration of wildfire, a wildfire agency with suppression resources in close proximity to the ignition point of the wildfire will reduce the size and duration of wildfire.

4.1 Description of Data

The final wildfire dataset was created by combining two separate data sets, one for CALFIRE and the other for the USFS. Each data set has information on individual wildfires. Both data sets span from 2001 to 2011 and represent wildfires within the counties of the selected study area.

The CALFIRE data were compiled and prepared by the Fire and Resource Assessment Program (FRAP) by request as a point object GIS feature class. The dataset was compiled from ICS-209 wildfire reporting forms employed by CALFIRE. When CALFIRE responds to wildfire the responsible Fire Chief must prepare a ICS-209 on a daily basis. Once the fire is declared out each daily report is then compiled into a final ICS-209 report.[4] See Figure 2A in the appendix for the actual form itself. The CALFIRE data set originally consisted of approximately 44,000 observations and 104 variables. Many of these variables are identification numbers generated by the GIS program ARCMAP while cleaning the data, so the majority of these are not helpful for empirical analysis. Many of these observations were missing values necessary to for the empirical testing of the predictions outlined in chapter 3. The date of the wildfire's discovery time and declared control time were missing for a number of variables and had to be deleted. A number of fires CALFIRE responded to were purely structure fires, vehicle fires, or fires that were simply

[44] As discussed with Tonya Hoover the Administrative/Executive Office of the State Fire Marshall's Office of California on April 17th, 2013.

classified as ”other”. As this is a study of the impact of institutions on wildfire these non-wildfires were deleted from the CALFIRE data set. With these observations deleted from the CALFIRE data slightly more than 20,000 observations remain. The CALFIRE data also included approximately 2,000 USFS fires, by using the same process to clean the CALFIRE observations 305 USFS fires where derived from the dataset prepared by FRAP.

The primary USFS dataset was downloaded from the Kansas City Fire Access Software, a program administered by the USFS to provide wildfire data to researchers and the general public.(KCFAST, 2013) This particular data was downloaded and provided to me by Dr. Johnathan Yoder of Washington State University. These fires are recorded using the National Interagency Fire Management Integrated Database (NIFMID) forms used by the United States Department of Agriculture and the Department of Agriculture to record wildfire data. See Figure 1A in the appendix for the actual form itself. The initial data set originally contained slightly more than 20,000 observations on wildfire ignitions with 62 variables. A number of the wildfire suppression agencies such as the National Park Service or the Bureau of Land Management have too few fires for any useful empirical analysis, thus these observations were removed. For example only 3 National Park Service wildfires were contained in the dataset, and such a small number of wildfires for this agency would be of little help in a data set this size. Similar to the cleaning of the CALFIRE dataset, any wildfire observations with missing values for discovery date, control date, and protection agency. With the removal of these observations the KCFAST data set contains 9,000 USFS wildfires and slightly over 300 CALFIRE wildfire observations.

Both datasets share many of the same variables. For example acres burned, duration, county, and protection agency are very simple to link between the data sets. On the other hand, wildfire cause, land ownership, and many ecological variables require some additional efforts to completely link to two data sets. Table 1A in the appendix lists where each variable can be found on each agencies respective wildfire reporting forms, and also indicates which variables do not entirely match up and where extra efforts to generate compatible variables is necessary.

The NIFMID data set is much more specific in terms of wildfire cause. For example the NIFMID dataset contains over 40 specific causes while the CALFIRE data set only contains 19 possible causes of wildfire ignition. For this purpose three dummies have been generated to bridge the two data sets. A dummy has been created to indicate whether the wildfire ignition was human caused, naturally occurring (typically lightning), or unknown cause.

Many naturally occurring parameters within the study area are not compatible between the data sets. However as both data sets include longitude and latitude, missing natural parameters can be added to either data set via the intersect function. For example the categorical vegetation variables employed by the NIFMID dataset do not match with the vegetation variables. To bridge these two data sets, both were intersected with a vegetation type and vegetation density GIS shapefile accessed through FRAP. Through this process compatible vegetation variables were generated for each dataset. Similarly, the CALFIRE dataset lacked variables describing the elevation of each ignition point. For this purpose a GIS shapefile was acquired from the U.S. Geological Survey and intersected with the CALFIRE ignition point data set.

Through the use of GIS software very few variables had to be compromised in the process of joining the two data sets together. This process of merging these two datasets in outlined in the Data Generating Process found in the appendix. A diagram of each GIS process is also provided in Figure 5A of the appendix. I will discuss the variables themselves in greater detail in the next section.

4.2 Description of the Study Areas.

As discussed in Chapter 2 CALIFIRE and the USFS are the two most prevalent wildfire suppression agencies within the counties of the study area. The USFS was given charge of the National Forests beginning in the early 20th century with some additional acres added during next 4 decades. CALFIRE was assigned to defend various forest lands outside of federal lands in the mid 1940’s. Figure 2.2 in Chapter 2 shows the protection area of both agencies with respect to the counties of the study area. Most, but not all of the counties within the study area contain areas where the protection areas of both agencies border each other. A description of protection acreage, fire occurrence, fire size, and fire duration is provided in Table 2A in the appendix. A brief description of the dominate vegetation and the location of the county within the study area is also provided in the table. Note that this table uses an equal variance t-test for the purpose of the means test. Out of the counties that are listed 10 were found to be statistically different in terms of wildfire size and 13 were found to be significantly different in terms of wildfire duration. There are also large variations in the dominant eco-systems within the counties. This indicates that this study area of 26 counties does not present the ideal natural experiment.

From Table 2A, CALFIRE has many more wildfire occurrences than the USFS, however the vast majority of CALFIREs wildfires are of shorter duration and size. While the many shared borders within the study area are potentially an excellent natural experiment as they often share similar natural parameters, a sub-section within the study area will be selected to try to generate a more natural experiment. Wildfires along the border between the USFS and CALFIRE protection areas present an excellent opportunity for such an endeavor.

4.3 Description of Variables

Combining the individual wildfire datasets as discussed previously results in a data set with approximately 29,000 wildfire observations. Numerous dummy variables were generated for this empirical analysis; many to represent the natural parameters of the fire shed. Dummy variables where generated for vegetation types, depending on which eco-region of Northern California the particular vegetation type is found, as well as the density of the vegetation. A summary of the eco region dummies for the entire dataset and by agency can be found in Tables 4.1 and 4.2

Table 4.1: Eco-Region Dummy Variables; Full Sample.

Dummy Variable	Definition	Frequency	Percent of Observations
D_Fthlls	Ignition point in Foothills Eco Zone	1892	8.27%
D_Lwmtn	Ignition point in Low Montane Eco Zone	11246	49.16%
D_Hghmtn	Ignition point in High Montane Eco Zone	894	3.91%
D_Sbalp	Ignition point in Sub Alpine Eco Zone	245	1.00%
D_H2o	Ignition point in Wetland Eco Zone	115	0.39%
D_Grslnd	Ignition point in Grassland Eco Zone	3021	13.20%
D_Dsrt	Ignition point in Desert Eco Zone	396	1.73%
D_Agurb	Ignition point in Agriculture/Urban Eco Zone	2623	11.46%
D_Barrn	Ignition point in Barren Eco Zone	267	1.16%
D_Unknwn	Ignition point in Unknown Eco Zone	891	3.89%
D_Cstl	Ignition point in Costal Eco Zone	957	4.18%

Source: See data generating process

These eco-region categories were based off the vegetation of the ignition point using previous studies of vegetation and wildfire risk (Miller et al 2011). Due to the fact that there are over 60 types of vegetation within the selected study area, each was assigned an Eco-region category where the vegetation type is most commonly found. The most common Eco-region in terms of wildfire is the Low Montane area. In this area ponderosa pine and white fir trees and shrubs are the most commonly occurring vegetation types. The Eco-region dummy variables sorted by the wildfire agency can be found in Table 4.2.

Table 4.2: Eco-Region Dummy Variables by Agency.

Definition	CALFIRE FREQ	USFS FREQ	Percent CALFIRE	Percent USFS
Ignition point in Foothills Eco Zone	1873	19	12.58%	0.24%
Ignition point in Low Montane Eco Zone	6002	5244	40.32%	67.72%
Ignition point in High Montane Eco Zone	56	838	0.38%	10.82%
Ignition point in Sub Alpine Eco Zone	67	178	0.45%	2.29%
Ignition point in Wetland Eco Zone	43	52	0.28%	0.70%
Ignition point in Grassland Eco Zone	2903	118	19.50%	1.52%
Ignition point in Desert Eco Zone	204	192	1.37%	2.47%
Ignition point in Agriculture/Urban Zone	2458	165	16.51%	2.13%
Ignition point in Barren Eco Zone	136	131	0.89%	1.69%
Ignition point in Unknown Eco Zone	773	168	4.85%	2.17%
Ignition point in Costal Eco Zone	495	462	3.32%	5.96%

Source: See data generating process

The Low Montane eco-region forms a plurality for both CALIFE and the USDS. The most common eco-regions for the USFS are Low Montane and High Montane, which make up 78 percent of the agencies wildfires. The most common vegetation within the High Montane eco-region are red fir and Jeffery pine shrubs and trees, and well as quaking aspen trees. While a large portion of CALFIREs wildfires are in the Lower Montane eco-region similar to the USFS, large numbers of wildfires occurring in areas dedicated to agriculture and urban areas as well as grasslands. These three eco-regions account for approximately 75 percent of CALFIRE's wildfires. About 10 percent of CALFIREs wildfires occur in the Foothills eco-region, which is mostly made of conifers and oaks.

In addition to the eco-region dummy variables dummies where also generating indicating the size of the vegetation as well. The vegetation size of the data set ranges from small seedlings to large mature trees. The different categories of vegetation size can be found in Table 4.3 below.

Table 4.3: Vegetation Size Dummy Variables; Full Sample.

Dummy Variable	Definition	Frequency	Percent of Observations
D_Vegd0	Vegetation Size Unknown	6478	28.31%
D_Vegd1	Vegetation Size Seedling	32	0.139%
D_Vegd2	Vegetation Size Sapling/Young Shrub	997	4.35%
D_Vegd3	Vegetation Size Pole/Mature Shrub	4183	18.32%
D_Vegd4	Vegetation Size Small Tree/Decadent Shrub	8237	36.00%
D_Vegd5	Vegetation Size Medium/Large Tree	2616	11.43%
D_Vegd6	Vegetation Size Multi-Layered	331	1.44%

Source: See data generating process

The vegetation size for slightly less than a third of the wildfires is unknown. Aside from this small to large trees and over grown shrubs account for the largest portion of vegetation size for the full sample. The Eco-region dummy variables sorted by the wildfire agency can be found in Table 4.4.

Table 4.4: Vegetation Size Dummy Variables by Agency.

Definition	CALFIRE FREQ	USFS FREQ	Percent CALFIRE	Percent USFS
Vegetation Size Unknown	5798	680	38.34%	8.79%
Vegetation Size Seedling	3	29	0.19%	0.37%
Vegetation Size Sapling/Young Shrub	818	179	5.40%	2.31%
Vegetation Size Pole/Mature Shrub	3017	1166	19.95%	15.08%
Vegetation Size Small Tree/Decadent Shrub	4295	3942	28.40%	50.9%
Vegetation Size Medium/Large Tree	1010	1606	6.67%	20.77%
Vegetation Size Multi-Layered	181	150	1.19%	1.93%

Source: See data generating process

For the most part CALFIRE's wildfires take place in areas where the vegetation size in unknown, slightly less than 50 percent of its wildfires take place in either areas of mature shrubs and tree poles or small trees and decadent shrubs. The vegetation size for the USFS however for the most part much larger, with small trees/decadent shrubs or medium to large trees representing 70 percent of USFS wildfires.

Certain years have weather conditions such as high winds and little precipitation that often result in severe wildfi[illegible]ummies may capture these effects. The dummy variables for each year and the wildfire occurrence for each year can be found in Table 4.5.

Table 4.5: Year Dummy Variables; Full Sample.

Dummy Variable	Definition	Frequency	Percent of Observations
D_2011	Dummy for year 2011	1451	6.35%
D_2010	Dummy for year 2010	1383	6.05%
D_2009	Dummy for year 2009	2044	8.94%
D_2008	Dummy for year 2008	2536	11.10%
D_2007	Dummy for year 2007	2279	9.97%
D_2006	Dummy for year 2006	2159	9.45%
D_2005	Dummy for year 2005	1441	6.31%
D_2004	Dummy for year 2004	2330	10.20%
D_2003	Dummy for year 2003	2605	11.40%
D_2002	Dummy for year 2002	1916	8.36%
D_2001	Dummy for year 2001	2710	11.86%

Source: See data generating process

The years 2001, 2003, 2004, and 2008 are the more extreme years in terms of wildfire occurrence. The last three years of the dataset appear to be much milder in comparison. The yearly dummy variables sorted by the wildfire agency can be found in Table 4.6.

Table 4.6: Fires by Agency 2001-2011

Year	CALFIRE FREQ	USFS FREQ	Percent CALFIRE	Percent USFS
2011	1116	335	6.84%	4.82%
2010	987	396	6.15%	5.58%
2009	1307	737	8.23%	9.25%
2008	1698	838	10.48%	10.64%
2007	1643	636	9.61%	8.43%
2006	1469	690	9.77%	9.11%
2005	1022	419	7.42%	5.88%
2004	1442	888	10.20%	11.22%
2003	1532	1073	11.40%	13.30%
2002	1320	596	8.38%	8.24%
2001	1586	1124	10.86%	14.10%

Source: See data generating process

For the most part the wildfire occurrence for each agency mirrors that of the full sample in Table 4.5. Dummy variables were also generated for the county and the year the fire took place in to further control for non-agency exogenous effects.

Variables were also included to capture the economic values within the fire shed. Population density of the county was found for each year spanning from 2001 to 2011 and then matched with its respective wildfire. As land value GIS datasets are difficult to procure, the land value of the census tract where the ignition took place was used as a substitute. Census tracts are subdivisions within counties with approximately 2000 to 8000 persons within them. These are relatively static though they can be changed every decade when a new census is taken. Census tracts are typically centered on a metropolitan area. (United States Census Bureau) The total amount of property tax collected from each census tract by year was matched up with each individual wildfire to give an approximation of the assets at risk within the fire shed. The process of creating the final dataset was created for this analysis is described in full detail in the appendix.

Variables to capture the effects of the wildfire ignition where also generated. A dummy variable indicating that the wildfire was a naturally occurring ignition was generated. This essentially indicates a lighting strike as the ignition cause. In additional to this a dummy variable was also generated to indicate whether the wildfire ignition was caused by human activity. Wildfires with unknown causes were deleted from the dataset.

A variable representing the WUI category as discussed in Chapter 2 was also generated. The WUI index takes place on a scale from 0 to 9, with 0 representing no WUI and 9 representing a WUI with the highest risk to human life and property. For example areas with lush vegetation but no development or areas with massive development but no vegetation take a WUI index of 0. An area with a High Density Interface, where areas of high housing density coincide with high vegetation cover have a WUI Index of 9. In addition to this a variable for elevation is also included.

A dummy variable indicating whether the suppressing agency is CALFIRE or the USFS was also generated. This variable will allow me to test whether the institutional differences between CALFIRE and the USFS have a significant impact upon the size and duration of wildfires. While a number of the differences between the institutions are known, however the impact of specific organizational differences is not evident from this variable.

The summary of statistics for the entire dataset and for each agency can be found in tables 4.7, 4.8, and 4.9 respectively. These include all variables used in the modeling process, with the exception of the A means test of difference for the entire data set in terms duration and wildfire size finds that mean USFS wildfires are 100 acres greater than CALFIRE wildfires, and this is significant at the 1% confidence level. Duration is also significant at the 1% confidence level, in this case the USFS mean for duration is 30 hours greater than that of CALFIRE. The protection areas of the USFS are also at a much higher elevation than CALFIRE. The mean elevation for USFS ignition points is about 4500 feet, while CALFIRE's mean elevation is 1800 feet. A means test of difference finds that this variable is significant at the 1% percent level of confidence.

Table 4.7 Summary of Statistics

Variable	Definition	Mean	Median	Min	Max	Std Dev
Size	Total acres burned	62.72	0.1	0	66113	1183
Duration	Hours between detection and control	19.61	1	0	4944	130
Elevation	Elevation in feet of the ignition point	2802	2062	0	9500	2052
Land Value	Property Tax of Census Tract of Ignition	2722365	2181700	0	14708800	2122976
WUI_Index	WUI Category	0.94	0	0	9	1.66
Pop Density	Pop Density Per Acre by County of Ignition	0.116	0.07	0.0034	2.23	0.195

Source: See Final Dataset Summary in Appendix

Table 4.8 Summary of Statistics of Dummy Variables

Dummy Variable	Definition	CALFIRE Frequency	USFS Frequency	Percent CALFIRE	Percent USFS
D_Natural	Natural Occurring Ignition	4002	4809	26.88%	62.02%
D_Human	Human Caused Ignition	10883	2938	73.11%	37.89%
CALFIRE	Whether the Suppressing Agency is CALFIRE	14885	7753	65.55%	34.45%

Source: See Final Dataset Summary in Appendix

Table 4.9 Comparison of CALFIRE (N=20,679) and FS (N=9175) Samples

Variable Name	Mean			Min		Max	
	CALFIRE	USFS	Diff: T-Test	CALFIRE	USFS	CALFIRE	USFS
Size	28.51	129.4	***-6.11	0.1	0.1	47647	66113
Duration	8.21	42.83	***-18.61	0.1	0.1	3178	4944
Elevation	1862.1	4665.4	***-128.1	0	0	7900	9500
Land Value	3298440	1598604	***61.94	0	0	14708800	8179800
WUI_Index	1.3306	0.1788	*** 52.61	0	0	9	9
Pop Density (Per Acre)	0.147	0.06	***34.26	0.0038	0.0038	2.23	0.36

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.
Source: See Final Dataset Summary in Appendix.

On average, the USFS finds itself suppressing far less wildfires than CALFIRE, but often these wildfires are of greater size and duration. A scatterplot of duration and size by agency in Figure 4.1 depicts this.

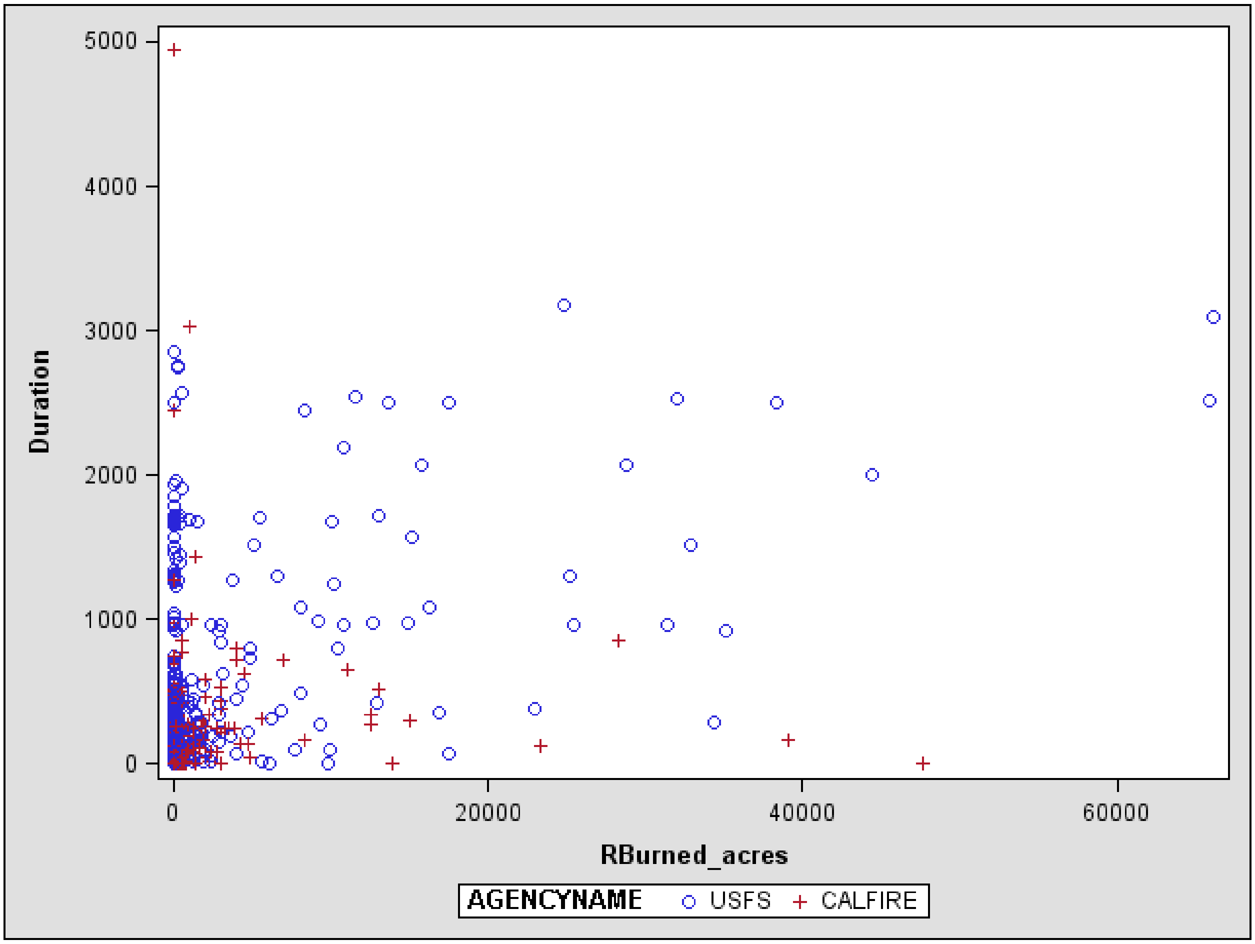

Figure 4.1: Scatterplot Y-Axis: Wildfire Size (Burned Acres) X-Axis Duration(Hours) by Agency

As summarized in Table 4.8 and Table 4.10 and depicted Figure 4.1 CALFIRE for the most part is engaged in suppressing small shortly lived fires. While the USFS is involved in suppressing many of these wildfires as well, it also has a propensity for large and extended wildfires. This is further explored in the graphs of Figure 4.2 and Figure 4.3.

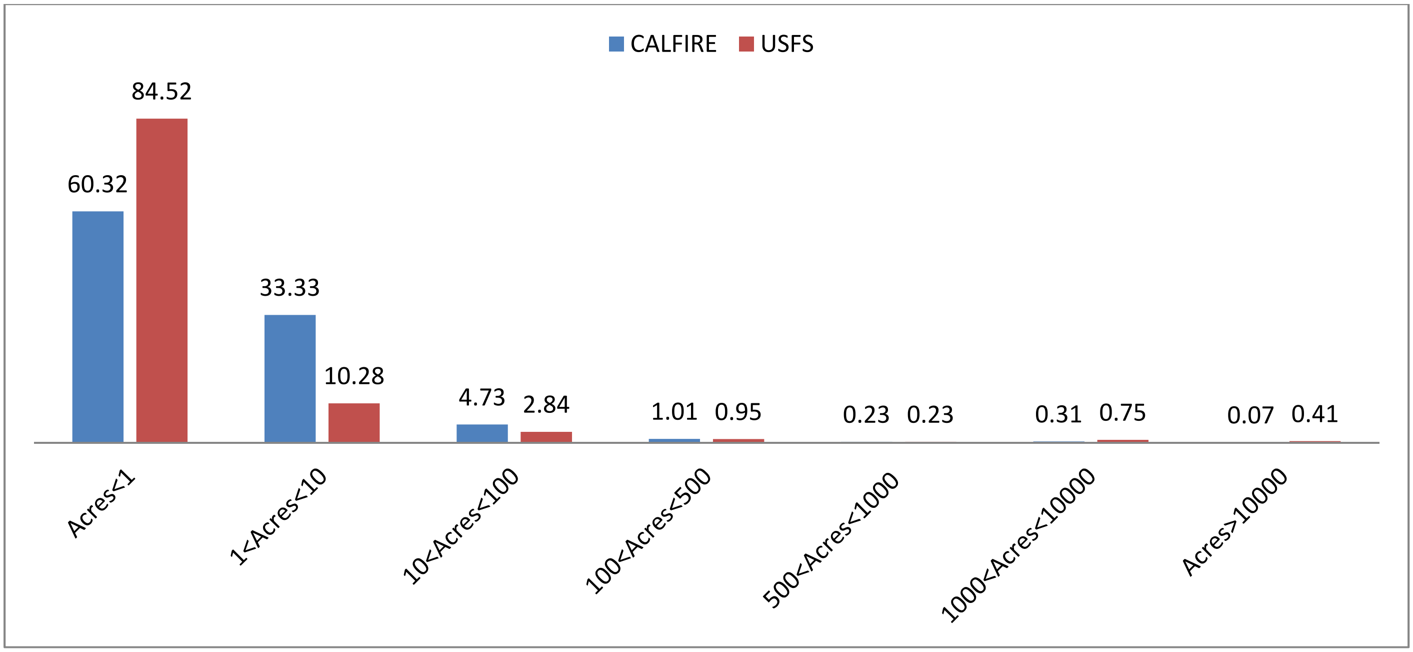

Figure 4.2: Percentage Categories of Wildfire Size by Agency

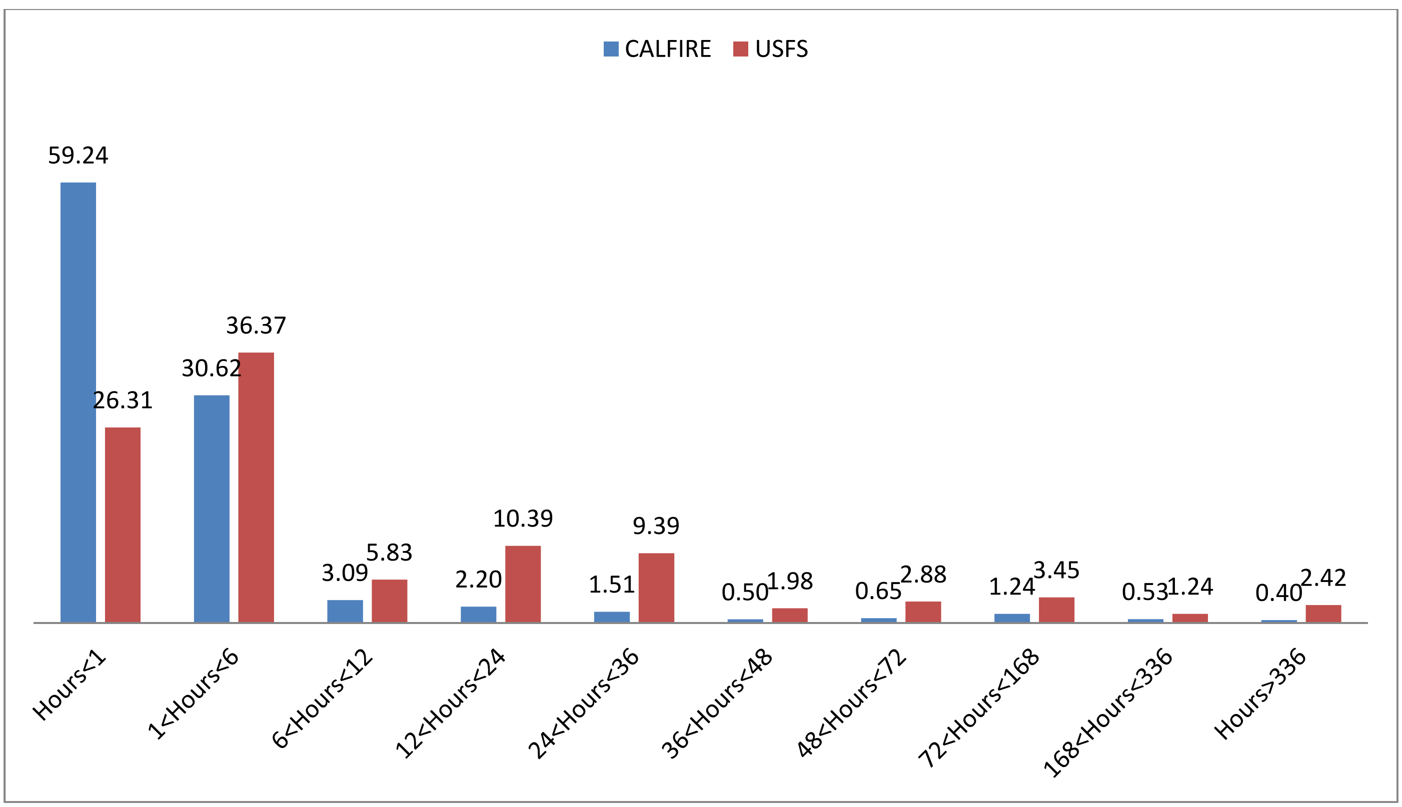

Figure 4.3: Percentage Categories of Wildfire Duration by Agency

In terms of wildfire size the USFS actually suppresses a greater percent of smaller wildfires than CALFIRE, however it should be noted that these less than one acre make up a large portion of wildfire size for both agencies. The much larger wildfires, those greater than 1000 acres are more common for the USFS than CALFIRE. These large infernos which often garner the attention of the national media would explain as to why the USFSs average fire size is so large. In terms of wildfire duration nearly 90 percent of CALFIRE wildfires are declared controlled within 6 hours of initial detection. In comparison about 80 percent of the USFS wildfires are declared controlled within one day of initial detection. While 20 percent of the USFS wildfires are greater than one day in duration, less than five percent of CALFIRES have such duration.

Both the USFS and CALFIRE have a number of suppression facilities positioned within their responsibility zones. A number of these facilities are shared by both agencies in areas where protection areas boarder. The percentage of the full sample wildfires within a 1 mile, 5 mile, 10 mile, and 25 mile radius is depicted in Table 4.10, where CALFIRE's suppression resources are often much closer to the ignition point of the wildfire.

Table 4.10 Proximity of Wildfires to Suppression Facilities by Agency

Wildfires within Radius	25mile	10mile	5mile	1mile
Percent USFS	99.56%	75.91%	35.19%	3.52%
Percent CALFIRE	99.83%	89.05%	55.47%	6.14%

Source: Study Area Suppression Facilities

In summary the variables fall in the following categories; the agency dummy variable, economic variables which include property taxes and population density, ignition variables which include wildfire cause and ownership of the ignition point, the elevation and WUI Index of the ignition, and the many dummy variables intended to control for the natural parameters of the fire shed. From the descriptive statistics CALFIRE has a much higher incidence of wildfires within its Protection Areas, but on average these wildfires are of smaller size and duration then that of the USFS.

4.4 Empirical Strategies

In this section the hypotheses of Chapter 3 will be tested against the empirical data of the final dataset. In order to test these predictions I use an OLS regression estimate technique where the dependent variable (y_i) is regressed on the dummy agency parameter (*d_CALFIRE)*[5] with regression coefficients δ, an explanatory set of variables for naturally occurring parameters of the fire shed (X_i) with the regression coefficient vector (B_1), an explanatory set of variables for the economic parameters of the fire shed (Z_i) with the regression coefficient vector (B_2), time variables of the wildfires T_i with coefficient vector B_3 and an error term (u_i). This specified in equation 4.1.

$$\ln(y_i) = \alpha + d_{CALFIRE} \cdot \delta + X_i \cdot B_1 + Z_i \cdot B_2 + T_i \cdot B_3 + G_i \cdot B_4 + U_i$$

(4.1)

Ideally a variable controlling for the level of moisture and the weather at the point of wildfire ignition; a wildfire that ignites in an area with drought like conditions would drastically alter its dynamics more so than the timely arrival of suppression effort. Unfortunately such data could not incorporated as conditionals are not spatially available on a point basis. The semi log model specification in equation 4.1 means the regression coefficients can be mathematically interpreted as showing the percentage change for the dependent variable in terms of a unit change in the independent variable. An OLS regression assumes the residuals are independent. The fact that the data comes from 26 individual counties is cause for concern that this assumption may very well not hold true. For this reason all regressions are estimated with clustered standard errors for each county.

[5] CALFIRE=1 indicates that CALFIRE was the suppressing agency and CALFIRE=0 indicates that the USFS was the suppressing agency.

4.5 Full Sample Regression Results

The regression results from the log models of wildfire size and wildfire duration can be found in Tables 4.11 , 4.12, and 4.13 respectively. Many of the wildfire sizes in the ICS-209 dataset take a value of zero, which is odd as any ignition will burn some amount, however small. For this reason wildfires with a value of zero for size have been rounded to 0.1 acres. The regression results can be found in the two tables below. Due to the different nature of small wildfires and large wildfires in terms of suppression organization on the part of the agency as discussed in Chapter 2, I have used two samples; one sample with wildfires less than one acre in size, and another with wildfires one acres or greater in size.

Table 4.11: Parameter Estimates from Regression Models
Dependent Variable: Duration; Full Sample

Variable	Expected Sign	1	2	3	4	5	6
Intercept		0.4334736	1.6071589	1.2002264	0.5418369	0.2281209	0.3464932
		[1.10]	[5.21***]	[3.84***]	[1.32]	[0.59]	[0.87]
CALFIRE	-	-0.444623	-0.7618667	-0.6951307	-0.4388846	-0.3483778	-0.3410786
		[-3.19***]	[-5.49***]	[-4.60***]	[-3.15***]	[-2.60**]	[-2.53**]
Popdense	-		-5.5503684		-5.152063		-4.9759149
			[-3.02***]		[-2.48**]		[-2.46**]
Property Tax	-		-0.0000001		-0.0000001		-0.0000001
			[-2.73**]		[-1.25]		[-1.45]
D_Natural	+			0.3872834		0.3607609	0.3619307
				[3.07***]		[3.10***]	[3.10***]
Elevation	+	0.0001804			0.0001731	0.000175	0.0001668
		[5.46***]			[5.25***]	[5.60***]	[5.44***]
WUI_Index	+	-0.1483463			-0.1481775	-0.1463876	-0.146124
		[-9.65***]			[-9.81***]	[-9.39***]	[-9.58***]
Observations		22450	22450	22450	22450	22450	22450
F-Value(df)		1335.26 (24)	2041 (24)	2048 (24)	755.48 (24)	4150.5 (24)	466.72 (24)
R-Squared		0.2235	0.2022	0.2075	0.2243	0.2302	0.231

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

Table 4.12: Parameter Estimates from Regression Models
Dependent Variable: Size; Wildfires<1 Acre in Size

Variable	Expected Sign	1	2	3	4	5	6
Intercept		-2.0859107	-2.10	-2.13	-2.08	-2.11	-2.11
		[-41.85***]	[-50.60***]	[-62.32***]	[-36.84***]	[-42.87***]	[-38.08***]
CALFIRE	-	-0.2573372	-0.26	-0.24	-0.26	-0.25	-0.25
		[-12.69***]	[-13.94***]	[-13.59***]	[-12.67***]	[-11.30***]	[-11.33***]
Popdense	-		-1.4663705		-1.4734895		-1.4149753
			[-3.35***]		[-3.38***]		[-3.25***]
Property Tax	-		0.0000001		0.0000001		0.0000001
			[0.66]		[0.34]		[0.01]
D_Natural	+			0.05		0.05	0.0451343
				[2.88***]		[2.94***]	[2.93***]
Elevation	+	-0.000004			-0.0000037	0.00	-0.0000047
		[-0.76]			[-0.68]	[-0.95]	[-0.91]
WUI_Index	+	-0.0024719			-0.002594	-0.002	-0.002246
		[-1.81*]			[-1.88*]	[-1.50]	[-1.56]
Observations		15674	15674	15674	15674	15674	15674
F-Value (df)		93826.3(24)	19251.4(24)	9747.95(24)	5018.63(24)	7812.51(24)	6172.00(24)
R-Squared		0.1527	0.1534	0.1551	0.1536	0.1554	0.1562

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

Table 4.13: Parameter Estimates from Regression Models
Dependent Variable: Size; Wildfires≥1 Acre in Size

Variable	Expected Sign	1	2	3	4	5	6
Intercept		2.62	2.95	2.67	2.79	2.49	2.66
		[4.87***]	[5.10***]	[4.87***]	[5.08***]	[4.73***]	[4.92***]
CALFIRE	-	-0.85	-0.93	-0.88	-0.85	-0.79	-0.79
		[-6.89***]	[-7.09***]	[-6.54***]	[-6.77***]	[-6.19***]	[-6.07***]
Popdense	-		-4.8278986		-4.8149456		-4.8267389
			[-2.27**]		[-2.24**]		[-2.29**]
Property Tax	-		-0.0000001		-0.0000001		-0.0000001
			[-2.69**]		[-2.40**]		[-2.21**]
D_Natural	+			0.19		0.18	0.181367
				[3.06***]		[2.90***]	[2.84***]
Elevation	+	0.0000172			0.0000050	0.0000165	0.0000048
		[0.66]			[0.19]	[0.63]	[0.18]
WUI_Index	+	-0.1359901			-0.1344958	-0.136	-0.1343458
		[-8.65***]			[-8.87***]	[-8.60***]	[-8.80***]
Observations		7200	7200	7200	7200	7200	7200
F-Value (df)		94.68 (24)	49.60 (24)	184.13 (24)	165.7	224.20 (24)	115.85 (24)
R-Squared		0.109	0.09877	0.09896	0.1105	0.1111	0.1125

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

In each regression variables intended to control for the natural parameters of the fire shed are included as discussed previously in Section 4.2. These include control variables for the vegetation type, vegetation size, individual counties, and years. A simple regression is run to test the effect of agency on wildfire size and duration without consideration to the economic and ignition variables to test the prediction regarding impact of agency organization upon wildfire. This can be found in Column 1 of Tables 4.11, 4.12, and 4.13. Variables for the elevation and WUI_Index are also included in this regression. In all three models the agency dummy variable has a negative coefficient, meaning that when CALFIRE is the suppressing agency the duration and size of wildfire decreases. This is found to be significant at the 1 percent level of confidence for all three models. Elevation is found to have a negative coefficient for both categories of wildfire size, however this is not found to be statistically significant. In the model of duration elevation has a positive coefficient and is found to be statistically significant. The WUI_Index a negative coefficient in all three models, which means that a more dangerous the WUI_Index will reduce wildfire size and duration. The WUI_Index is found to be significant at the 1 percent level of confidence for the models of duration and wildfires greater than 1 acres, and significant at the 5 percent level of confidence for the model of wildfire size less than 1 acre.

In Column 2 of Tables 4.11, 4.12, and 4.13 the economic variables of the fire shed are added. This is intended to test the prediction that greater assets at risk within the fire shed will result in reduced wildfire size and duration. With the addition of these variables the coefficient sign remains the same for the agency dummy variable in all three models, and the significance of the variable is also increased. In the model of duration and both models of wildfire size population density has a negative coefficient. This means that as the population density increases wildfire size and duration will decrease. This is found to be significant at the 1 percent level of confidence for all three models. Land values which are approximated through the property tax variable are found to have a negative coefficient for the model of duration and wildfire one acre or greater, but has a positive coefficient for the less than one acre model of wildfire size. This is found to be significant at the 5 percent level for the model of wildfires one acre or greater but is not significant for the other two models. When the variables for elevation and WUI Index are included alongside the economic variables in Column 4 of Tables 4.11, 4.12, and 4.13, the coefficients and significance of the agency and economic variables remain unchanged. WUI Index is found to have a negative coefficient and is significant for the model of duration and both categories of size. Elevation has a positive coefficient for the model of duration and the one acre or greater model of size, however it is only significant for the model duration. For the model of size for wildfires less than one acre elevation was found to have a negative coefficient, but is not significant.

The ignition point variable is added in Column 3 of Tables 4.11, 4.12, and 4.13. This is intended to capture the various effects of the ignition point itself. In all models the dummy variable for naturally occurring wildfire is found to have a positive coefficient and this is found to be significant for all models at the 1 percent level. In both the NIFMID dataset and the ICS-209 data set the cause of a number of wildfires were listed as unknown cause. As previously mentioned wildfires without a known cause were eliminated from the data set. The variables for elevation and WUI Index were added to this model in Column 5 of the above tables. These variables maintain the same effects and significance as when they were added to the models of economic variables in Column 4.

The final model which includes the agency dummy, economic variables, the ignition cause dummy, elevation, and the WUI Index can be found in Column 6 of Tables 4.11, 4.12, and 4.13. In all three models CALFIRE as the suppressing agency is found to have a negative coefficient and is significant at the 1 percent level of confidence, population density is also found to have a negative coefficient and is significant for all three models. The coefficient sign is found to be ambiguous across the three models, and is only significant for the one acre or greater model of size in Table 4.13. A naturally occurring wildfire is found to have a positive coefficient and is also significant at the 1 percent level of confidence for all three models. Similar to Column 4 and 5, the effects of the WUI Index and elevation remain the same for each respective model.

In this next section the same regression techniques and strategies will be used to estimate data from sub-sections of the study area that are intended to create a more natural experiment.

4.6 Klamath Sub-Samples

Using the same method of modeling for the full sample model, regressions were run for a sub-sample within the study area. This was done as a way to create a more natural experiment where the natural parameters of the fire shed are much more similar. As shown in the previous sections the entire study area makes for a poor natural experiment, almost all of the variables were found to be significantly significant via a means test. Sub-samples were selected from counties with approximately similar ratios of CALFIRE and USFS protection area, and wildfires occurring in similar ecosystems near the border of CALFIRE and the USFS protection areas. With these subsamples a more natural experiment can be generated to better test the predictions as discussed in Chapter 3. Wildfires that are within two miles of the border between CALFIREs and the USFS Protection areas within these counties were selected as part of the subsample.

The Klamath sub-sample is centered on the Klamath mountain range in the Northwest section of the study are and consists of Shasta, Siskiyou, and Trinity counties. All of these counties are sparsely populated and the majority of wildfires take place in low or upper montane ecosystems. Figure 4.4 depicts the location of this subsample within the study area and the boundaries of CALFIRE and USFS protection areas within the sub-sample.

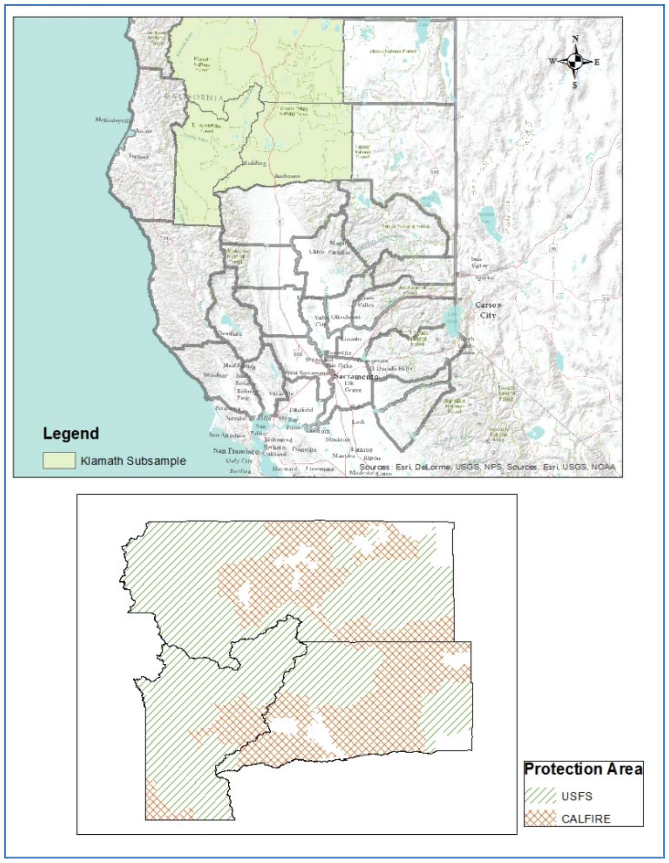

Figure 4.4: Map of Klamath Subsample, with CALFIRE and USFS Protection Areas.

4.7 Klamath Subsample Descriptive Statistics and Regressions

In the Klamath sub sample the protection area of the USFS and CALFIRE border primarily along the Shasta-Trinity National Forest which contains Mt. Shasta. This area is prone to very large wildfires for both CALFIRE and USFS protection areas and is very sparsely populated. Trinity County itself has no incorporated communities whatsoever. In order to generate a better natural experiment I have further limited the subsample to wildfires within montane eco-regions no more than 2 miles from the border between the USFS and CALFIRE. The descriptive statistics of the Klamath sub-sample can be found in Tables 4.14, 4.15, and 4.16.

Table 4.14: Summary of Statistics; Klamath Sub-Sample, N=497

Variable	Mean	Median	Min	Max	Std Dev
Size	26.15	0.1	0.1	2750	210.17
Duration	13.16	1.98	0.1	677.25	45.53
Elevation	3908.95	3553.25	1200	8100	1237.20
Land Value	1524846	1554600	1224800	1977100	272568
WUI_Index	0.4436	0	0	9	1.27
Pop Density	0.016	0.0067	0.003	0.072	0.0217

Source: See Data Generating Process

Table 4.15: Summary of Statistics of Dummy Variables; Klamath Sub-Sample

Dummy Variable	CALFIRE Frequency	USFS Frequency	Percent CALFIRE	Percent USFS
D_Natural	35	138	20.46%	25.60%
D_Human	135	231	78.94%	17.45%
d_CALFIRE	171	228	42.85%	57.14%

Source: See Data Generating Process

Table 4.16: Summary of Statistics by Agency; Klamath Sub-Sample

Variable Name	Mean			Min		Max	
	CALFIRE	USFS	Diff: T-Test	CALFIRE	USFS	CALFIRE	USFS
Size	35.74	18.94	0.79	0.1	0.1	2750	1865
Duration	9.82	15.62	-1.25	0.1	0.1	241	677.3
Elevation	3638.2	4112	***-3.85	1244.5	1200	6721	8100.0
Land Value	1495426	1546913	** -1.87	1224800	1224800	1977100	1977100
WUI_Index	0.9474	0.0658	*** 7.28	0	0	9	6
Pop Density (Per Acre)	0.0164	0.0162	0.09	0.00626	0.00360	0.0719	0.0719

Source: See Data Generating Process

In comparison to the full sample, the duration and size of the wildfires in the Klamath sub-sample are much smaller. The average elevation is much higher than the full sample, population density and lands values are significantly lower. On average the WUI_Index is also much lower as well. There is also much less discrepancy in terms of land values, population density, and elevation between CALFIRE and the USFS in the sub-sample. The difference in population density and land values across the two agencies is almost non-existent and on average elevation only differs between the two by 200 feet on average. While this presents something closer to a natural experiment than the full sample Table 4.16 shows via an equal variance means that elevation, land values, and WUI_Index are still significantly different. It should be noted that the t-values for the Klamath subsample are less robust than those of the full sample. While this is an improvement over the full sample as wildfire size, duration, and population density are no longer found to be different from one another this still does not represent a natural experiment as would be desirable.

Using the same variables as the full sample models, regressions are run on the Klamath sub-sample data. Due to the fact that there are only 3 counties in relatively close proximity, rather than the heterogeneous 26 counties of the full sample the standard errors are not clustered in these regressions. The regressions using the data from the Klamath sub-sample can be found in Table 4.17, Table 4.18 and Table 4.19 below.

Table 4.17: Parameter Estimates from Regression Models

Dependent Variable: Duration; Klamath Sub-Sample

Variable	Expected Sign	1	2	3	4	5	6
Intercept		-0.92	-1.48	0.98	-4.12	-1.04	-4.04
		[-0.78]	[-0.71]	[0.98]	[-1.88*]	[-0.88]	[-1.86**]
CALFIRE	-	-0.14	-0.27	-0.05	-0.13	0.05	0.06
		[-0.66]	[-1.27]	[-0.23]	[-0.59]	[0.23]	[0.25]
Popdense	-		100.86691		145.83		146.64968
			[0.66]		[0.96]		[0.97]
Property Tax	-		1.23E-06		0.00000106		9.37E-07
			[2.03**]		[1.78**]		[1.58]
D_Natural	+			0.69		0.57	0.54584
				[3.23***]		[2.64***]	[2.50***]
Elevation	+	0.00042675			0.00042	0.0003557	0.00035682
		[3.57***]			[3.53***]	[2.93***]	[2.93***]
WUI_Index	+	-0.11609			-0.10629	-0.139	-0.12937
		[-1.10]			[-1.01]	[-1.33]	[-1.23]
Observations		399	399	399	399	399	399
F-Value (df)		2.88 (26)	2.46 (26)	2.84 (25)	2.83 (28)	3.08 (27)	2.99 (29)
R-Squared		0.1675	0.1469	0.1601	0.1765	0.1829	0.1903

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

Table 4.18: Parameter Estimates from Regression Models
Dependent Variable: Size; Klamath Sub-Sample Wildfires≥1 Acres

Variable	Expected Sign	1	2	3	4	5	6
Intercept		7.14	-9.55	5.48	-8.51	6.90	-8.36
		[4.09***]	[-1.13]	[3.83***]	[-1.01]	[3.93***]	[-0.99]
CALFIRE	-	-0.71	-0.73	-0.47	-0.85	-0.49	-0.71
		[-1.42]	[-1.51]	[-0.88]	[-1.74*]	[-0.91]	[-1.34]
Popdense	-		1924.84677		1962.68485		1945.36923
			[1.48]		[1.50]		[1.48]
Property Tax	-		2.57E-06		0.00000313		2.96E-06
			[2.03**]		[2.43**]		[2.25**]
D_Natural	+			0.44		0.55	0.33603
				[0.90]		[1.11]	[0.69]
Elevation	+	-.00039416			0.00	-0.0004347	-.00060283
		[-1.25]			[-1.89**]	[-1.38]	[-1.92**]
WUI_Index	+	-0.12604			-0.08146	-0.144	-0.09326
		[-0.69]			[-0.46]	[-0.79]	[-0.52]
Observations		96	96	96	96	96	96
F-Value (df)		1.61 (20)	1.90 (20)	1.63 (19)	1.94 (22)	1.59 (21)	1.86 (23)
R-Squared		0.3001	0.3368	0.2892	0.3689	0.3115	0.373

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

Table 4.19: Parameter Estimates from Regression Models
Dependent Variable: Size; Klamath Sub-Sample Wildfires<1 Acres

Variable	Expected Sign	1	2	3	4	5	6
Intercept		-2.79	-3.10	-2.97	-3.00	-2.81	-2.97
		[-8.35***]	[-5.45***]	[-10.77***]	[-4.92***]	[-8.45***]	[-4.90***]
CALFIRE	-	-0.34	-0.34	-0.29	-0.34	-0.29	-0.29
		[-5.08***]	[-5.26***]	[-4.37***]	[-5.07***]	[-4.12***]	[-4.15***]
Popdense	-		-25.73116		-27.14576		-26.38448
			[-0.63]		[-0.66]		[-0.65]
Property Tax	-		2.93E-07		0.000000295		2.63E-07
			[1.67*]		[1.67*]		[1.50]
D_Natural	+			0.14		0.16	0.14788
				[2.23**]		[2.41**]	[2.28**]
Elevation	+	-0.0000123			-0.0000155	-0.0000333	-0.0000352
		[-0.36]			[-0.45]	[-0.94]	[-1.00]
WUI_Index	+	-0.00387			-0.00158	-0.011	-0.00856
		[-0.11]			[-0.05]	[-0.33]	[-0.25]
Observations		303	303	303	303	303	303
F-Value (df)		2.87 (25)	3.02 (25)	3.25 (24)	2.79 (27)	3.03 (26)	2.92 (28)
R-Squared		0.2056	0.2144	0.2191	0.2149	0.222	0.2295

* Indicates Significant at the 10% Level of Confidence, ** Indicates Significant at the 5% Level of Confidence, *** Indicates Significant at the 1% Level of Confidence.

The models of wildfire size for the sub-sample mirror the findings of the full sample regressions. This is true for both the model of wildfires greater or equal to one acre in Table 4.17 and wildfires less than one acre in Table 4.19. The agency dummy is found to have a negative coefficient and is found to significant at the 1 percent level for both models. In the case of one acre or larger wildfires the magnitude of the coefficient is much larger than the economic variables are once again ambiguous in a similar fashion to the full sample. Population density is found to be significant at the 1 percent level of confidence and have a negative coefficient. Land values approximated through property taxes have a positive coefficient and are not found to be significant for either model of size. In the next section I will summarize the findings and results of the empirical analysis.

4.8 Summary of Empirical Results

The empirical results support one of the two predictions that were outlined in Chapter 3. Prediction 2, the agency that possesses greater assets in proximity to the wildfire will reduce wildfire size and duration regardless of the natural parameters of the fire shed. In the duration model, both models of size for the full sample and the Klamath sub-sample this was found to hold true. When CALFIRE was the suppressing agency the size and duration of the wildfire was reduced. The results provide an ambiguous answer to Prediction 1; that greater economic assets at risk within the fire shed will result in reduced wildfire size and duration, as wildfire agencies will place great emphasis on protecting these areas. The results from the regressions were inconsistent; for the most part increased population density was found to decrease wildfire size and duration and was significant at the 1 percent level of confidence. Property taxes on the other hand, had no consistent coefficient, and were not found to be statistically significant. One possible explanation for this could be that population densities negative coefficient is the result of greater wildfire detection; a wildfire occurring in an area where the likelihood of it being discovered and reported to wildfire agencies quickly would reduce the size and duration of the wildfire as discussed previously in Chapter 3.

The empirical results also offer a number of insights that are not directly connected to the predictions. One is the dummy variable representing naturally occurring wildfire. This was included to control for the impact of ignition cause on wildfire outcomes. In the full sample model of duration this variable was found to have a positive coefficient and was statistically significant at the 1 percent level of confidence. The fact a naturally occurring wildfires increases duration may be the result of the fact that the vast majority of these natural wildfires are the result of dry lightning strikes. Unlike human caused wildfires which are most likely to occur in areas where there is human activity, naturally occurring wildfires may be much more spatially random as to where they occur. The fact that the location of these wildfires may be more random, and therefore can ignite in areas far away from detection and suppression resources may be reason behind why this category of ignition increases wildfire size and duration. Another interesting insight from the empirical results is the coefficient of the WUI_Index and WUI_Elevation variables, which is the case for both models and size and the model of duration in both the full sample and the Klamath sub-sample. This appears counter intuitive as one would assume that as the risk of loss from the WUI_Index increases the size and duration of wildfire would also increase, however, the WUI indicates housing density with respect to vegetation density. This means that this variable could be serving as an indicate of assets at risk within the fire shed in a more concise manner the property tax variable. Greater housing density within areas of dense vegetation would in effect present greater risk to assets within the fire shed, which Prediction 1 stated would reduce wildfire size and duration.

Chapter 5: Conclusion

The purpose of this study was to pick up where previous fire economics research had left off. While past research based upon the LCPL model of wildfire has given consideration at assets at risk and the cost and benefits of wildfire suppression past studies did not take into account a number of important factors; the dynamics of wildfire, ownership of the fire shed, and institutional differences between wildfire suppression agencies, the importance of which is critical to understanding the costs and benefits of wildfire suppression. As discussed by Lueck and Yoder (2012), the dynamics of wildfire makes the timely arrival of suppression resources of the upmost importance in reducing the size and duration of wildfires. In turn, the timely arrival of adequate suppression resources is dependent upon the structure of the suppression organization itself, as well as the natural parameters of the fire shed itself. Using the LCPL model as a basis I also included the manner in which wildfire suppression agencies could influence the net benefits resulting from wildfire.

The 26 counties of Northern California were selected as the study area because at face value they offered what appeared to be an excellent natural experiment. The protection areas for CALFIRE and the USFS crossed throughout these counties with many shared borders. Ideally these shared borders would contain wildfires in areas of similar vegetation, elevation, and assets at risk thus leaving the suppressing agencies as the only difference between them; therefore offering an excellent natural experiment to test the impact of agency differences upon wildfire size and duration. Using data from the CALFIRE ICS-209 incident reporting form, and the NIFMID reporting form employed by federal land management agencies I generated a dataset of 23,000 wildfires spanning from 2001 to 2011. Using a semi-log model I tested the impact of agency and the value of assets within the fire shed on the size and duration of wildfire while also controlling for the vegetation, year, ignition cause, and county effects. This was done for all the wildfires within the study area, and again for a sub-sample of wildfires near the border within a three county area. I found that the agency itself does indeed have a negative impact on wildfire size and duration and this was found to be significant. The effect of valuable assets within the fire shed on wildfire was more mixed. While higher population density has a negative impact on duration and size and was found to be significant, property taxes as proxy for land values had no consistent coefficient and were not found to be significant. The WUI_Index however had a negative coefficient and was found to be significant, this variable may actually act as a better proxy for assets at risk within the fire shed than property taxes.

While this study offers insight as to how institutional differences across wildfire suppression agencies impacts wildfire size and duration, there are a number of short comings to discuss. First; the empirical investigation is a one snapshot picture of wildfire dynamics in terms of time. This ignores the impact of fire prevention and mitigation efforts on the part of the wildfire agencies. The effort dedicated to such activities in the present state would help to reduce wildfire size and duration in future time periods. Second; some data used in the empirical models is less than ideal. For example the property taxes collected from the Census Tract were the wildfire ignition took place was used to approximate the land values of the fire shed. Finally the study area or the sub-section did not present an ideal natural experiment. For the most part equal variance means tests for a number of variables such as elevation and economic variables shows that are significantly different across wildfire agencies, this fact presents a major hurtle in comparing the institutional effects of wildfire agencies.

To an extent this study answers the research questions outlined in the predictions. Prediction 1; that greater assets at risk within the risk shed such as population density and land values was left unanswered. Prediction 3; that agencies organized for quick response to wildfires will reduce wildfire size and duration was found to hold true. Regardless of the outcome of testing the predictions the most important implication is the foundation this study lays to pursue future work of a similar manner. The process generating the data set with which to test the predictions was a very difficult one. Now that this process has been established the same study could possibly be conducted perhaps using more representative variables and a sample of wildfire which presents a better natural experiment.

Appendix

INDIVIDUAL WILDLAND FIRE REPORT
(Ref. FSH 5109.14)

1. Fire Name	2. Local Fire Number (Local use only)

3. Location	4. Township	Range	Section	Sub-section	Principal Meridian

IDENTIFICATION

5. Region	6. Forest	7. District	8. Fire Number	9. Protecting Agency at Origin	10. Ownership at Origin	11. State at Origin	12. County at Origin	13. Fire Mgnt Zone

OCCURRENCE

14. Point of Origin		15. Time of Ignition				16. Time of Discovery			
Latitude	Longitude	Mo.	Day	Year	HHMM	Mo.	Day	Year	HHMM

17. Detection Method	18. Statistical Cause	19. General Cause	20. Specific Cause	21. Class of People

ACTION

22. Initial Strategy: ☐ Suppression ☐ Wildland fire used for resource benefits.

23. Escaped Fire: ☐

24. Time of Initial Action				25. Time Final Suppression Strategy Attained				26. Time Fire Out			
Mo.	Day	Year	HHMM	Mo.	Day	Year	HHMM	Mo.	Day	Year	HHMM

27. Forces Used: Up to Time of Attainment of Initial Strategy or Escape

Resource Type	Agency Group (F or C)	Quantity	Resource Type	Agency Group (F or C)	Quantity	Resource Type	Agency Group (F or C)	Quantity
______ /	______ /	______	______ /	______ /	______	______ /	______ /	______
______ /	______ /	______	______ /	______ /	______	______ /	______ /	______
______ /	______ /	______	______ /	______ /	______	______ /	______ /	______
______ /	______ /	______	______ /	______ /	______	______ /	______ /	______
______ /	______ /	______	______ /	______ /	______	______ /	______ /	______

DESCRIPTION

28. Estimated FS FFF Cost (whole dollars)	29. FS Acres (All Forests)	30. Non-FS Acres Protected by FS	31. Non-FS Acres Not Prot by FS	**Total Acres**	32. Acres Managed for Resource Benefit
	.	.	.	.	.

33. FMZ NVC/ Acre ($)	34. Fire Intensity Level	35. Rep Weather Station	36. NFDRS Fuel Model	37. Cover Class	38. Slope Pct	39. Aspect	40. Elevation (feet)

OPTIONS

41. Special Codes ______/______ ______/______ ______/______ ______/______ ______/______ ______/______
______/______ ______/______ ______/______ ______/______ ______/______ ______/______

43. Submitted by:	44. Date	45. Approved by:	46. Date

SUPPLEMENT FOR LARGE FIRE ACRES BURNED

47. Prot Agency	48. FS Unit	49. Land Ownership	50. Acres	47. Prot Agency	48. FS Unit	49. Land Ownership	50. Acres
______	______ / ______	______	______ . ____	______	______ / ______	______	______ . ____
______	______ / ______	______	______ . ____	______	______ / ______	______	______ . ____
______	______ / ______	______	______ . ____	______	______	______	______ . ____

Figure 1A: NIFMID Individual Fire Report
Source: United State Forest Service

Incident Status Summary (ICS-209)

1: Date	2: Time	3: Initial | Update | Final	4: Incident Number	5: Incident Name

6: Incident Kind/Strategy	7: Start Date Time	8: Cause	9: Incident Commander	10: Incident Command Organization	11: State-Unit

12: County	13: Latitude and Longitude Lat: Long: Ownership at Origin:	14: Short Location Description (in reference to nearest town):

15: Size/Area Involved	16: % Contained or MMA	17: Expected Containment Date:	18: Line to Build	19: Estimated Costs to Date	20: Declared Controlled Date: Time:

21: Injuries this Reporting Period:	22: Injuries to Date:	23: Fatalities	24: Structure Information			
			Type of Structure	# Threatened	# Damaged	# Destroyed
25: Threat to Human Life/Safety: Evacuation(s) in progress ---- No evacuation(s) imminent -- Potential future threat -------- No likely threat ---------------			Residence			
			Commercial Property			
			Outbuilding/Other			

26: Projected incident movement/spread in 12, 24, 48 and 72 hour time frames:

27: Values at Risk: include communities, critical infrastructure, natural and cultural resources in 12, 24, 48 and 72 hour time frames:

28: Critical Resource Needs (amount, type, kind, and number of operational periods in priority order in 12, 24, 48 and 72 hour time frames): **ex. 3 CRW1 (4); 1 HEL1 (5);**

29: Major problems and concerns (control problems, social/political/economic concerns or impacts, etc.) Relate critical resources needs identified above to the Incident Action Plan.

30: Observed Weather for current operational period:
Wind Direction: Wind Speed (mph): Peak Gusts:
Max. Temperature: Min. Relative Humidity:

31: Fuels/Materials Involved: A drop down box with the 13 Fire Behavior Fuel Models has been added. The incident would select the predominant fuel model with the option to include additional fuels information in the text box.

32: Today's observed fire behavior (leave blank for non-fire events):

33: Significant events today (closures, evacuations, significant progress made, etc.)

34: Forecasted Weather for next operational period:
Wind Speed (mph): Temperature:
Wind Direction: Relative Humidity:

35: Estimated Control Date and Time:	36: Projected Final Size:	37: Estimated Final Cost:

38: Actions planned for next operational period:

39: For fire incidents, describe resistance to control in terms of:

1. Growth Potential -
2. Difficulty of Terrain -

40: Given the current constraints, when will the chosen management strategy succeed?

41: Projected demobilization start date:

42: Remarks:

43: Committed Resources

Agency	CRW1		CRW2		HEL1	HEL2	HEL3	ENGS		DOZR		WTDR	OVHD	Camp Crews	Total Personnel
	SR	ST	SR	ST	SR	SR	SR	SR	ST	SR	ST	SR	SR		
Total															

44: Cooperating and Assisting Agencies Not Listed Above:

Figure 2A: ICS-209 Status Summary

Source: CALFIRE Office of the State Fire Marshall

Table 1A: Linking Variables to ICS and USFS Reporting Forms

Variable	NIFMID Q#	ICS-209 Q#	Variable Units/Definition
Fire Name	5	1	N/A
Discovery Date	7	16	Calendar Date
Alarm Time	7	16	Hours/Min
Control Date	20	25	Calendar Date
Control Time	20	25	Hours/Min
Cause	8	18, 19, 20	Categorical
Point of Origin	13	14	Longitude, Latitude
Ownership	13	10	Categorical
County	12	12	County Name
Fire Size Total	15	29-31	Acres
Township	14	4	Nearest Town Name
INITIAL_SUPPRESSION_STRATEGY	N/A	22	Binary
Protecting Agency at Orgin	13	9	Categorical
VEGETATION_COVER_TYPE	N/A	37	Categorical
NFDRS_FUEL_MODEL	N/A	36	Categorical
NF Acres	N/A	29	Acres
Non-FS Acres Protected by FS	N/A	30	Acres
Non-FS Acres Not Protected by FS	N/A	31	Acres
FIRE_INTENSITY_LEVEL	N/A	34	Categorical
SLOPE_PERCENT	N/A	38	Percentage
ELEVATION	N/A	40	Feet
ASPECT_CLASS	N/A	39	Categorical
ESCAPED_FIRE	N/A	23	Binary
Suppression Cost	28	37	Dollars
Region	N/A	5	Number
Forest	N/A	6	Number
District	N/A	7	Number
PRINCIPAL_MERIDIAN	N/A	4	Categorical
RANGE	N/A	4	Categorical
Section	N/A	4	Number
REP_WEATHSTA_NUMBER	N/A	35	Number
CLASS_OF_PEOPLE	N/A	21	Categorical
SUM_DAMAGES	24	N/A	Dollars

Source: See Data Generating Process

Dataset Generating Process

My final dataset described in Chapter 4 comprises slightly less than 30,000 fires with the 26 selected counties. To generate the final dataset set the following smaller datasets were used in GIS;

1. **Selected County Area.** This dataset contains the 26 selected counties. Variables include the county name, area, and perimeter of each county. This data set was downloaded from FRAP and originally entitled *California Counties*

2. **ICS-209 Wildfire**. This dataset contains information on wildfires recorded by CALFIRE using the ICS-209 reporting process, and consists of 20,378 CALFIRE wildfires and 242 USFS wildfires. This data set included 6 variables for the date and time of discovery, containment, and control of the wildfire, a variable for the fire name, one for longitude and latitude, acres burned, ignition cause and protection area. This date set was acquired from CALFIRES Fire and Resource Assessment Program (FRAP). While this data set contains data for the area and perimeter is does not display such information in GIS. Therefore any connections between this data set and other datasets will be on the basis of the wildfire ignition point, rather than the entire wildfire. The variables for this data set were taken from the ICS-209 forms used by fire bosses to record individual wildfire data for CALFIRE. A blank copy of this form can be found in Figure 3A of the appendix.

3. **NIFMID Wildfire.** This dataset contains ignition points of wildfires recorded by the USFS using the NIFMID reporting process, and consists of 8,888 USFS wildfires and 325 CALFIRE wildfires. This data set included 5 variables for location, 4 separate categories for acres burned, 10 duration variables, 2 variables for slope and elevation, 3 for suppression strategies, and wildfire name and protection area. This dataset was acquired from Kansas City Fire Access Software, an online program from which researchers can acquire wildfire data compiled by the USFS. Similar to the ICS-209 Wildfire dataset this is also based on point data and any connections with other datasets will be on the basis of the ignition point, not the entire fire. . The

variables for this data set were taken from the NIFMID form used by fire bosses to record individual wildfire data for the USFS. A blank copy of this form can be found in Figure 2A of the appendix.

4. **Vegetation Type and Size.** This dataset contains a categorical variable for the types of vegetation found within the selected 26 counties. In addition to this categorical variables for vegetation size are also included. This dataset was downloaded from FRAP and originally titled *Fire Regime and Condition Class.* This was originally a raster dataset that was converted to a vector data set so it could be used for geospatial analysis.

5. **Wildlife Urban Interface.** This dataset contains variables for the categories of Wildlife Urban Interface (WUI) within the study area from the year 1990 and 2000, and also included variables for the perimeter and area of WUI areas within the selected 26 counties.

6. **California Economic Variables.** This dataset contains each census tract within the 26 selected counties. Within these census tracts a variable for aggregate property taxes collected was generated and included. The census tracts themselves were downloaded from the Census Bureau's MAF/TIGER database. The economic data per census tract was then downloaded through the Census Bureau's American Factfinder web program.

7. **Land Ownership.** This dataset details the land ownership across the selected 26 counties. Examples of ownership include federal agencies, state agencies, non-profit organizations, and private land holders. The dataset was downloaded through FRAP and originally titled as *California Land Use*.

8. **Elevation.** As the NIFMID data set contained variables for elevation and the ICS-209 data set does not, this data needed to be added to the ICS-209 dataset so it could ultimately be merged with the NIFMID dataset. This dataset was downloaded from the United States Geological Survey.

Using the above GIS datasets a number of geoprocessing actions were performed using AcrGIS 10.1 software. All of the above data sets are Feature Classes; meaning that they are homogenous collections of common features each having the same spatial representation. The intersect process is used frequently in the unification of all variables into a single data set. The intersect process in ArcGis essentially acts as a horizontal merging process between to data sets based upon their spatial relation. For example consider the NIFMID ignition point data set. If we were to merge it with the Vegetation Type and Size dataset, a new feature class would be generated containing the original NIFMID data with additional columns containing relative vegetation data for each ignition point.

A GIS data set can consist of either vector data or raster data. Vector data consists of discrete continuous points, lines, and polygons and thus allow for geoprocessing and spatial analysis. Raster data on the other hand consist of discontinuous pixels to represent data. For example many satellite images are formatted as raster data. In order for any empirical analysis to be possible raster data must be converted into vector data. This process was necessary for the Vegetation Type and Size data set to be of any use

The ultimate goal of this process is to add the desired variables to the NIFMID and ICS-209 sets and merge them into one final dataset for analysis. However there exist many incongruences between these two datasets. As a result each geo-process had to be performed separately on each ignition point data set. This is due to several reasons; a number of variables shared between both datasets use different systems of categories to express similar values. For example both ICS-209 and NIFMID contain a variable for wildfire cause; but the ICS-209 only lists 9 types of causes while the NIFMID lists 36. Thus dummies to bridge these two sets would have to be generated in SAS later. In addition to this the ICS-209 dataset and the NIFMID dataset use different coordinate systems; the ICS-209 uses the GCS North American 1983 coordinate system while the NIFMID uses the GCS WGS 1984 coordinate system. In order to preserve the spatial accuracy of these datasets each geoprocessing action had to be performed on each separately. Otherwise the resulting variables would not be accurate.

In generating the final data set multiple layers of GIS where incorporated. An outline of the process can be found in the accompanying Figure 3A. First, the 26 selected counties where created as a separate feature class file. These counties where then intersected with the ICS-209 Wildfire dataset, and the NIFMID data set. This process added a variable for each wildfire point indicating which county it had taken place in. As described raster data set of vegetation type and vegetation size was downloaded from FRAP and converted into individual polygons for vegetation type and size. These polygons where then intersected with the ignition point datasets to add variables indicating the vegetation in the immediate area of the wildfire ignition point.

A feature class of land ownership was acquired from CALFIRE Fire Resource Assessment Program (FRAP). This feature class was then intersected with both ignition point data sets. The resulting ignition point data sets now also include a variable indicating who owned the land of the wildfire ignition point. Some examples include the various Department of the Interior land management agencies, the USFS, the State of California, or private landholders.

As the original ICS-209 Wildfire dataset lacked data for the elevation of the wildfire, a feature class of elevation was downloaded from the U.S. geological survey. However this data set does not represent the exact elevation of the ignition point, the elevation feature class consisted of the average elevation in an area of 1/9 of a second of longitude by 1/9 of a second of latitude. This data was then intersected with the CALFIRE ignition point data set to add an elevation variable. This process was not necessary for the NIFMID dataset as it already contained a variable for elevation.

Wildlife Urban Interface (WUI) classification was also added to each ignition point data set. WUI helps to classify areas where fire prone vegetation densities and human activities mix. The WUI dataset was downloaded from the Silvis Laboratory based in Madison WI. The WUI dataset was then intersected with both ignition point datasets in order to generate a WUI classification variable for each wildfire ignition point.

The economic variables were added using the census tract level of the ignition rather than the county level to more accurately reflect the values at risk from wildfire within the fire shed. For this purpose feature classes for each census tract were downloaded from the U.S. Census and the property taxes collected and population were manually entered into the census tract dataset and then intersected with each ignition point data set in order to add these variables. In addition to this further economic data was added by intersecting both ignition point datasets with the landownership data sets.

Through these GIS geo-processes the following variables were added to both ignition points data sets; the county of the ignition, the immediate vegetation type and size, ownership of the ignition point, census tract, population, and property taxes collected. In addition to this elevation was data was also added to the CALFIRE data set. Both datasets where then exported into SAS where various dummies were generated to make the two sets compatible in terms of all variables, these variables are described in Chapter 4.1. Once completely compatible these two datasets where merged in SAS with total of 29,883 variables. The final step of the process was completed in SAS because of the many incongruent categorical variables, and ArcMap cannot generate binary variables to compensate for this. The differences in coordinate systems between the NIFMID and ICS-209 datasets were another reason to complete the GIS geoprocessing prior to joining them into the final dataset.

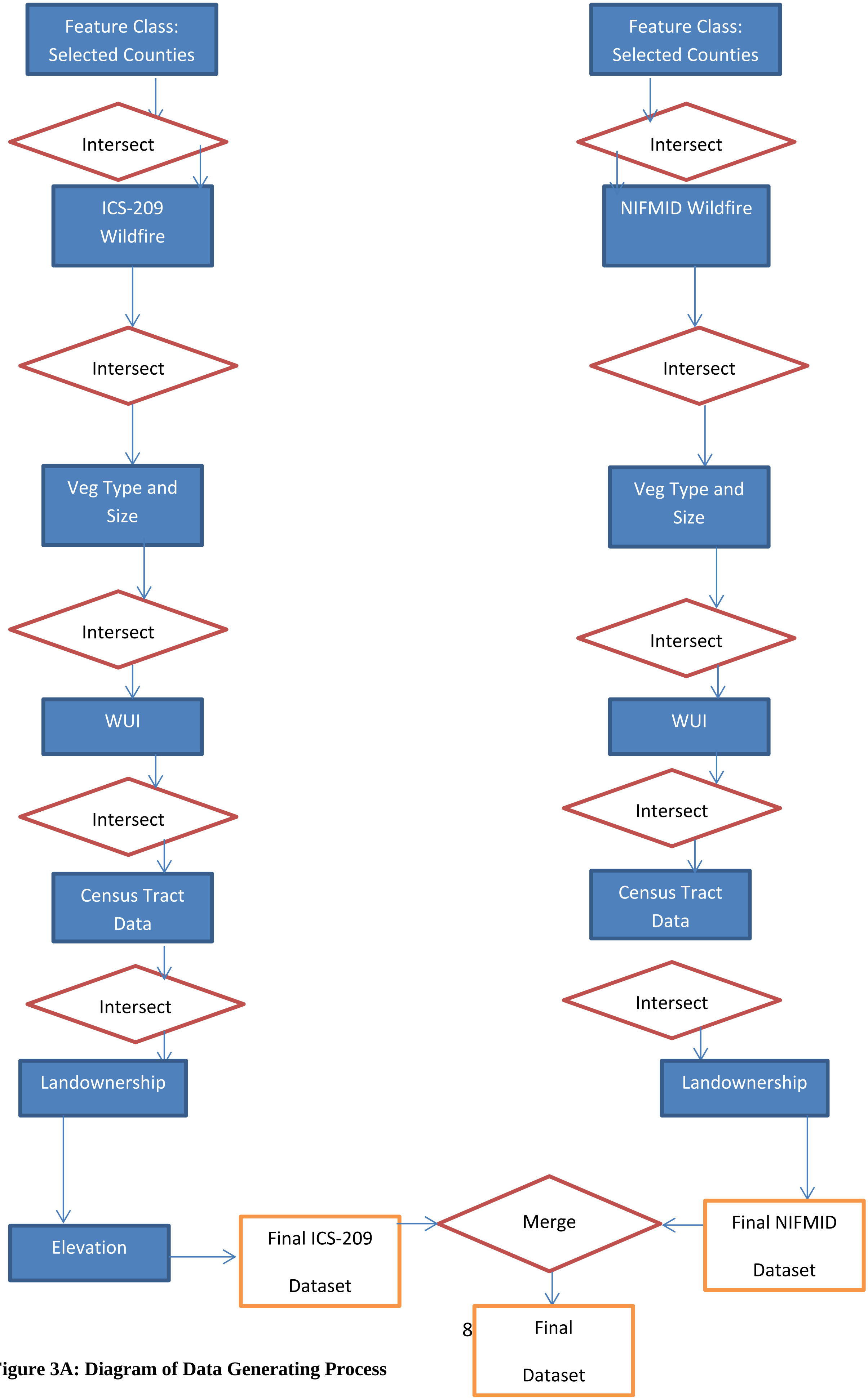

Figure 3A: Diagram of Data Generating Process

Table 2A: County Descriptions of Wildfire Size and Duration by Agency

Agency	Acres	Percent Acres	Fires	Fires per Acre	Average Size	Average Duration
Amador	Grasslands, Oak forest, Conifer; Ponderosa, White fir. (SE)					
CALIFRE	294567	75.95	666	0.00226	8.06*	1.71
USFS	85519	22.05	160	0.00187	86.45*	2.16
Butte	Agriculture, Urban; Ponderosa, White fir; Red fir, Jeffery Pine, Aspen. (CC)					
CALIFRE	562019	52.37	1693	0.00301	26.8***	0.12*
USFS	127899	11.92	100	0.00078	86.2***	9.15*
Calaveras	Grassland, Ponderosa, White fir; Red fir, Jeffery Pine, Aspen. (SE)					
CALIFRE	623217	94.02	1378	0.00221	13.83	5.51
USFS	36716	5.54	65	0.00177	7.88	3.09
Colusa	Agriculture, Urban; Grassland; Oak forest, Conifer. (SC)					
CALIFRE	292383	39.49	109	0.00037	16.69**	0.18***
USFS	73207	9.89	20	0.00027	1255.33**	3.2***
Del Norte	Ponderosa, White fir, Oak forest, Conifer. (NW)					
CALIFRE	188372	29.03	258	0.00137	2.28*	0.17***
USFS	442127	68.14	202	0.00046	237.18*	2.08***
El Dorado	White fir, Red fir, Jeffery Pine, Aspen. (SE)					
CALIFRE	460120	40.19	1912	0.00416	2.56**	0.57
USFS	665858	58.16	1032	0.001550	9.76**	2.47
Glenn	Agriculture, Urban; Grassland, Ponderosa, White fir. (CC)					
CALIFRE	314142	37.00	64	0.00020	20.31	0.09***
USFS	222248	26.17	75	0.000337	486.79	4.31***
Humboldt	Grasslands, Costal. (NW)					
CALIFRE	1670111	72.82	1161	0.00070	31.29	0.6***
USFS	378592	16.51	331	0.00087	73.98	3.05***
Lake	Ponderosa, White fir, Oak forest, conifer, Agriculture, Urban. (SW)					
CALIFRE	482072	56.66	772	0.00160	45.98	0.15***
USFS	291952	34.31	91	0.00031	81.87	1.74***
Lassen	Lowlands, Red fir, Jeffery Pine, Aspen, Ponderosa, White fir. (NE)					
CALIFRE	961237	31.81	784	0.00082	40.18	0.63***
USFS	520857	17.24	352	0.00068	109.40	1.85***
Mendocino						
CALIFRE	1995647	88.77	1715	0.00086	34.05***	22.00
USFS	197773.4	8.80	42	0.00021	350.19***	4.98
Modoc	Lowlands, Red fir, Jeffery Pine, Aspen, Ponderosa, White fir. (NE)					
CALIFRE	517171	19.23	391	0.00076	8.38	0.79
USFS	1523514	56.64	885	0.00058	29.55	3.12
Nevada	Ponderosa, White fir, Red fir, Jeffery Pine, Aspen, Oak forest, Conifer. (CE)					
CALIFRE	337724	54.14	1074	0.00318	7.01	0.06***
USFS	261743	41.96	306	0.00117	12.45	2.48***
Placer	Ponderosa, White fir, Red fir, Jeffery Pine, Aspen, Grassland. (SE)					
CALIFRE	321954	33.54	1342	0.00417	4.13***	0.08***

USFS	495657	51.63	420	0.00085	95.78***	3.51***
Plumas	Red fir, Jeffery Pine, Aspen, Ponderosa, White fir, Lowlands. (CE)					
CALIFRE	119845	7.16	139	0.00116	376.14	0.27
USFS	1489516	89.05	1296	0.00087	103.66	3.68
Shasta	Ponderosa, White fir, Oak forest, Conifer Red fir, Jeffery Pine, Aspen. (NC)					
CALIFRE	1421196	57.65	1896	0.00133	33.14	0.43
USFS	819212	33.23	604	0.00074	56.09	2.06
Sierra	Red fir, Jeffery Pine, Aspen, Ponderosa, White fir, Lowlands. (CE)					
CALIFRE	29	0	0	0	0	0
USFS	587251	95.44	390	0.00066	12.07	1.54
Siskiyou	Ponderosa, White fir, Red fir, Jeffery Pine, Aspen, Grasslands. (NC)					
CALIFRE	1259860	31.01	1139	0.00090	11.46**	0.36***
USFS	2522194	62.09	1485	0.00059	193.75**	3.1***
Tehama	Oak forest, Conifer, Grassland, Ponderosa, White fir. (CC)					
CALIFRE	1226222	64.78	1088	0.00089	25.02***	0.01***
USFS	500426	26.44	145	0.00029	262.36***	5.38***
Trinity	Ponderosa, White fir, Oak forest, Conifer, Grassland. (NW)					
CALIFRE	350033	17.05	296	0.00085	30.09*	0.16***
USFS	1702703	82.95	1049	0.00062	347.99*	4.52***
Yuba	Agriculture, Urban, Ponderosa, White fir, Grassland. (CC)					
CALIFRE	194024	47.09	85	0.00044	13.95	0.08***
USFS	70227	17.04	586	0.00834	7.12	1.8***

Note: As Sacramento, Sierra, Sonoma, Sutter and Yolo Counties lack one protection area of one of the two agencies a means test was not performed for them. The location of the county in the study area is abbreviated in terms of cardinal directions.

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