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Title: Do fuel treatment costs affect wildfire suppression costs and property damages?
An analysis of costs, damages avoided and return on investment

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Do fuel treatment costs affect wildfire suppression costs and property damages?
An analysis of costs, damages avoided and return on investment

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ABSTRACT

Spatial wildfire suppression costs regressions have been re-estimated at a more disaggregated level for the nine Geographic Area Coordination Center (GACC's) regions using five years of data for fires involving National Forests. Results of these revised regression determined that only in the California GACCs did mechanical fuel treatment reduce wildfire suppression costs. However, the results of our second major hypothesis tests that fuel treatments, by making wildfires less damaging and easier to control, may reduce property damages (i.e., structures—barns, out buildings, etc. and residences lost) seems to be confirmed for acres treated with prescribed burning. In four out of the seven geographic (GACC) regions prescribed burning lowered the number of structures damaged by wildfire. The results for mechanical fuel treatment were more mixed, with a significant negative effect in reducing property damages in two of the three regions with a significant coefficient on mechanical fuel treatment. These results are consistent with past research that suggests that for fuel treatments to reduce wildfire suppression costs it may be necessary to substantially increase the amount of area treated. Further, our results also bring forth another hypothesis that perhaps fuel treatment efforts may reduce the likelihood of large wildfires. This possibility is related to another new hypothesis that our research generated: fuel treatments may reduce the likelihood that small fires will grow into larger more expensive fires to control. If this is the case there is likely to be a substantial cost savings arising from fuel treatments in reducing the number of large fires.

The results of our analysis "Do forest fuel reduction treatments reduce wildfire suppression costs and property damages? A multi-regional nationwide analysis of determinants of USDA Forest Service wildfire suppression costs and wildfire property damages" was presented at the V International Symposium on Fire Economics, Planning and Policy: Wildfires and Ecosystem Services by Armando González-Cabán.

After presenting preliminary results at the V International symposium on Fire Economics, Planning and Policy: Wildfires and Ecosystem Services we received numerous helpful suggestions. As a result we greatly expanded the literature review and refined the regression model specification as suggested by the comments we received. The resulting paper was presented at the Western Agricultural Economics Association on July 10, 2017. After receiving those comments, a final journal manuscript on the results of the tests of whether fuel treatments reduce suppression

costs and property damages was submitted to the *Forest Policy and Economics.*

Keywords: Geospatial regression analysis, hazardous fuel reduction, mechanical fuel treatment, multiple regression analysis, OLS, prescribed burning, wildland-urban interface,

Table of Contents

Chapter I. Introduction

The costs of wildfire management have escalated in the past decades, largely due to increased expenditures for suppressing large wildfires and fires in the wildland-urban interface. Frequent siege-like fire (most recently being called mega fires) incidents have enormous costs in loss of life, property, natural resources and wellbeing. For example, during the last decade the USDA Forest Service (FS) alone has incurred fire suppression costs of over $19 billion fighting wildfires that have burned more than 39 million ha of forest and brush lands (NIFC 2014). Furthermore, in the period from 1999 to 2010 more than 1100 homes were burned annually and a total of 230 lives lost (Gude et al. 2013). Additionally, there is growing recognition of the futility of fighting fires in ecosystems where prior fire exclusion policies have led to dangerous fuel accumulations.

The economic consequences of alternative management strategies are not well understood. Cost-effectiveness comparison between prescribed fire and mechanical fuel treatments fire suppression expenditures are poorly understood. Current analysis tools for justifying budgets and displaying tradeoffs rarely incorporate consideration of all relevant contributors to fire management costs and net value changes.

1. Project Purposes in Relation to Updated Literature Review

Wildfire suppression costs and fuel treatment costs are two of the most important components in fire management operations. One of the significant problems in studying fuel treatment costs and its relationship with fire suppression costs is the difficulty in trying to establish the productivity of fuel treatments in term of reductions in suppression costs and losses. That is, analytically, the main problem is how to determine a production function for fuel treatments (Omi 2008).

The first purpose of this research project is an analysis and statistical model of the costs of different types of fuel treatments. The importance of estimating the costs of fuel treatment for budgeting and other fire planning purposes has received only limited attention over the past two decades. Rideout and Omi (1995) were one of the first to perform a statistical analysis of the factors influencing fuel treatment costs. Their model used regional dummy variables and included dummy variables for type of fuel treatment (e.g., mechanical, chemical). In 1997, González-Cabán performed an analysis of variance of factors influencing prescribed burning costs in three USDA Forest Services regions. Twelve years later, Hartsough et al. (2008) conducted an analysis using seven western U.S. states. They compared net costs of mechanical fuel reduction (cost net of sale of any wood products) to costs of prescribed burning, and combinations of thinning with prescribed burning. One of the last literature reviews of the cost of fuel reduction treatments in 2008 by Rummer concludes "…there is a questionable basis for many of the general estimates used to date". He cautioned against relying on existing cost literature to estimate costs of future fuel treatments. There is an obvious need to update the analysis of factors influencing fuel treatment costs.

A second purpose of this project is to determine if fuel treatments reduce wildfire suppression costs. The third hypothesis is whether fuel treatments reduce property damages. These two effects provide the means to estimate the return on investment of fuel treatments.

The first step in our analysis process is to understand wildfire suppression costs and the factors affecting it. One of the first empirical studies attempting this was by McKetta and González-Cabán in 1985. They presented descriptive statistics on estimates of these costs for various modes of suppression (e.g., handcrews vs. helitack, engines, etc.). However it is important to go beyond just statistically summarizing the costs, and move toward an explanatory analysis of what factors determines the wide range of costs of suppression observed. A statistical model was developed that provides an understanding of the factors that influence suppression costs and statistically test whether fuel treatment influences suppression costs.

By and large the three most common reasons for explaining the current increase in wildfire damages and suppression costs are: 1) fuels build up resulting in part from past fire suppression policies, 2) warmer temperatures and drought conditions, and 3) expansion of the WUI into fire-prone landscapes.

A study of suppression costs in Western United States FS Regions (1 through 5) by Gebert et al. (2007), found that higher home values (non-biophysical variable) within 20 miles of a wildfire ignition increased suppression expenditures. All other variables that influenced suppression costs were biophysical variables like extreme fire behavior, drought conditions, wildfire intensity levels, and energy release component. Though not specific to the presence or absence of WUI, Liang et al. (2008) studied wildfire suppression expenditures for 100 large wildfires occurring in the Northern Region (R1) of the US Forest Service. They found wildfire size and the percentage of private land within the burned area had a strong effect on suppression expenditures. This finding supports the idea that non-biophysical variables have an effect on fire suppression costs.

Most recently, Gude et al. (2013) used fires in California's Sierra Nevada to estimate the relationship between housing and fire suppression costs. That is, whether the presence of homes is associated with increases in fire suppression costs after controlling for other biophysical parameters (e.g., size, terrain, weather, etc.). Their study found a small, but statistically significant increase in suppression costs with the presence of homes within a 6-miles radius of an active wildfire.

Recently, Scofield et al. (2015) analyzed the effect of the spatial configuration of house in the WUI on costs of fighting nearly 300 wildfires in Colorado, Montana and Wyoming from 2002 to 2011. Schofield et al. (2015: 3) found that not only does homes in the WUI matter, but that whether the homes are widely dispersed in that landscape (e.g., 35 acre parcel development common in Colorado) versus whether they are clustered together also has an effect on wildfire suppression costs. These authors found that clustering homes in the WUI greatly reduced firefighting costs relative to dispersal of the same number of homes throughout the landscape.

Rideout et al. (2008) explored the topic of whether, theoretically, fuel treatments have the potential to reduce wildfire suppression costs in the treated area. They showed that it is difficult to establish an unambiguous relationship between fuel treatments and resulting suppression costs, without factoring in the implied level of net fire damage. Further, prior fuel treatments often make fire suppression efforts more effective, and hence more, not less, suppression may be warranted in areas that have been treated, than in untreated areas (which may be too unsafe to engage in wildfire suppression or wildfire suppression will do little to reduce damages). On the other hand, because fire suppression may be easier making it more effective, final fire size might be smaller, potentially reducing fire suppression costs. But what the net effect of these possible relationships are is an empirical question that can only be addressed with data on actual fire suppression costs in treated versus untreated areas.

The recent empirical literature most closely related to the specific purpose of our research includes papers by Cochrane et al. (2012), Butry (2009), Thompson and Anderson (2015), Yoder and Ervin (2012) and Fitch et al. (2017). Cochrane et al. (2012) investigated the effect of 1300 individual fuel treatments on 14 large wildfires using a simulation approach. They calibrated a simulation model to these 14 large fires that had been treated and then used the model to simulate what would have been the fire behavior had these areas not been treated. They conclude that fuel treatments in these 14 large wildfire changed fire spreading rates and reduced the likelihood of fire crowning behavior. They indicate that much larger samples are needed, however. Their study was not intended to nor did they analyze the relationship between fuel treatments and suppression cost, although fire spreading rates and crowning behavior influences fire suppression costs. Thompson and Anderson (2015) also took a modeling approach but they did so to evaluate the effects of fuel treatment on fire suppression costs. They compared three modeling approaches that were applied in different geographic areas (i.e., Oregon, Arizona and the Great Basin). Across this broad geographic span they found that the potential existed for costs of fighting wildfires to be reduced by fuel treatments. However, they noted (Thompson and Anderson, 2015: 169): *"Second, the relative rarity of large wildfire on any given point on the landscape and the commensurate low likelihood of any given area burning in any year suggests the need for large-scale fuel treatments….Thus in order to save large amounts of money on fire suppression, land management agencies may need to spend large amounts of money on large-scale fuel treatment"*. But, Reinhardt et al. (2008) believe the inability to know where the few large and expensive to suppress fires will occur suggest that such widespread fuel treatments might only reduce fire suppression expenditures if used in conjunction with controlling residential development in fire-prone areas and a tempering of the "all-out" approach to fire suppression. Otherwise, they feel it may be a mistake to think that fuel treatments by themselves can reduce wildfire suppression expenditures. Much like Thompson and Anderson (2015), Barnett et al. (2016) also found a relative rarity (6.8%) of the intersection of fuel treatments and wildfire on federal lands in the same coterminous U.S. area we study. In the face of this rarity, Barnett et al. (2016) emphasizes the need to prioritize fuel reduction projects. An example of such prioritization is Jones et al. (2017) where the focus on fuel treatments is on accessible portions of urban watersheds.

Butry (2009) utilized a propensity scoring method to analyze the effect of prescribed fire on what they refer to as wildfire-intensity weighted acres. He makes the case that propensity scoring has advantages over OLS regression when there may be unobservable variables and these unobservable variables are correlated with the prescribed fire fuel treatment. Unfortunately he does not compare the propensity scoring approach to OLS for his data, but suggests OLS models may underestimate the impact of prescribed fire. Nonetheless, even using a propensity scoring model with his fine scale spatial data for the St. Johns River Water Management District in northeast Florida, he finds that in only one of the nine comparisons does prescribed fire reduce wildfire intensity-acres at the 5% level (another one is what he labels "weakly significant" at the 11% level). The largest effect is that a 1% increase in prescribed fire reduces wildfire intensity-acres by 0.0436%, and the average effect across the entire sample is 0.0138%. Thus, even when statistically significant, the effect of fuel treatments is very small.

Fitch et al. (2017) has an intermediate size analysis area of five National Forests in northern Arizona dominated by ponderosa pine. They focus on fires 800 acres and larger. Their wildfire suppression cost regression model includes as explanatory variables the dominant vegetation cover, wildfire size, and distance to WUI areas. Their dependent variable used a natural log transformation of wildfire suppression cost per hectare. Their results indicate that the further the wildfire area was from WUI areas, the lower the wildfire suppression costs. In their modeling effort fuel treatments worked through reducing the proportion of wildfire burning at high severity and mixed severity. A 1% increase in proportion of the wildfire burning at high and mixed severity increased wildfire suppression costs by 6.43% and 4.91% relative to low severity.

Yoder and Ervin (2012) were one of the first to directly test the effect of fuel treatments on fire suppression costs at the county level in the western U.S. To conduct this analysis, they ran the natural log of total suppression costs at the county level as a function of: wildfire acreage, prescribed (RX) burn acres, mechanically thinned acres, amount spent on RX burning, amount spent on thinning, vegetation type, WUI area, temperature, and precipitation. While their model had good explanatory power (R^2=0.71) generally neither the acres of prescribed burning nor the cost of prescribed burning nor the acres thinned nor the cost of thinning had a negative and significant effect on suppression costs (just one of the 16 variables).

Several inferences can be made from this literature. First, to isolate the effect of fuel treatment on wildfire suppression costs, it is important to control for whether the wildfire was in WUI and biophysical variables. Specifically, wildfire suppression costs were related to fire size, terrain (e.g., slope), and wildfire intensity levels. Higher fuel loads (e.g., density and type of vegetation) also appear to affect wildfire suppression cost, and thus reducing fuel loading is one of the purposes of prescribed burning and mechanical fuel treatments. Thus, our empirical model specification includes all of these factors in an attempt to control for them when testing whether fuel reduction treatments reduces wildfire suppression costs.

In contrast to Yoder and Ervin (2012) who use county averages, our analyses use individual fire level data. This provides a finer geographic resolution than using counties as a unit of analysis. Unfortunately, much of the literature on the effect of fuel treatment on wildfires that have used individual fire data have focused on fairly small geographic areas (e.g., one county or water district in Florida) and so limit the geographic generalizability of their findings. We have been able to do our analysis at the individual fire level for the entire National Forest System (excluding Alaska and Hawaii). Nonetheless, being nationally comprehensive down to the individual fire level requires that we use what data is consistently available nationwide, so not every variable that every paper has included can be included in our analysis. Nevertheless, we felt the broader geographical generalizability of our results filled an important gap in the fuel treatment-wildfire suppression cost analysis literature.

Specific Objectives of the Analysis

The expected benefits of our fire suppression cost research is twofold: (a) to determine if there is or is not a statistical relationship between fuel reduction policies and suppression costs and (b) to determine if there is or is not a statistical relationship between fuel reduction policies and property damages from wildfires. If relationship between fuel treatment and suppression costs and property damage is confirmed, then calculate the net suppression costs savings and hence benefits of fuel reduction treatments. Findings for (a) and (b) would help provide justification to Congress that funding additional fuel reduction treatments is a cost effective way to reduce long run suppression costs and wildfire damages. Further, our multiple regression fuels treatment cost regression model would account for many of the quantitative and qualitative variables that influence the costs of fuel treatment. The resulting model can be applied by fire managers to estimate the cost of fuel treatments tailored to the specifics of their particular application. The tailoring occurs by setting the values of the independent variables at the levels specific to the fuel treatment the manager wants an estimate of the cost for.

2. Project Hypotheses

Building upon the Gude (2014) and Yoder and Ervin's (2012) models, particularly in the latter, we estimate a multiple regression model to test hypotheses and quantify the effect of fuel treatment efforts on wildfire suppression costs and human and resource impacts. More specifically we will answer the following two questions:

(a) Do presuppression fuel treatments have the potential to reduce wildfire suppression costs in the treated area?
(b) Do presuppression fuel treatments reduce the number of houses damaged from wildfire?

Our regression models account for many of the quantitative and qualitative variables that influence the costs of suppression and fuel treatments. The regression models will allow us to test these two hypotheses about what factors influence the cost of suppression and fuels treatment as well their influence on human and resource impacts. Each of the variables included in the regression model are considered as a hypothesized variable influencing costs. These hypotheses are tested based on asymptotic t-statistics on each of the variables. The resulting model can also be applied by fire managers to estimate fuel treatment and suppression costs tied to the specifics of their particular fire situation. The linkage to local fire conditions occurs when the manager sets the values of the independent variables at the levels specific to the fuel treatment the manager wants an estimate of the cost for.

Chapter II Methods

1. Final Conceptual Framework

Building upon the available literature, we estimate a multiple regression model to test hypotheses and quantify the effect of fuel treatment efforts on wildfire suppression costs and structures damaged. Our regression models account for many of the quantitative and qualitative variables that influence the costs of wildfire suppression costs. We chose the natural log of the suppression cost per acre to deal with any potential for heteroscedasticity that might be a problem had we used total suppression cost. Our empirical model is:

<u>Dependent Variable</u>

$\mathbf{Ln(TSC_i/WFacres_i)}$	= natural log of (Total Suppression Costs$_i$/Wildfire Acres$_i$)
$\mathbf{TSC_i}$	**=** Total Suppression Costs of wildfire i
$\mathbf{WFacres_i}$	= size of wildfire i in acres

<u>Independent Explanatory Variables</u>

Acres_Mech	= Acres of the wildfire area with prior mechanical fuel treatment
Acres_RXFire	= Acres of the wildfire area with prior prescribed fire fuel treatment
$\mathbf{WUIY_i}$	= intercept shifter variable for whether the wildfire is in a WUI area
$\mathbf{Elev_i}$	= average elevation of the wildfire area in meters
$\mathbf{Slope_i}$	= average slope within the wildfire area
$\mathbf{pls_i}$	= percent of the area with low level of existing fuel loads

The model specified for all geographic regions (defined in more detail below) is:

(1) $\mathbf{ln(TSC_i/WFacres_i)} = B_0 - B_1(\mathbf{Acres\_Mech}) - B_2(\mathbf{Acres\_RXFire}) + B_3(\mathbf{WUIY_i}) + B_4(\mathbf{Elev_i}) + B_5(\mathbf{Slope_i}) - B_6(\mathbf{pls_i}) + \varepsilon_i$

The coefficients on the fuel treatment variables should be negative and significant if pre-suppression fuel treatment reduces fire suppression costs. Mathematically our hypotheses are:

(2) Ho: $B_{AcresRXFire} = 0$ Ha: $B_{AcresRXFire} < 0$

(3) Ho: $B_{AcresMech} = 0$ Ha: $B_{AcresMech} < 0$

The hypotheses are tested based on asymptotic t-statistics on the two types of pre-suppression fuel treatments.

Property Damage Model

(4) $\mathbf{ln(\#Structures_i)} = A_0 - A_1(\mathbf{lnWFacres_i}) - A_2(\mathbf{Acres\_Mech}) - A_3(\mathbf{Acres\_RXFire}) + A_4(\mathbf{WUIY_i}) + A_5(\mathbf{Elev_i}) + A_6(\mathbf{Slope_i}) - A_7(\mathbf{pls_i}) + \varepsilon_i$

Where #Structures is the sum of houses and other structures (barns, out buildings, unattached garages, etc.) damaged by wildfire$_i$. This equation was estimated with a count data model because there were a significant number of wildfires with no structures damaged and several wildfires with only a few structures damaged.

The hypotheses tests for property damage (# structures) is:

(5) Ho: $A_{AcresRXFire} = 0$ Ha: $A_{AcresRXFire} < 0$
(6) Ho: $A_{AcresMech} = 0$ Ha: $A_{AcresMech} < 0$

The hypotheses are tested based on asymptotic t-statistics on two the types of pre-suppression fuel treatments: RX burning and mechanical fuel treatments.

2. Study Sites

To make the study as comprehensive as possible and representative of all vegetation types and fuel models, and fuel treatment activities nationally we collected fuel treatment and wildfire suppression costs and associated data in all FS regions region except Alaska and Hawaii. Alaska and Hawaii are so significantly different from all regions in the conterminous US that would require a separate modeling effort. We implement our study by using all USDAFS Regions in the conterminous US.

Chapter III: Development of the Fuel Treatment Cost and Suppression Cost Data

1. Development of Database for Costs of Fuel Treatment

The primary data for the cost of fuel treatment analysis came from the Forest Service Activities System (FACTS). This system covers all the work codes routinely used by the USDAFS. From the large list of activities available in FACTS we used the existing literature to request data on a subset of all the FACTS activities that were relevant to the cost of fire fuel treatments or mechanical fuel treatments. Further, activities in the data were recoded to intercept shifter variables. This resulted in 25 variables. Table 1 below provides a short definition of the FACTS Activities and its FACTS activity code that are used to label the variables in the regression model. Detailed descriptions of these FACTS activity variables can be found in the FACTS User Guide (USDA Forest Service, 2013; http://fsweb.nrm.fs.fed.us).

Development of the Treatment Cost Database involved:

- All FACTS data sets on fuel treatments for the USDAFS Regions.
- FACTS Data for Regions 1, 2, 3, 4, 5, 6, 8 and 9 were cleaned of inliers (costs $1 per acre or less) and outliers (usually costs per acre over $5,000) and missing observations on critical variables.
- GIS spatial data for all Regions.
- GIS spatial data and FACTS data were been merged.
- The data by regions where grouped by Geographic Area Coordination Centers (GACC's).

Table 1 presents the key FACTS ID and associated name of the fuel treatment variables.

Table 1 Listing of Fuel Related FACTS ID Considered for the Statistical Analysis

FACTS ID	Activity Name
1111	Broadcast Burn
1112	Jackpot Burning
1113	Underburn Low Intensity
1120	Remove Fuels by Yarding
1130	Burning Piled Material
1131	Cover Brush Pile for Burning
1136	Pruning to Raise Canopy
1150	Re-arrange Fuels
1152	Compacting/Crushing Fuels
1153	Piling of Fuels Hand/Mach
1154	Chipping Fuels
1160	Thinning for Fuels
1180	Fuel Break
2360	Range Control Vegetation
2370	Range Piling Slash
2530	Invasive-Mechanical
4220	Commercial Thinning
4231	Salvage Cut (Intermediate Treatment)
4455	Slashing Pre-Site Preparation
4471	Site Prep for Planting-Burn
4474	Site Prep for Planting-Mechanical
4475	Site Prep for Planting-Manual
4511	Tree Release & Weed
4521	Pre-Commercial Thinning
4530	Prune
4540	Control for Understory Vegetation
6101	Wildlife Habitat RX Burn
8000	Insect & Disease Activities
0100	Other Activities

2. Development of Database for Wildfire Suppression Costs

- Wildfire Suppression data (FS-5100-29) was obtained for all years. However, there were significant concerns regarding the accuracy of the cost data reported, especially for small fires.
- A significant effort was made to collaborate with the USDAFS scientists at the Rocky Mountain Research Station in Missoula to obtain more accurate Wildfire Suppression Cost Data for large wildfires. This more accurate suppression cost data was obtained and merged into the other FS-5100-29 data describing wildfires to create a master database.
- The wildfire suppression data (FS-5100-29) with the FACTS treatment area data was merged to calculate the independent variables for the cost of fire suppression regression.
- Finally the wildfire suppression cost data and the GIS Spatial data was merged into one dataset.

Chapter IV: Results for Re-estimated Fuel Treatment Cost Analysis

A final fuel treatment cost multiple regression model was specified. The dependent variable is what the USDA Forest Service called Planned Direct cost per acre in its data set. The candidate independent variables included the setting in which the fuel treatment took place (e.g., WUI and Urban) and acres of the treatment at a minimum. Potentially, the model could include a variety of other variables such as data developed from GIS analysis like the Fire Regime Condition Class, slope, elevation, fuel loadings. While this model might be more predicatively accurate, the data requirement costs of a field manager actually trying to use this model to predict fuel treatment costs would be higher. Review of the Year 1 spatial (and non-spatial) models by California wildfire managers indicated that the simpler re-estimated models presented in Table 2 yielded results that were more plausible to them than the original spatial and non-spatial models from Year 1. However, we have retained the original spatial models in Appendix A, as they may serve as a starting point for future researchers wishing to improve upon these spatial models to make them more acceptable to wildfire managers.

The key variables that were used in the final fuel treatment cost analysis models are:

Acres: The number of acres actually treated by the activity. It is expected that the cost per acre would fall with the number of acres treated.

WUI: Wildland-Urban Interface; whether the activity occurred in or adjacent to an "… area, or zone where structures or other human development meet or intermingle with undeveloped wildland or vegetative fuels" (FACTS manual, page 39). Expected sign positive (more expensive to conduct activities in WUI due to extra precaution needed). Specifically, WUI signifies the fuel treatment area is in a Wildland-Urban Interface area. Using the drop down menu the user selects whether it is in a WUI (Yes) or not (No). If a fuel treatment area includes both then the program should be run twice: once with the acres in WUI and once with the acres not in WUI. The total cost of the treatment is the sum of the costs in the WUI and non-WUI areas.

Metropolitan County: A dummy variable equal to 1 for urban counties, zero otherwise; created using the name of the county entered in FACTS. This designation was based on the USDA Economic Research Service classification of economic areas. The rationale for this variable is that cost per acre of fuel treatment is usually influenced by whether the treatment area is in a metropolitan area where wages are higher. The user selects the county that contains the fuel treatment from the drop down menu, and then the variable for whether that county is in a metropolitan area or not is set to 1 or 0 automatically for the user. As with WUI, if the treatment area spans two counties, the user model should be run twice, one time with the amount of acres in one county and another time with the acres in the other county. The total cost of the treatment is the sum of the costs in the metropolitan and non-metropolitan counties.

One characteristic of all the models is that we only included the FACTS activities related to prescribed burning in the prescribed burning cost regression model. Likewise only FACTS activities related to mechanical fuel reduction were included in the mechanical fuel reduction cost regression.

The general form of the fuel treatment equations estimated is:

$$\ln(FTC_b \text{ or } FTC_m) = B_1(\ln \text{ acres treated}) + B_2(WUI) + B_3(Metro) + B_{F1}(FACTS1) \ldots + B_{Fn}(FACTSn)$$

Where the $FACTS_n$ activity n is the relevant FACTS activity associated with prescribed burning or mechanical fuel treatment.

$B_{F1\ldots}$ B_{Fn} coefficients on the FACTS activities indicate how much higher (+) or lower (-) the cost of that FACTS activity is from the baseline activity for prescribed burning or mechanical fuel reduction.

The sum of the coefficients represents the log of planned direct costs per acre. If one is interested in a different fuel treatment activity, then whatever that activity estimated coefficient is, is added to the sum of the other non FACTS two coefficients (i.e., WUI or Metro). Then to get estimated treatment cost per acre, the anti-natural log of that sum is taken (i.e., taking e(β(WUI(0 or 1))+ β(Metro)+β(FACTS#)). If the county is non-metro that makes metro equal to zero, so the sum would just be e(β(WUI(0 or 1))+ β(FACTS#)). Likewise if the area is not a WUI area and not a Metro area, the sum would just be e(β(FACTS#)).

As noted above, the original prescribed burning and mechanical fuel treatment cost models estimated in Year 1, were reviewed in Year 2 by wildfire managers and fire officers in California. They felt the more complicated models provided unrealistically large reductions in cost per acre as the amount of acreage treated increase. Further statistical analysis of the data revealed this problem was due to the specification of the acreage variable and its estimated coefficient in the model. This year the models were re-estimated using a different specification of the form of the acreage variable. The results (negative sign on the **LN of acres treated** coefficient) suggest that in three out of the four regressions that the cost per acre continues to fall as acreage increases but at a much slower rate. Wildfire managers and fire officers in California thought these models provided a more plausible relationship between acres treated and cost per acre.

Not surprisingly costs of performing prescribed burning and mechanical fuel reduction are higher in **WUI** areas, and in **Metro** areas where labor costs are higher. The explanatory power of the models is lower than desirable (about 12% to 24% of the variation in costs per acre is explained by the independent variables in the models). We attribute much of the low explanatory power to the "noisiness" in the FACTS treatment cost data, which as was mentioned in the previous section didn't always appear to be accurate. While we removed "inliers" (obviously incorrect \$0 and \$1 costs per acre), and outliers (0.1% of observations with costs more than 10 standard deviations from the mean), the data still has a great deal of variation that could not be explained by the particular activity and whether it occurred in WUI or a Metropolitan area.

Table 2 presents the results.

Table 2 Multiple Regressions of Fuel Treatment Costs per Acre in Northern and Southern California

Dependent Variable: LN of Costs Per Acre

VARIABLES	(1)	(2)	(3)	(4)
	South RX Burn	South Mech	North RX Burn	North Mech
LN of acres treated	-0.0694***	0.0138	-0.0637**	-0.0544***
(standard errors)	(0.0130)	(0.0137)	(0.0248)	(0.0132)
WUI	0.170***	0.466***	0.366***	0.273***
	(0.0409)	(0.0393)	(0.0635)	(0.0355)
Metro	0.547***	0.447***	0.481***	0.339***
	(0.0430)	(0.0398)	(0.116)	(0.0716)
1131.activity		-1.184**		-1.615***
		(0.461)		(0.203)
1136.activity		0.761***		-0.117
		(0.143)		(0.132)
1150.activity		0.212**		0.204*
		(0.0910)		(0.124)
1152.activity		1.229***		0.0424
		(0.0924)		(0.108)
1153.activity		0.329***		0.181**
		(0.0773)		(0.0809)
1154.activity		0.343***		-0.0859
		(0.0966)		(0.123)
1160.activity		0.295***		0.242***
		(0.0799)		(0.0891)
1180.activity		0.523**		0.426***
		(0.203)		(0.138)
2360.activity		-0.863***		
		(0.238)		
2370.activity		0.0598		
		(0.143)		
4220.activity		0.782***		0.0764
		(0.0907)		(0.0959)
4231.activity		0.382*		-0.183
		(0.217)		(0.171)
4331.activity		-0.966***		
		(0.164)		
4474.activity		-0.0215		0.941***
		(0.329)		(0.162)
4511.activity		0.743***		0.210*
		(0.133)		(0.117)
4521.activity		0.475***		0.224***
		(0.0769)		(0.0794)
4530.activity		-0.442***		-0.409
		(0.167)		(0.310)
4540.activity		0.850***		0.543***
		(0.290)		(0.165)
1112.activity	-0.926***		-0.319	
	(0.127)		(0.319)	
1113.activity	-0.333***		0.414**	
	(0.106)		(0.181)	
1130.activity	-0.550***		-0.433**	
	(0.0884)		(0.169)	
6101.activity	-1.424**		0.347	
	(0.707)		(0.290)	

4471.activity			-0.0811	
			(0.291)	
2530.activity				0.997***
				(0.175)
4455.activity				0.431**
				(0.203)
4475.activity				0.354**
				(0.140)
4494.activity				1.161***
				(0.208)
Constant	5.351***	4.621***	4.772***	5.290***
	(0.0993)	(0.0856)	(0.188)	(0.0846)
Observations	1,238	2,135	1,018	2,408
R-squared	0.168	0.243	0.121	0.136

Chapter V: Results for Re-estimated Fire Suppression Cost Analysis

1. Final Empirical Model

After extensive discussion with the Washington Office of the USDAFS, and the Rocky Mountain Research Station office in Missoula Montana, it was determine that the most accurate data on wildfire suppression costs were for moderate to large size wildfires. To ensure maximum data quality only wildfires in classes C and above (C, D, E, F and G were used). This corresponds to wildfires 300 acres or larger.

Fire Suppression Cost Variables

Dependent Variable

Ln(TSC/WFacres) = natural log of Total Suppression Costs/Wildfire Acres

Independent Explanatory Variables

Acres_Mech	=	Acres of the wildfire area with prior mechanical fuel treatment
Acres_RXFire	=	Acres of the wildfire area with prior fire fuel treatment
WUIY	=	intercept shifter variable for whether the fire is in a WUI area or
Elev	=	average elevation of the wildfire area
Slope	=	average slope within the wildfire area
% low severity	=	percent of area in low level of existing fuels

The starting or baseline model specified for all GACC groupings is:

$$\ln(TSC_i/WFacres_i) = B_0 - B_1(Acres\_Mech) - B_2(Acres\_RXFire) + B_3(WUIY_i) + B_4(Elev_i) + B_5(Slope_i) - B_6(pls_i) + \varepsilon_i$$

Refinement of Hypotheses

The original major hypothesis is that within a wildfire area, holding everything else about the wildfire constant, we would expect that the larger the percentage of the wildfire area treated with prescribed burning and mechanical fuel treatment the lower the Total Fire Suppression Cost per Wildfire Acre. Thus, we would expect that regression slope coefficients on B_1 and B_2 to be negative ($B_1<0$; $B_2<0$).

However, fuel treatments may allow firefighters to enter areas to successfully fight fires in areas that without fuel treatments would not have been safe or effective to enter. Thus, fuel treatments could result in more fire suppression effort (Rideout, et al. 2008). Such active suppression on the ground would of course raise suppression costs. In that case B_1 and B_2 could be positive rather than negative.

Depending on the mix of wildfires in a GACC grouping, there may be some wildfires where fuel treatment would reduce the wildfire suppression costs, but there may also be wildfires that with fuel treatments are now safe for fire fighters to enter, which would increase fire suppression costs. The net effect of these two offsetting effects (the first situation reducing suppression cost and the second situation increasing suppression costs), may result in the coefficient on fuel treatments with respect to suppression costs being not statistically different from zero (i.e., not systematic effect).

However, it is not that fuel treatments are not without other benefits to society. We also test whether the amount of the wildfire area with fuel treatment reduces wildfire damages to structures (e.g., barns, out buildings) and houses. As noted above fuel treatments may make it safer for firefighters to enter the area and be able to "save" houses and structures that without fuel reduction treatments would otherwise be lost. In terms of economic principles, fuel reduction treatments raise the productivity of a given dollar of fire suppression costs.

Combining GACC Regions
Unlike the cost of fuel treatment regressions (where there were very large sample sizes), the wildfire suppression data did not have equivalently large sample sizes. Therefore, we combined similar GACC's together to conserve degrees of freedom. Specifically, the Northern and Southern California GACC's were made into one fire suppression cost analysis area, although we did include a intercept shifter for the Southern California GACC to control for any possible differences in wildfire suppression costs per acre. The Eastern and Southern GACC's were combined based on them having the two lowest average wildfire suppression costs and geography. We also included an intercept shifter, in this case for the Southern GACC to allow for any systematic differences between the Eastern and Southern GACC's in terms of wildfire cost per acre. Separate regressions were run for all the other GACC's.

2. Selected Descriptive Statistics

Table 3a. Descriptive Statistics for East & South GACC's, Northern Rockies GACC and Rocky Mountain GACC

	East and SO		NRCC		RMCC	
Variable	Mean	Median	Mean	Median	Mean	Median
Ln (Supp Cost/WFAcres)	4.31	4.14	4.610	4.31	4.79	5.32
Acres_Mech	0.03	0.00	0.006	0.00	0.05	0.00
Acres_RXFire	136.40	0.00	182.000	0.00	153.07	0.00
WUIY	0.30		0.080		0.28	
Elevation (meters)	307.25	274.11	1680.400	1757.00	1907.00	2027.00
Slope	7.31	6.11	19.110	20.98	10.95	11.25
pls	17.22	17.38	4.417	2.80	7.24	5.44
#Structures Damaged/fire	0.38	0.00	0.460	0.00	1.75	0.00
Sample Size	174		142		81	

Table 3b. Descriptive Statistics for Southwest GACC, Northwest GACC, Great Basin GACC and California GACC's.

	SWCC		NWCC		GBCC		CACC's	
Variable	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Ln (Supp Cost/WFAcres)	4.73	4.74	5.75	6.29	5.92	5.85	6.73	6.94
Acres_Mech	0.03	0.00	0.04	0.00	0.03	0.00	0.01	0.00
Acres_RXFire	221.60	0.00	95.40	0.00	188.16	0.00	188.40	0.00
WUIY	0.18		0.19		0.19		0.32	
Elevation (meters)	1970.90	2044.40	1128.80	1757.00	2029.00	2027.00	1161.70	1058.20
Slope	11.81	11.83	18.10	20.98	17.23	11.25	17.43	17.77
pls	11.12	9.13	2.80	7.63	5.44	10.73	10.50	11.11
# Structures Damaged/fire	0.56	0.00	0.24	0.00	1.46	0.00	3.40	0.00
Sample Size	170		90		132		115	

Generally speaking only small percentages of wildfire areas have had fuel treatments. Thus, it will be challenging to detect the effect of fire on wildfire suppression costs. As can be seen by comparing the mean and median, far less than half the areas had any fuel treatments of any kind.

3. Statistical Results of Wildfire Suppression Cost by GACC Groups

Table 4a presents the regression results for the "best" model for the Eastern and Southern GACC's, Northern Rockies GACC and Rocky Mountain GACC.

Table 4a. Suppression Cost Per Acre Regression for Northeast & Southeast GACCs, Northern Rockies GACC and Rocky Mountain GACC.

	Group 1: GACCs Eastern and Southern		Group 2: GACC Northern Rockies		Group 3: GACC Rocky Mountain	
	Estimate	Probability	Estimate	Probability	Estimate	Probability
Intercept (t-statistic)	3.0522 (5.454)	1.76e-07 ***	3.8557 (4.389)	2.28e-05 ***	2.4894 (4.426)	3.25e-05 ***
GACCSoCC	0.5279 (1.864)	0.0641*				
Acres_Mech	-0.1718 (-0.260)	0.7951	4.3541 (-1.250)	0.2136	0.5303 (0.798)	0.4277
Acres_RXFire	-0.0004 (-1.035)	0.3023	-0.0001 (-1.810)	0.7610	-0.0005 (-0.952)	0.3440
WUIY	1.1712 (4.617)	7.76e-06 ***	2.8761 (3.806)	0.0002 ***	1.5817 (2.939)	0.0044 ***
Elevation	-0.0004 (-1.220)	0.2241	0.0005 (1.064)	2.893	0.0004 (0.880)	0.3820
Slope	0.0638 (3.194)	0.0017 ***	0.0012 (0.047)	0.9622	0.1023 (2.125)	0.0369 **
pls	0.0122 (0.449)	0.6542	-0.0651 (-1.464)	0.1566	0.0120 (0.524)	0.6020
R squared	**0.2024**		**0.1116**		**0.3800**	

*significant at the 10% level, ** significant at the 5% level and *** significant at the 1% level

Most of the variable coefficient signs make sense: wildfires involving WUI and steeper slopes have higher than average wildfire suppression costs per acre. Overall the explanatory power in the Eastern/Southern GACCs and the Rocky Mountain GACC is acceptable at 20% and 38%, respectively, for cross section data across such a broad geographic scope.

In terms of our hypotheses tests, neither of these variables, Acres_Mech Treatment nor Acres_ RXFire Treatment were statistically different from zero. That is, acres of the wildfire area treated with either mechanical or fire fuel treatments appear not to have a systematic effect on fire suppression costs in these three regions.

Table 4b. Suppression Cost per Acre Regression for Southwest GACC, Pacific Northwest and Great Basin GACC.

	Group 2: GACC Southwest		Group 3: GACC Pacific Northwest		Group 3: GACC Great Basin	
	Estimate	Probability	Estimate	Probability	Estimate	Probability
Intercept (t-statistic)	2.1744 (3.228)	0.0015 **	4.800 (6.350)	1.09e-08 ***	5.988 (7.587)	6.51e-12 ***
Acres_Mech	0.4490 (0.725)	0.4693	4.649e-01 (0.540)	0.5910	2.023e-01 (-0.295)	0.7685
Acres_RXFire	-0.0003 (-1.113)	0.2674	-2.533e-05 (-0.043)	0.9660	-6.473e-05 (-0.179)	0.8581
WUIY	0.4383 (1.177)	0.2410	-1.717e-01 (-0.256)	0.7980	9.063e-01 (2.127)	0.0353**
Elevation	0.0010 (2.763)	0.0064***	3.384e-04 (0.694)	0.4900	1.028e-05 (0.031)	0.9754
Slope	0.0646 (2.809)	0.0056***	4.523e-02 (1.604)	0.1130	-1.225e-02 (-0.530)	0.5971
pls	-0.0178 (-0.597)	0.5514	-2.599e-02 (-1.068)	0.2890	-6.183e-03 (-0.280)	0.7803
R-square	**0.1181**		**0.0539**		**0.0445**	

*significant at the 10% level, ** significant at the 5% level and *** significant at the 1% level

These models have fewer statistically significant variables and lower explanatory power. Only in the Great Basin GACC do wildfires involving WUI have higher wildfire suppress costs per acre. Only in the Southwest GACC does steeper slopes have higher than average wildfire suppression costs per acre. Overall the explanatory power is pretty low for these three regression models.

In terms of our hypotheses tests, neither of Acres_Mech Treatment nor Acres_ RXFire Treatment were statistically different from zero. That is, acres of the wildfire area treated with either mechanical or fire fuel treatments appear not to have a systematic effect on wildfire suppression costs per acre in these three regions.

Table 4c. Suppression Cost Per Acre Regression for Southern and Northern California GACC

	Group 4: GACCs Southern & Northern CA	
	Estimate	Probability
Intercept	6.227e+00	1.69e-15 ***
(t-statistic)	(9.329)	
GACCSoCA	-2.614e-01	0.4116
	(-0.824)	
Acres_Mech	-6.451e+00	0.0048***
	(-2.882)	
Acres_RXFire	-1.053e-04	0.2220
	(-1.228)	
WUIY	-5.679e-01	5.21e-07 ***
	(-5.018)	
Elevation	-0.0005	0.1145
	(-1.591)	
Slope	3.992e-02	0.05764*
	(1.919)	
pls	2.704e-02	0.1725
	(1.373)	
R-square	**0.1720**	

*significant at 10%; **significant at 5% level and ***significant at 1% level

In the Northern and Southern California GACC's the variable coefficient signs make sense: wildfires on steeper slopes result in higher than average wildfire suppression costs per acre. The explanatory power is acceptable with 17% of the variation in the wildfire suppression cost per acre explained by the independent variables.

In terms of our hypotheses tests, the statistical significance and negative sign on Acres Mech Treatment indicates that the more acres of a wildfire area treated with mechanical fuel reduction, the lower the costs per acre of wildfire suppression in California. However, Acres Fire Treatment was not statistically different than zero. That is, acres of the wildfire area treated with a fire fuel treatment appear not to have a systematic effect on fire suppression costs.

4. Summary of Fire Suppression Cost Regression Results and Hypotheses Test

As noted above in our discussion of hypotheses, it is possible that the general lack of statistical significance of the fuel treatment variables may be due to opposing effects: in some wildfires fuel treatment did lower suppression costs, but in other wildfires, fuel treatments allowed fire fighters to enter areas that would otherwise not be safe, thereby raising wildfire suppression costs. As Rideout et al. (2008) point out this is result is theoretically possible under plausible circumstances. In addition, as noted by Thompson and Anderson (2015) there may simply be too little of fuel treatments in areas with wildfires to detect any effects of fuel treatments on wildfire suppression costs. That lack of significance of prescribed burning (Acres_RX) and mechanical fuel reduction (Acres_Mech) almost uniformly across all but one GACC regions is consistent with the findings of Yoder and Ervin (2012) at the county level for the western U.S. and Butry (2009) for his micro-scale analysis in one area of Florida. Our results are also consistent with the general finding of Gude et al. (2014) that the Firewise Communities Program of reducing vegetative fuels around homes did not reduce wildfire suppression costs either.

These results also bring about a new hypothesis, which perhaps the real impact of fuel treatments is to reduce the probability that small fires grow into larger wildfires that are more expensive to control. If this is the case, then there may be **a cost savings** from fuel treatment programs in reducing the need to number of large wildfires. Unfortunately, we were unable to obtain the data that would be necessary to test this new hypothesis in the fourth year of the project.

Chapter VI: Results for Effect of Fuel Treatment on Property Damages

Our second hypothesis test is that fuel reduction treatments such as prescribed burning and mechanical fuel reduction would reduce the number of homes and other structures damaged by wildfires by raising the marginal productivity of a given expenditure of fire suppression money. This is a finding of Bostwick et al. for one fire (Wallow Fire) in the southwestern U.S. Obviously testing with multiple fires in multiple geographic regions is necessary to determine if this is the usual result or not.

As was shown previously in Tables 3a and 3b, the relatively low number of structures (i.e., houses, barns, out buildings) damaged relative to the large number of fires suggested that a count data model might be the appropriate statistical technique to estimate the effect of fuel treatments on property damages. A count data is well suited to handle small integers, including zeros better than OLS regression does. At the recommendation of our project statistician we adopted a rather parsimonious model to test for the effect of the number of acres of the wildfire treated with mechanical fuel reduction (Acres_Mech) and the number of acres treated with prescribed fire fuel treatment (Acres_RX). Other variables included were size of wildfire (lnWFacres) and whether the fire occurred in a Wildland Urban Interface (WUI) area. We would expect larger fires and certainly fires burning in WUI areas where there are homes and developed structures in place to potentially have higher property damages.

The results are presented in Tables 5a, 5b and 5c.

Table 5a. Count data models for Structures damaged by wildfire Eastern & Southern GACCs, Northern Rockies GACC and Rocky Mountain GACC

	Group 1: GACCs Eastern and Southern		**Group 2: GACC Northern Rockies**		**Group 3: GACC Rocky Mountain**	
	Estimate	Probability	Estimate	Probability	Estimate	Probability
Intercept (t-statistics)	-9.1775 (-4.86)	2.84e-05 ***	-1.129e+01 (-8.540)	< 2e-16 ***	-1.491 (-21.171)	2e-16***
GACCSoCC	-4.6055 (-7.562)	3.97e-14 ***				
lnWFacres	0.5181 (2.937)	0.00331***	1.183 (8.496)	< 2e-16 ***	1.579 (26.740)	2e-16 ***
Acres_Mech	-58.5281 (-0.990)	0.32228	-2.986 (-4.049)	5.14e-05 ***	-4.561 (-2.313)	0.0207*
Acres_RXFire	0.0020 (5.515)	3.49e-08 ***	-5.435e-04 (-1.810)	0.0704*	-5.096e-03 (-13.828)	2e-16***
WUIY	4.6003 (4.472)	7.76e-06 ***	3.321 (10.969)	< 2e-16 ***	3.838 (26.521)	2e-16 ***
Elevation	0.0005 (0.506)	0.61320	1.480e-03 (4.212)	2.53e-05 ***	2.857 (1.905)	40.0568*
Slope	-0.3360 (-2.617)	0.00887 **	-1.626e-01 (-6.324)	2.55e-10 ***	6.334e-02 (4.344)	1.46e-05***
pls	0.2400 (4.746)	2.07e-06 ***	-4.790e-03 (-0.116)	0.9079	-8.112e-02	0.003 ***

*significant at the 10% level, ** significant at the 5% level and *** significant at the 1% level

Table 5b. Count data models for Structures damaged by wildfire Southwest GACC, Pacific Northwest GACC and Great Basin GACC

	Group 4: GACC Southwest		Group 5: GACC Northwest		Group 6: GACC Great Basin	
	Estimate	Probability	Estimate	Probability	Estimate	Probability
Intercept	-2.434e+01	<2e-16 ***	-8.2249	4.87e-05 ***	-3.8016	< 2e-16***
(t-statistic)	(-14.881)		(-4.062)	(-9.712)		
lnWFacres	1.184	<2e-16 ***	0.7736	1.47e-05 ***	0.5613	< 2e-16 ***
	(10.167)		(4.334)	(16.948)		
Acres_Mech	5.561e-01	0.556	0.1315	0.7649	-3.6940	0.195
	(0.589)		(0.299)	(-1.296)		
Acres_RXFire	-5.792e-05	0.487	-0.0002	0.6682	-0.0061	9.04e-05 ***
	(-0.695)		(-0.429)	(-3.915)		
WUIY	4.391	<2e-16 ***	1.7696	0.00054 ***	1.1464	< 2e-16 ***
	(11.619)		(3.460)	(9.924)		
Elevation	3.002e-03	<2e-16 ***	0.0007	0.3878	0.0002	0.212
	(11.774)		(0.864)	(1.249)		
Slope	2.148e-01	<2e-16 ***	0.0119	0.7023	-0.0505	4.63e-09 ***
	(9.415)		(0.382)	(-5.860)		
pls	-1.888e-02	0.734	-0.2456	0.9079	0.0101	0.217
	(-0.340)		(-2.979)	(1.233)		

*significant at the 10% level, ** significant at the 5% level and *** significant at the 1% level

Table 5c. Count data models for Structures damaged by wildfire California GACCs

	Group 7: GACCs Southern & Northern CA	
	Estimate	Probability
Intercept	-6.6272	<2e-16 ***
(t-statistics)	(-14.523)	
GACCSoCA	1.6216 (10.126)	<2e-16 ***
lnWFacres	1.0229 (2.251)	<2e-16**
Acres_Mech	16.0169 (11.395)	<2e-16 ***
Acres_RXFire	-0.0099 (-4.035)	5.45e-05 ***
WUIY	-0.6337 (-5.018)	5.21e-07 ***
Elevation	-0.0005 (-2.524)	0.0116**
Slope	0.0432 (4.637)	3.53e-06 ***
pls	-0.2559 (-13.838)	< 2e-16 ***

*significant at 10%; **significant at 5% level and ***significant at 1% level

The results in Tables 5a-5c show that wildfires in WUI areas naturally resulted in more structures damaged. In terms of our hypothesis, in four GACC's the coefficient on prescribed fire is negative and statistically significant, indicating that as acres treated with prescribed fire went up, the number of structures damaged decreased (in two GACC's prescribed fire was not significant). The results were more mixed for mechanical fuel reduction. Only in two of the GACC's did the area of mechanical fuel reduction have a negative and statistically significant effect on reducing the number of structures damaged by fire. It may be the stronger results for prescribed burning arise because an order of magnitude of more acres were treated with prescribed fire compared to mechanical fuel reduction (something not too surprising given the relative cost of the two different types of fuel reduction activities). Thus, for some geographic areas, Rideout et al.'s (2008) interpretation that prescribed burning and mechanical fuel reduction may reduce property damages seems to apply.

Chapter VII: Conclusion

In the fourth and final year, we updated the fuel treatment costs regressions and had them reviewed by wildfire specialists in California. In addition, we refined the wildfire suppression cost regressions as well. Overall, we found that the extent of fuel treatments may be too limited to have a significant effect on reducing wildfire suppression costs. As noted in the literature, it may be that for fuel treatments to have a significant effect on wildfire suppression costs, there has to be a more substantial effort on prescribed burning and mechanical fuel reduction than as is the case (Thompson and Anderson, 2015). Alternatively, as pointed out by Rideout et al. (2008) fuel treatments may increase the effectiveness of wildfire suppression efforts leading to reduced resource and property damages. In the case of property damages, Rideout et al.'s (2008) hypothesis seems borne out. In our data, areas with prescribed burning did reduce property damages when a wildfire occurred.

The results of this research was presented in two papers at the Fifth International Symposium on Fire Economics, Planning and Policy. The first presentation focused on the revised costs of fuel treatment regression models in California. The second presentation focused on the results on the effect of the two fuel treatment methods (e.g., prescribed burning and mechanical fuel treatment) on wildfire suppression costs and property damage. Both of the papers were included in the CD provided to participants at the Fifth International Symposium on Fire Economics, Planning and Policy. Finally, the revised paper was presented at the 2017 Western Agricultural Economics Association meetings.

A journal manuscript with the results of the effect of fuel treatment on wildfire suppression costs and property damages was written and submitted for technical review. After the technical review we followed the reviewers' suggestions and revised and re-estimated the empirical models. After comments received after presentation at the two professional meetings we greatly updated and expanded the literature review of the manuscript and refined the empirical model. The resulting manuscript was submitted to the journal, *Forest Policy and Economics* in July of 2017.

VIII. Deliverables and Science Delivery

Deliverable Type (see proposal instructions)	Description	Delivery Dates
Database	Fuel treatments and suppression costs databases	Completed November 2015
Conference presentation	Western Regional Science Association Conference	Completed February 2016
Conference presentation	Fifth International Symposium on fire economics	Completed November 2016
Proceedings paper publication	Fifth International Symposium on fire economics	Completed November 2016
Paper presentation	Western Agricultural Economics Association	Completed July 2017
Refereed publication	Journal article submission to *Forest Policy and Economics*	Completed July 2017

IX. Roles of Investigators and Associated Personnel

Personnel	Role	Responsibility
Armando González-Cabán	PI	Overall project coordination and analysis of data and regression models development, reports & manuscripts writing
John B. Loomis	Co-PI	Field project coordinator, analysis of data, regression models development, reports & manuscripts writing
Douglas Rideout & Robin Reich (deceased)	Co-PIs	Consultants on econometrics and fire economics, regression models development
José J. Sánchez	Co-PI	Data analysis, regression models development and estimation
Post-Doc Researcher	Analyst	Data collection, data revision, regression models development

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APPENDIX A

Spatial and Non-Spatial Regression Results for FACTS Cost of Mechanical and Fire Fuel Treatments for all Continental U.S.

The cost of fuel treatment regressions have been estimated for all Prescribed Burning Fuel Reductions (spatial and non-spatial) and Mechanical Treatment (spatial and non spatial). Separate regressions were estimated for prescribed fire and fire related activities and for mechanical treatments and their related activities.

One the characteristics of all the models, is that we used a testing down to statistically significant variable so not every variable is included in every model. Thus a variable or FACTS activity that is omitted did not have a cost statistically different than the baseline activity. The baseline activity varied treatment. For **fire fuel treatment the baseline activity was broadcast burning,** which was FACTS activity 1111. For the **mechanical fuel treatment the default activity is 1120, which is Yarding—**removal of fuels by carrying or dragging. Thus, the costs of the other treatments are measured relative to the Yarding. So to calculate a predicted cost, the analyst would just determine if the fuel treatment is in the WUI or not in the WUI and whether it is in a Metropolitan county or not (0 if no, 1 if yes). The implicit cost of the default activity varies with these two variables. Specifically, if the treatment is in the WUI and a Metro county, those two coefficients represent the joint cost of WUI, Metro and the default activity. This sum of the coefficients represents the log of planned direct costs per acre. If one is interested in a different fuel treatment activity, then whatever that estimated coefficient is of that activity is added to the sum of the other two coefficients. Then to get estimated treatment cost per acre, the anti-natural log of that sum is taken (i.e., taking e(WUI(0 or 1)+Metro+FACTS#)). If the county is non-metro that makes metro equal to zero, so the sum would just be e(WUI(0 or 1)+FACTS#).
ActN8000 represents any activity related to insect or disease control.

The general form of the spatial fuel treatment equations estimated is:

FTC_{b} or $_{m} = B_{1}(WUI)+B_{2}(Metro)+B_{F1}(FACTS1)\ldots+B_{Fn}(FACTSn) +B_{Sp1}(Spatial_{1})\ldots+B_{Sp}(Spatial_{t})$

Where $FACTS_{n}$ is FACTS activity relevant to b(prescribed burning) or m(mechanical fuel treatment).

B_{Fn} coefficients on the FACTS activities in terms of how much higher (+) or lower (-) they are from the baseline activity for prescribed burning or mechanical fuel reduction.

B_{Sp} is coefficients on the spatial variables such as elevation, slope, crown density, %low severity fuels, %mixed severity fuels, Fire Return Interval.

A total of 28 cost of fuel treatment regressions were run: (a) one for each GACC for mechanical fuel treatments and a separate regression for fire fuel treatments; (b) each of these model was estimated with and without spatial variables to determine the significance of adding the spatial variables such as elevation, slope, fuel severity class, and fire return interval. Originally the intent of these models was to include estimated costs of treatment in the fire suppression cost regressions.

Here we summarize the general pattern of results from the 28 models. The full 28 spatial and non spatial regression model statistical output is provided in the next section.

- **WUI** was positive and statistically significant in all 28 prescribed burning and mechanical fuel treatment equations, i.e., higher costs to do fuel treatments in areas with a WUI.
- **Metro** was positive and statistically significant in 22 of the prescribed burning and mechanical fuel treatment equations, i.e., higher costs to do fuel treatments in areas within Metropolitan counties.
- Average **elevation** of the fuel treatment was significant 8 out of 14 spatial models
- Average **slope** of the fuel treatment was significant 7 out of 14 spatial models
- Average **fuel severity** (either low or mixed or both) was significant in all 14 spatial models
- Average **crown bulk density** was significant in 12 of the 14 spatial models
- **Fire Return Interval** was significant in 9 of the 14 spatial models.

After reviewing all 28 estimating model results in their entirety, the project statistician believed that the excessive statistical noise in these equations due to the underlying poor FACTS cost data quality might introduce error into the relatively good quality fire suppression costs data (at least for the large fires) so acres treated was used in the fire suppression cost equations.

1. Results for Northern California GACC-Fire Fuel Treatment

Table 1. Regression Results for Fire Fuel Treatment—Northern California GACC
Non Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Significance level
WUI0	4.97018	0.15550	31.963	0.0000 ***
WUI1	5.25181	0.15384	34.137	0.0000 ***
Metro cnty	0.77697	0.05536	14.035	0.0000 ***
activity1112	-0.65053	0.20793	-3.129	0.00179 **
activity1113	0.28078	0.15038	1.867	0.06207 .
activity1130	-0.32627	0.14180	-2.301	0.02153 *
activity4471	-0.15009	0.27096	-0.554	0.57973
activity6101	0.41257	0.26676	1.547	0.12217
activity8000	2.33348	0.28732	8.122	0.00000 ***
lnacres	-0.80620	0.01697	-47.519	0.00000 ***

*** significant at the 99.99% level; ** significant at the 99.9%;
* significant at the 99% level; + significant at the 95% level; R square: 68%

A few details of this model are worth noting as its form of the regression is similar to the remaining GACC's. First WUI0 signifies the fuel treatment area is **not** in a Wildland Urban Interface area. WUI1 signifies the fuel treatment area **is** in a Wildland Urban Interface area. Including both is possible as the model is estimated without a constant term.

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not significantly different than costs of the reference activity, Broadcast Burning over a majority of the unit. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a reasonably good explanatory power of 68%, meaning that 68% of the cost per acre is explained by this set of variables. This means that 32% of the variability in costs per acre is unexplained by the model.

The next table presents the results for the Northern California GACC including two spatial variables.

Table 2 Regression Results for Northern California Fire Fuel Treatment Costs—Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Significance Level
WUI0	4.726343	0.158555	29.809	0.0000 ***
WUI1	4.952459	0.158060	31.333	0.0000 ***
Metro cnty	0.783953	0.053829	14.564	0.0000 ***
activity1112	-0.390815	0.204257	-1.913	0.0559 .
activity1113	0.270055	0.146597	1.842	0.0656 .
activity1130	-0.235709	0.138775	-1.698	0.0896 .
activity4471	-0.016400	0.264180	-0.062	0.9505
activity6101	0.484501	0.259539	1.867	0.0621 .
activity8000	2.366464	0.279527	8.466	0.0000***
lnacres	-0.791682	0.016561	-47.804	0.0000 ***
% low severity	0.039356	0.004454	8.836	0.0000 ***
% mixed severity	-0.041329	0.004378	-9.441	0.0000 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; R square: 70%

This spatial model performs quite well with numerous statistically significant variables. The explanatory power is 70% meaning that 70% of the variation in the cost per acre is explained by the set of independent variables. The spatial variables are statistically significant making this model somewhat superior to the non-spatial prescribed burning model. Thus if the fire management officer or fire specialist has GIS data on the mix of fuels, percentage of fires in the treatment area that are low severity or mixed severity then costs will be estimated more precisely using that information with the spatial model. Whatever percentages these two variables are set at by the fire specialist, the user model the then calculates the percentage of the area is in high severity fire.

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not significantly different than costs of the reference activity, Broadcast Burning over a majority of the unit. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a reasonably good explanatory power of 70%, meaning that 70% of the cost per acre is explained by this set of variables. This means that only 30% of the variability in costs per acre is unexplained by the model.

2. Results for Southern California GACC-Fire Fuel Treatment

Table 3 presents the results for the non-spatial fire fuel treatment model. Note, that the Default Activity is 1111, which is Broadcast Burning covering the majority of the unit. Thus, the costs of the other treatments are measured relative to that. ActN8000 represents any activity related to insect or disease control.

Table 3. Regression Results for Fire Fuel Treatment—Southern California GACC
Non Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Significance Level	
WUI0	5.48507	0.14677	37.371	0.0000	***
WUI1	5.53243	0.15386	35.957	0.0000	***
Metro cnty	0.83870	0.08758	9.577	0.0000	***
activity1112	-1.39359	0.18062	-7.716	0.0000	***
activity1113	-0.99771	0.18787	-5.311	0.0000	***
activity1130	-1.21428	0.13016	-9.329	0.0000	***
activity8000	-0.52530	0.23276	-2.257	0.0247	*
lnacres	-0.75163	0.02570	-29.243	0.0000	***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; R square: 76%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not significantly different than costs of the reference activity, Broadcast Burning over a majority of the unit. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a reasonably good explanatory power of 76%, meaning that 76% of the cost per acre is explained by this set of variables. This means that only 24% of the variability in costs per acre is unexplained by the model.

Table 4. Regression Results for Fire Fuel Treatment—Southern California GACC
Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Significance Level
WUI0	5.624736	0.161542	34.819	0.0000 ***
WUI1	5.674312	0.162679	34.880	0.0000 ***
Metro cnty	0.643834	0.086352	7.456	0.0000 ***
activity1112	-1.427712	0.171917	-8.305	0.0000 ***
activity1113	-1.180036	0.181622	-6.497	0.0000 ***
activity1130	-1.202148	0.123261	-9.753	0.0000 ***
activity8000	-0.618483	0.219590	-2.817	0.0000***
lnacres	-0.731005	0.024485	-29.856	0.0000 ***
slope	0.026349	0.005551	4.747	0.0000 ***
%low severity	-0.035019	0.007951	-4.404	0.0000 ***
%mixedseverity	0.013160	0.008640	1.523	0.12871

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; R square: 79%

As can be seen by looking at the number of highly statistically significant variables there are several activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not significantly different than costs of the reference activity, Broadcast Burning over a majority of the unit. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a very good explanatory power of 79%, meaning that 79% of the cost per acre is explained by this set of variables. This means that only 21% of the variability in costs per acre is unexplained by the model.

3. *Results for Northern California GACC- Mechanical Fuel Reduction Activities*

Table 5 presents the results for the non-spatial mechanical fuel treatment model for Northern California. Note, that the Default Activity is 1120, which is Yarding—removal of fuels by carrying or dragging. Thus, the costs of the other treatments are measured relative to the Default Activity (1120). ActN8000 represents any activity related to insect or disease control.

Table 5. Regression Results for Northern California Mechanical Fuel Treatment
Non Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability	
WUI0	5.21495	0.07551	69.065	0.0000	***
WUI1	5.55609	0.07144	77.769	0.0000	***
Metro cnty	0.48708	0.04791	10.166	0.0000	***
activity1131	-1.69792	0.20797	-8.164	0.0000	***
activity1136	-0.13413	0.13353	-1.004	0.315228	
activity1150	0.12285	0.11249	1.092	0.274913	
activity1152	0.32036	0.09122	3.512	0.000452	***
activity1153	0.04535	0.07009	0.647	0.517646	
activity1154	-0.20933	0.10855	-1.928	0.053898	.
activity1160	0.06098	0.07721	0.790	0.429708	
activity1180	0.52961	0.13635	3.884	0.000105	***
activity2530	1.11187	0.17382	6.397	1.85e-10	***
activity4220	0.15049	0.08787	1.713	0.086888	.
activity4231	-0.18408	0.17068	-1.079	0.280898	
activity4455	0.41172	0.21411	1.923	0.054592	.
activity4474	0.84322	0.17977	4.691	0.0000	***
activity4475	0.41136	0.14012	2.936	0.003354	**
activity4494	1.15351	0.21370	5.398	7.31e-08	***
activity4511	0.35372	0.10704	3.305	0.000963	***
activity4521	0.26733	0.07013	3.812	0.000141	***
activity4530	-0.38995	0.42507	-0.917	0.359024	
activity4540	0.58679	0.16372	3.584	0.000344	***
activity8000	-0.26051	0.20813	-1.252	0.210805	
lnacres	-0.74075	0.01211	-61.182	0.000000	***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; R square: 66%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference activity, Yarding--removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area or in a Metropolitan area it has higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a reasonable explanatory power of 66%, meaning that 66% of the cost per acre is explained by this set of variables.

Table 6 presents the results for the spatial mechanical fuel treatment model. Note, that the Default Activity, 1120, is the same as in the non-spatial model, which is Yarding—removal of fuels by carrying or dragging. Thus, the costs of the other treatments are measured relative to that the Default Activity 1120. ActN8000 represents any activity related to insect or disease control. The spatial model utilizes the coordinates of the treatment area to calculate the mean percent mixed severity fuels, crown bulk density, and mean fire return interval.

Table 6. Northern California Regression Results for Mechanical Fuel Treatment
Spatial Model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	**Estimate**	**Std. Error**	**t value**	**Significance**	
Level					
WUI0	5.170251	0.080884	63.922	0.00000	***
WUI1	5.514510	0.076959	71.655	0.00000	***
Metro cnty	0.463407	0.048158	9.623	0.00000	***
activity1131	-1.659023	0.208114	-7.972	0.00000	***
activity1136	-0.122768	0.133563	-0.919	0.35808	
activity1150	0.104435	0.112499	0.928	0.35332	
activity1152	0.341299	0.091312	3.738	0.00018	***
activity1153	0.045672	0.070084	0.652	0.51466	
activity1154	-0.184486	0.108741	-1.697	0.08989	.
activity1160	0.065290	0.077181	0.846	0.39766	
activity1180	0.549366	0.136508	4.024	0.00000	***
activity2530	1.097713	0.234437	4.682	0.00000	***
activity4220	0.161504	0.088163	1.832	0.06707	.
activity4231	-0.231112	0.171819	-1.345	0.17870	
activity4455	0.371081	0.214210	1.732	0.08332	.
activity4474	0.789024	0.180166	4.379	0.0000	***
activity4475	0.405898	0.140316	2.893	0.00384	**
activity4494	1.162337	0.213779	5.437	0.00000	***
activity4511	0.358432	0.106994	3.350	0.00081	***
activity4521	0.275943	0.070156	3.933	0.00000	***
activity4530	-0.299834	0.425303	-0.705	0.48087	
activity4540	0.577340	0.163887	3.523	0.00043	***
activity8000	-0.237488	0.208321	-1.140	0.25438	
lnacres	-0.740065	0.012192	-60.701	0.00000	***
crown bulk density	0.003273	0.002281	1.435	0.15149	
%mixed severity	0.022808	0.005525	4.128	0.00000	**
Fire return interval	-0.022021	0.005391	-4.085	0.00000	***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; R square: 64%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference FACTS activity #1120, Yarding-- removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has reasonable explanatory power of 64%, meaning that 64% of the cost per acre is explained by this set of variables. Surprisingly, the explanatory power of the spatial model is only 1% higher than the non-spatial model despite all the spatial variables being statistically significant.

4. Results for Southern California GACC- Mechanical Fuel Reduction Activities

Table 7 presents the Southern California GACC for mechanical fuel treatment cost non spatial model.

Table 7. Regression Results for Southern California Mechanical Fuel Treatment
Non Spatial Model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability	
WUI0	4.45675	0.12512	35.620	0.00000	***
WUI1	4.81634	0.11970	40.235	0.00000	***
Metro cnt	0.71205	0.06100	11.673	0.00000	***
activity1131	-0.88492	0.45364	-1.951	0.05130	.
activity1136	1.02346	0.17925	5.710	0.00010	***
activity1150	-0.04950	0.11871	-0.417	0.6767	
activity1152	1.35374	0.14914	9.077	0.00000	***
activity1153	0.71179	0.11579	6.147	0.00000	***
activity1154	0.57651	0.13769	4.187	0.00000	***
activity1160	0.50185	0.11428	4.391	0.00000	***
activity1180	0.82466	0.22183	3.717	0.00021	***
activity2360	-0.72564	0.24096	-3.011	0.00265	**
activity2370	0.08136	0.15567	0.523	0.60130	
activity4220	0.78415	0.11453	6.847	0.00000	***
activity4231	0.50480	0.21779	2.318	0.02063	*
activity4331	-0.85730	0.17461	-4.910	0.00000	**
activity4474	0.10831	0.32662	0.332	0.74024	
activity4511	0.23218	0.20086	1.156	0.24795	
activity4521	0.41988	0.10358	4.054	0.00000	***
activity4530	-0.38160	0.17475	-2.184	0.02918	*
activity8000	0.17611	0.30713	0.573	0.56649	

lnacres	-0.72982	0.01909	-38.227	0.00000	***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; R square: 64%

The model also has reasonable explanatory power of 64%, meaning that 64% of the cost per acre is explained by this set of variables.

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference FACTS activity #1120, Yarding-- removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

Table 8 presents the Southern California GACC for mechanical fuel treatment cost spatial model.

Table 8. Regression Results for Southern California Mechanical Fuel Treatment Spatial Model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	**Estimate**	**Std. Error**	**t value**	**Probability**	
WUI0	4.100e+00	1.641e-01	24.984	0.00000	***
WUI1	4.319e+00	1.548e-01	27.910	0.00000	***
Metro cnty	7.189e-01	6.765e-02	10.626	0.00000	***
activity1131	-8.338e-01	4.381e-01	-1.903	0.05727	.
activity1136	1.035e+00	1.740e-01	5.951	0.00000	***
activity1150	-4.163e-02	1.151e-01	-0.362	0.71756	
activity1152	1.224e+00	1.450e-01	8.446	0.00000	***
activity1153	6.984e-01	1.124e-01	6.216	0.00000	***
activity1154	6.002e-01	1.357e-01	4.424	0.00000	***
activity1160	4.964e-01	1.120e-01	4.433	0.00000	***
activity1180	6.716e-01	2.170e-01	3.096	0.00201	**
activity2360	-5.538e-01	2.341e-01	-2.366	0.01816	*
activity2370	2.790e-01	1.524e-01	1.831	0.06736	.
activity4220	8.742e-01	1.115e-01	7.839	0.00000	***
activity4231	5.114e-01	2.106e-01	2.429	0.01531	*
activity4331	-7.682e-01	1.711e-01	-4.490	0.00000	***
activity4474	2.695e-01	3.157e-01	0.854	0.39345	
activity4511	3.108e-01	1.942e-01	1.601	0.10975	
activity4521	4.553e-01	1.001e-01	4.548	0.00000	***
activity4530	-3.629e-01	1.691e-01	-2.146	0.03211	*
activity8000	1.072e-01	2.981e-01	0.360	0.71929	
lnacres	-7.272e-01	1.845e-02	-39.416	0.00000	***

Crown bulk den	-2.719e-02	4.148e-03	-6.556	0.00000	***
Elevation	3.589e-04	5.746e-05	6.246	0.00000	***
Slope	1.681e-02	3.212e-03	5.233	0.00000	***
%low sever	2.368e-02	5.780e-03	-4.097	0.00000	***
%mixed sever	1.614e-02	5.511e-03	2.929	0.00347	**

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; R square: 66%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference FACTS activity #1120, Yarding-- removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area or in a Metropolitan area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has reasonable explanatory power of 66%, meaning that 66% of the cost per acre is explained by this set of variables. Surprisingly, the explanatory power of the spatial model is only 1% higher than the non-spatial model despite all the spatial variables being statistically significant.

5. *Results for Pacific Northwest GACC- Mechanical Fuel Reduction Activities*

Table 9. Pacific Northwest Non-spatial mechanical treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	**Estimate**	**Std. Error**	**t value**	**Probability**
WUI0	4.39309	0.05769	76.152	< 2e-16 ***
WUI1	4.48385	0.05868	76.412	< 2e-16 ***
Metro cnty	-0.24380	0.02703	-9.020	< 2e-16 ***
activity1136	0.77298	0.10698	7.226	5.51e-13 ***
activity1150	0.49557	0.06423	7.716	1.37e-14 ***
activity1152	1.54322	0.13517	11.417	< 2e-16 ***
activity1153	1.24280	0.05263	23.616	< 2e-16 ***
activity1154	0.72273	0.07339	9.848	< 2e-16 ***
activity1160	1.16644	0.07479	15.595	< 2e-16 ***
activity1180	0.99894	0.18258	5.471	4.62e-08 ***
activity4131	0.92087	0.27700	3.324	0.00089 ***
activity4143	1.20218	0.40425	2.974	0.00295 **
activity4151	1.46769	0.33089	4.436	9.33e-06 ***
activity4152	0.88227	0.21458	4.112	3.97e-05 ***
activity4193	1.43324	0.19498	7.351	2.20e-13 ***
activity4194	1.50793	0.31536	4.782	1.77e-06 ***
activity4210	0.01892	0.13900	0.136	0.89173
activity4220	0.88518	0.05715	15.489	< 2e-16 ***
activity4231	2.03343	0.14436	14.086	< 2e-16 ***
activity4241	-1.73217	0.20173	-8.587	< 2e-16 ***
activity4455	0.88801	0.37428	2.373	0.01769 *
activity4474	1.70014	0.20702	8.212	2.56e-16 ***
activity4475	0.04060	0.16518	0.246	0.80586
activity4494	1.48233	0.37480	3.955	7.73e-05 ***
activity4495	0.17655	0.10800	1.635	0.10215
activity4511	0.89133	0.11690	7.625	2.77e-14 ***
activity4521	0.99849	0.05007	19.943	< 2e-16 ***
activity4530	0.98575	0.12526	7.869	4.10e-15 ***
activity4540	1.59922	0.40466	3.952	7.82e-05 ***
activity6103	0.95346	0.17474	5.456	5.03e-08 ***
activity9008	0.82999	0.44229	1.877	0.06062 .
lnacres	-0.85360	0.01038	-82.200	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 56%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference FACTS activity #1120, Yarding-- removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficient is sensible. The model also has reasonable explanatory power of 56%, meaning that 56% of the cost per acre is explained by this set of variables.

Table 10. Pacific Northwest spatial mechanical treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	3.779e+00	9.275e-02	40.746	< 2e-16 ***
WUI1	3.904e+00	8.949e-02	43.623	< 2e-16 ***
Metro cnty	-1.458e-01	3.043e-02	-4.792	1.69e-06 ***
activity1136	9.369e-01	1.060e-01	8.839	< 2e-16 ***
activity1150	6.508e-01	6.449e-02	10.091	< 2e-16 ***
activity1152	1.469e+00	1.311e-01	11.207	< 2e-16 ***
activity1153	1.290e+00	5.150e-02	25.047	< 2e-16 ***
activity1154	8.633e-01	7.169e-02	12.041	< 2e-16 ***
activity1160	1.193e+00	7.321e-02	16.298	< 2e-16 ***
activity1180	9.062e-01	1.771e-01	5.116	3.20e-07 ***
activity4131	7.972e-01	2.684e-01	2.970	0.00299 **
activity4143	1.086e+00	3.918e-01	2.772	0.00559 **
activity4151	1.491e+00	3.210e-01	4.644	3.48e-06 ***
activity4152	1.141e+00	2.092e-01	5.455	5.07e-08 ***
activity4193	1.397e+00	1.895e-01	7.370	1.91e-13 ***
activity4194	1.428e+00	3.061e-01	4.666	3.13e-06 ***
activity4210	-8.120e-02	1.351e-01	-0.601	0.54784
activity4220	7.725e-01	5.643e-02	13.689	< 2e-16 ***
activity4231	2.055e+00	1.409e-01	14.586	< 2e-16 ***
activity4241	-1.422e+00	1.962e-01	-7.247	4.71e-13 ***
activity4455	7.512e-01	3.633e-01	2.068	0.03872 *
activity4474	1.668e+00	2.008e-01	8.304	< 2e-16 ***
activity4475	2.686e-01	1.625e-01	1.654	0.09826 .
activity4494	1.755e+00	3.643e-01	4.817	1.49e-06 ***
activity4495	4.389e-01	1.069e-01	4.104	4.10e-05 ***
activity4511	9.583e-01	1.136e-01	8.436	< 2e-16 ***
activity4521	9.755e-01	4.916e-02	19.842	< 2e-16 ***
activity4530	9.985e-01	1.221e-01	8.176	3.46e-16 ***
activity4540	1.770e+00	3.924e-01	4.512	6.53e-06 ***
activity6103	1.274e+00	1.704e-01	7.479	8.42e-14 ***
activity9008	9.614e-01	4.295e-01	2.239	0.02521 *
lnacres	-8.294e-01	1.037e-02	-80.000	< 2e-16 ***
elevation	1.248e-04	4.562e-05	2.736	0.00623 **
slope	6.687e-03	1.857e-03	3.601	0.00032 ***
crown density	2.829e-02	1.919e-03	14.744	< 2e-16 ***
%low severity	-2.339e-02	2.163e-03	-10.813	< 2e-16 ***
%med severity	4.029e-02	3.792e-03	10.627	< 2e-16 ***
Fire return Interval	-1.505e-02	3.187e-03	-4.723	2.37e-06 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 58%

The spatial model has a similar performance of the non spatial model, and an explanatory power only slightly higher at 58% than the non spatial model (56%). However, all the spatial variables are highly statistically significant indicating their inclusion is improves the model. The coefficients also make sense in that steeper slopes raise treatment costs, and as does crown density. The percent of the area in low severity fuels reduces fuel treatment costs, while percent medium severity fuels increases fuel treatment costs.

6. Results for Pacific Northwest GACC- Fire Fuel Reduction Activities

Table 11. Pacific Northwest prescribed fire treatment non spatial model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	5.07237	0.11823	42.904	< 2e-16 ***
WUI1	5.01892	0.11920	42.105	< 2e-16 ***
Metro cnty	0.22373	0.03458	6.470	1.16e-10 ***
activity1112	-0.14905	0.14167	-1.052	0.292849
activity1113	-0.12388	0.11513	-1.076	0.282002
activity1117	1.29765	0.15994	8.113	7.31e-16 ***
activity1130	-1.06841	0.11090	-9.634	< 2e-16 ***
activity4511	0.63544	0.36682	1.732	0.083337 .
activity4521	0.17715	0.14955	1.185	0.236307
activity6101	0.91234	0.24279	3.758	0.000175 ***
lnacres	-0.82484	0.01176	-70.127	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 66%

The statistically significant coefficient for Metro make sense as that adds to the cost of prescribed fire treatments. The explanatory power of this non spatial model is very good at 66% and 8 of the 11 variables are statistically significant at the 90% level or higher.

Table 12. Pacific Northwest prescribed fire treatment spatial model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	5.214821	0.125575	41.527	< 2e-16 ***
WUI1	5.154646	0.126619	40.710	< 2e-16 ***
Metro cnty	0.128834	0.037858	3.403	0.000676 ***
activity1112	-0.156043	0.139821	-1.116	0.264508
activity1113	-0.158051	0.113811	-1.389	0.165029
activity1117	1.075917	0.161941	6.644	3.66e-11 ***
activity1130	-1.088531	0.109574	-9.934	< 2e-16 ***
activity4511	0.539806	0.362353	1.490	0.136410
activity4521	0.104159	0.147973	0.704	0.481552
activity6101	0.909554	0.240349	3.784	0.000157 ***
lnacres	-0.818160	0.011833	-69.143	< 2e-16 ***
crown den	-0.010101	0.002271	-4.448	9.01e-06 ***
%low severity	-0.009806	0.002599	-3.773	0.000165 ***
%med severity	-0.017307	0.005648	-3.064	0.002203 **
Fire return Interval	0.021920	0.004956	4.423	1.01e-05 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 67%

The spatial variables are all statistically significant, although the explanatory power over the non spatial model barely increases, but it is still good (67%). As with the non spatial model performing prescribed burning costs slightly more in metropolitan counties than in non metropolitan counties.

7. Results for Great Basin GACC- Mechanical Fuel Reduction Activities

Table 13. Great Basin Non-spatial mechanical treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	4.17507	0.11439	36.499	< 2e-16 ***
WUI1	4.23103	0.11661	36.284	< 2e-16 ***
activity1136	0.31257	0.17045	1.834	0.06679 .
activity1150	0.19903	0.11090	1.795	0.07281 .
activity1152	0.44445	0.15189	2.926	0.00346 **
activity1153	0.85371	0.11417	7.478	1.03e-13 ***
activity1154	0.18657	0.11491	1.624	0.10458
activity1160	0.46427	0.10892	4.263	2.09e-05 ***
activity1180	-0.21205	0.14657	-1.447	0.14807
activity4117	0.18294	0.19415	0.942	0.34613
activity4151	1.18349	0.22115	5.352	9.48e-08 ***
activity4177	-0.63475	0.30746	-2.064	0.03907 *
activity4183	1.78347	0.30745	5.801	7.39e-09 ***
activity4193	2.50301	0.44653	5.605	2.29e-08 ***
activity4220	2.14414	0.19185	11.176	< 2e-16 ***
activity4231	-0.32304	0.34374	-0.940	0.34743
activity4232	0.39953	0.32415	1.233	0.21786
activity4474	1.13886	0.21948	5.189	2.28e-07 ***
activity4511	0.08468	0.12591	0.673	0.50132
activity4521	0.53141	0.10821	4.911	9.63e-07 ***
activity9008	-0.83628	0.44745	-1.869	0.06174 .
lnacres	-0.67301	0.01271	-52.939	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level;
+ significant at the 95% level; . significant at the 90% level. R square: 57%

The explanatory power of the non spatial model is reasonable at 57%. Mechanical fuel treatments in WUI areas cost slightly more than in non WUI areas.

Table 14 Great Basin Spatial mechanical treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	3.387e+00	1.501e-01	22.568	< 2e-16 ***
WUI1	3.494e+00	1.504e-01	23.228	< 2e-16 ***
activity1136	4.133e-01	1.704e-01	2.425	0.015384 *
activity1150	3.325e-01	1.102e-01	3.019	0.002563 **
activity1152	4.269e-01	1.497e-01	2.851	0.004386 **
activity1153	7.824e-01	1.125e-01	6.954	4.47e-12 ***
activity1154	2.930e-01	1.140e-01	2.570	0.010238 *
activity1160	5.183e-01	1.072e-01	4.836	1.40e-06 ***
activity1180	-1.944e-01	1.480e-01	-1.314	0.189099
activity4117	-8.858e-02	1.945e-01	-0.455	0.648821
activity4151	8.429e-01	2.195e-01	3.841	0.000125 ***
activity4177	-8.665e-01	3.025e-01	-2.864	0.004214 **
activity4183	1.768e+00	3.016e-01	5.861	5.19e-09 ***
activity4193	2.472e+00	4.381e-01	5.643	1.86e-08 ***
activity4220	2.302e+00	1.887e-01	12.200	< 2e-16 ***
activity4231	-3.205e-01	3.376e-01	-0.950	0.342432
activity4232	2.925e-01	3.195e-01	0.916	0.359911
activity4474	1.216e+00	2.153e-01	5.647	1.80e-08 ***
activity4511	2.446e-01	1.242e-01	1.969	0.049074 *
activity4521	6.032e-01	1.074e-01	5.619	2.12e-08 ***
activity9008	-9.764e-01	4.392e-01	-2.223	0.026302 *
lnacres	-6.986e-01	1.280e-02	-54.584	< 2e-16 ***
elevation	3.802e-04	4.651e-05	8.174	4.58e-16 ***
crown den	-7.224e-03	4.386e-03	-1.647	0.099635 .
%low severity	-1.871e-02	4.002e-03	-4.675	3.09e-06 ***
%med severity	1.035e-02	4.588e-03	2.256	0.024134 *
Fire return Interval	8.524e-03	3.309e-03	2.576	0.010055 *

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 59%

The explanatory power of the spatial model is improved slightly to 59%. Mechanical fuel treatments in WUI areas cost slightly more than in non WUI areas. The spatial variables are all statistically significant indicating their importance in the model.

8. Results for Great Basin GACC- Fire Fuel Reduction Activities

Table 15. Great Basin Non-spatial fire fuel treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	4.26792	0.15305	27.886	< 2e-16 ***
WUI1	4.66202	0.15230	30.610	< 2e-16 ***
Metro cnty	0.45232	0.08632	5.240	2.12e-07 ***
activity1112	-0.28352	0.25421	-1.115	0.26509
activity1113	-0.09179	0.13036	-0.704	0.48156
activity1117	1.01901	0.13936	7.312	7.12e-13 ***
activity1130	-0.29612	0.11408	-2.596	0.00964 **
activity4471	2.43138	0.36723	6.621	7.06e-11 ***
activity6101	0.31493	0.23543	1.338	0.18143
lnacres	-0.76863	0.02273	-33.817	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 71%

The Great Basin fire treatment model has intuitive coefficients. In particular, the cost of performing a prescribe fire is higher in WUI areas and in Metropolitan counties than non-WUI areas and rural areas (i.e., non metropolitan counties). The explanatory power is quite good at 71% of the cost of treatment explained by the variables included in the model.

Table 16. Great Basin Spatial fire fuel treatment model

Variable	Estimate	Std. Error	t value	Probability
WUI0	3.244e+00	2.377e-01	13.647	< 2e-16 ***
WUI1	3.742e+00	2.296e-01	16.296	< 2e-16 ***
metro1	5.429e-01	8.413e-02	6.453	2.04e-10 ***
activity1112	-6.900e-02	2.452e-01	-0.281	0.778506
activity1113	8.482e-02	1.291e-01	0.657	0.511461
activity1117	9.983e-01	1.340e-01	7.451	2.71e-13 ***
activity1130	-2.325e-01	1.103e-01	-2.109	0.035311 *
activity4471	2.722e+00	3.537e-01	7.697	4.73e-14 ***
activity6101	7.874e-01	2.333e-01	3.376	0.000777 ***
lnacres	-7.764e-01	2.223e-02	-34.921	< 2e-16 ***
Elevation	5.372e-04	8.014e-05	6.704	4.17e-11 ***
Crown density	-1.781e-02	7.767e-03	-2.293	0.022169 *
%low severity	2.380e-02	7.794e-03	3.054	0.002342 **
%med severity	-2.399e-02	7.851e-03	-3.055	0.002332 **

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 74%

Addition of spatial variables boosted the explanatory power somewhat (to 74%) meaning that nearly three-quarters of the variation in treatment costs per acre is explained by the variables in the models.

9. Results for Northern Rocky Mountain GACC- Mechanical Fuel Reduction Activities

Table 17. Northern Rockies non spatial mechanical treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	5.12926	0.10840	47.319	< 2e-16 ***
WUI1	5.02026	0.10554	47.567	< 2e-16 ***
metro1	0.17042	0.04576	3.725	0.000201 ***
activity1136	1.00789	0.28398	3.549	0.000395 ***
activity1150	-0.14070	0.10420	-1.350	0.177064
activity1152	1.02462	0.30332	3.378	0.000743 ***
activity1153	0.19398	0.10342	1.876	0.060826 .
activity1154	0.52720	0.18535	2.844	0.004492 **
activity1160	0.06765	0.11826	0.572	0.567332
activity1180	-0.18009	0.19681	-0.915	0.360274
activity4220	-0.57793	0.17426	-3.316	0.000927 ***
activity4231	0.18825	0.21823	0.863	0.388429
activity4232	0.25275	0.32958	0.767	0.443232
activity4241	0.47149	0.26779	1.761	0.078433 .
activity4455	-0.06948	0.18520	-0.375	0.707586
activity4511	0.06061	0.12326	0.492	0.623000
activity4521	0.01095	0.10234	0.107	0.914833
activity4530	-0.60256	0.11253	-5.355	9.49e-08 ***
activity6103	0.21975	0.28319	0.776	0.437847
activity6133	0.69220	0.30491	2.270	0.023297 *
activity8200	1.40052	0.36718	3.814	0.000140 ***
lnacres	-0.70086	0.01387	-50.529	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 59%

The Northern Rockies fire treatment model has intuitive coefficients. In particular, the cost of performing a prescribe fire is higher in WUI areas and in Metropolitan counties than non-WUI areas and rural areas (i.e., non-metropolitan counties). This is to be expected as salary and wages are higher in WUI and Metropolitan co unties. The explanatory power is good at 59% of the cost of treatment explained by the variables included in the model. This means that 41% of the variability in costs per acre is unexplained by the model.

Table 18. Northern Rockies spatial mechanical treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	5.022381	0.114464	43.877	< 2e-16 ***
WUI1	4.922062	0.113791	43.255	< 2e-16 ***
metro1	0.155132	0.046030	3.370	0.000764 ***
activity1136	1.010867	0.282995	3.572	0.000362 ***
activity1150	-0.145236	0.103794	-1.399	0.161876
activity1152	1.066799	0.302458	3.527	0.000429 ***
activity1153	0.185434	0.103098	1.799	0.072220 .
activity1154	0.555593	0.185269	2.999	0.002741 **
activity1160	0.062529	0.117884	0.530	0.595868
activity1180	-0.197150	0.196379	-1.004	0.315527
activity4220	-0.570744	0.174809	-3.265	0.001112 **
activity4231	0.093164	0.219238	0.425	0.670919
activity4232	0.294898	0.328834	0.897	0.369928
activity4241	0.430463	0.268989	1.600	0.109680
activity4455	-0.115457	0.184705	-0.625	0.531980
activity4511	-0.001568	0.125333	-0.013	0.990019
activity4521	0.008538	0.102239	0.084	0.933451
activity4530	-0.592732	0.112770	-5.256	1.62e-07 ***
activity6103	0.292695	0.282478	1.036	0.300239
activity6133	0.588437	0.305579	1.926	0.054281 .
activity8200	1.467325	0.366385	4.005	6.42e-05 ***
lnacres	-0.702905	0.013898	-50.575	< 2e-16 ***
slope	0.005830	0.002259	2.581	0.009913 **
crown density	0.011666	0.004664	2.501	0.012460 *
%low severity	0.006357	0.002902	2.191	0.028582 *
%mixed severity	-0.006870	0.003056	-2.248	0.024649 *

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 59.7%

The additional variables in the spatial model did not add much explanatory power as it increased by less than 1% going from 59% to 59.7%.

10. Results for Northern Rocky Mountain GACC- Fire Fuel Reduction Activities

Table 19. Northern Rocky Mtn Non-spatial fire treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	4.87181	0.09451	51.550	< 2e-16 ***
WUI1	5.06419	0.08839	57.293	< 2e-16 ***
activity1112	-0.14361	0.15124	-0.950	0.342492
activity1113	-0.04692	0.07556	-0.621	0.534736
activity1117	0.50941	0.10067	5.060	4.71e-07 ***
activity1130	-0.28971	0.07694	-3.765	0.000173 ***
activity4471	1.23486	0.36496	3.384	0.000734 ***
activity4491	0.48916	0.26254	1.863	0.062628 .
activity6101	-0.21000	0.20889	-1.005	0.314911
lnacres	-0.80975	0.01541	-52.538	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 69%

As can be seen by looking at the number of highly statistically significant variables there are several activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not significantly different than costs of the reference activity, Broadcast Burning over a majority of the unit. Further, if the activity occurs in a WUI area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficients are sensible.

The model also has a very good explanatory power of 69%, meaning that 69% of the cost per acre is explained by this set of variables. This means that only 31% of the variability in costs per acre is unexplained by the model.

Table 20. Northern Rocky Mountain Spatial fire treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	5.007273	0.107335	46.651	< 2e-16 ***
WUI1	5.186337	0.101336	51.180	< 2e-16 ***
activity1112	-0.163626	0.153215	-1.068	0.285714
activity1113	-0.026419	0.075777	-0.349	0.727407
activity1117	0.564439	0.103863	5.434	6.41e-08 ***
activity1130	-0.274643	0.078938	-3.479	0.000517 ***
activity4471	1.239038	0.363796	3.406	0.000677 ***
activity4491	0.505484	0.262233	1.928	0.054093 .
activity6101	-0.194303	0.210130	-0.925	0.355284
lnacres	-0.811780	0.015568	-52.144	< 2e-16 ***
crown density	-0.012775	0.005916	-2.159	0.030981 *
%low severity	-0.012050	0.004412	-2.731	0.006382 **
%Med severity	0.015161	0.006065	2.500	0.012530 *
Fire return int.	-0.009698	0.004613	-2.102	0.035687 *

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 69%

The explanatory power of the spatial model is the same as the non spatial at 69%. Fire fuel treatments in WUI areas cost slightly more than in non WUI areas. The spatial variables are all statistically significant indicating their importance in the model.

11. Eastern GACC Mechanical Fuel Treatment

Table 21. Eastern GACC Non-spatial mechanical treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	4.383923	0.245923	17.826	< 2e-16 ***
WUI1	4.765758	0.243778	19.550	< 2e-16 ***
metro1	0.002321	0.047617	0.049	0.961135
activity1150	0.289046	0.252168	1.146	0.251784
activity1152	-0.201494	0.266230	-0.757	0.449205
activity1153	0.631350	0.243210	2.596	0.009480 **
activity1154	-0.509194	0.257364	-1.978	0.047964 *
activity1160	0.832528	0.250662	3.321	0.000907 ***
activity1180	0.148292	0.247313	0.600	0.548809
activity2530	0.136849	0.283551	0.483	0.629396
activity4102	-0.690028	0.253221	-2.725	0.006467 **
activity4113	-0.141746	0.278918	-0.508	0.611350
activity4115	-0.833374	0.345411	-2.413	0.015895 *
activity4117	-0.375225	0.244675	-1.534	0.125242
activity4131	-0.227191	0.273472	-0.831	0.406173
activity4132	-0.436839	0.292548	-1.493	0.135485
activity4143	-0.152399	0.492284	-0.310	0.756905
activity4151	-0.304651	0.254605	-1.197	0.231572
activity4194	-0.831920	0.298645	-2.786	0.005376 **
activity4220	-0.478510	0.242728	-1.971	0.048772 *
activity4231	0.514056	0.385926	1.332	0.182960
activity4241	-2.718943	0.355611	-7.646	2.78e-14 ***
activity4270	-0.113799	0.355421	-0.320	0.748854
activity4473	0.434391	0.442204	0.982	0.326015
activity4474	0.731944	0.248699	2.943	0.003274 **
activity4475	0.331949	0.321976	1.031	0.302636
activity4484	0.848519	0.294497	2.881	0.003989 **
activity4492	1.337335	0.321621	4.158	3.30e-05 ***
activity4493	0.591448	0.243612	2.428	0.015248 *
activity4494	0.786543	0.260613	3.018	0.002566 **
activity4495	0.878584	0.242037	3.630	0.000288 ***
activity4511	0.695760	0.240365	2.895	0.003824 **
activity4521	0.651676	0.242142	2.691	0.007157 **
activity4530	0.512856	0.272977	1.879	0.060376 .
activity6107	0.416858	0.245359	1.699	0.089428 .
lnacres	-0.809845	0.013720	-59.028	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 66%

As can be seen by looking at the large number of highly statistically significant variables there are many activities that have statistically different costs than one another. The cost of any activity that is omitted means that their cost is not different than costs of the reference FACTS activity #1120, Yarding-- removal of fuels by dragging or carrying. Further, if the activity occurs in a WUI area it has slightly higher costs than fuel treatments that do not. In this sense the signs on the coefficient is sensible. The model also has reasonable explanatory power of 66%, meaning that 66% of the cost per acre is explained by this set of variables.

Table 22. Eastern GACC Spatial mechanical fuel treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	3.9071264	0.2444706	15.982	< 2e-16 ***
WUI1	4.3029128	0.2422624	17.761	< 2e-16 ***
activity1150	0.0284042	0.2425665	0.117	0.906790
activity1152	-0.3119648	0.2581113	-1.209	0.226896
activity1153	0.2686337	0.2332869	1.152	0.249613
activity1154	-0.6801202	0.2468920	-2.755	0.005910 **
activity1160	0.6710139	0.2401604	2.794	0.005239 **
activity1180	0.2493748	0.2367054	1.054	0.292187
activity2530	-0.0729713	0.2988396	-0.244	0.807107
activity4102	-0.8096384	0.2424046	-3.340	0.000848 ***
activity4113	-0.3864286	0.2688923	-1.437	0.150791
activity4115	-0.9887793	0.3305775	-2.991	0.002803 **
activity4117	-0.4641746	0.2342411	-1.982	0.047615 *
activity4131	-0.5107780	0.2636142	-1.938	0.052767 .
activity4132	-0.5652140	0.2809421	-2.012	0.044326 *
activity4143	-0.2894396	0.4718174	-0.613	0.539621
activity4151	-0.4674388	0.2435222	-1.919	0.055018 .
activity4194	-0.9624090	0.2861206	-3.364	0.000779 ***
activity4220	-0.6676128	0.2328283	-2.867	0.004168 **
activity4231	0.1670540	0.3923523	0.426	0.670302
activity4241	-2.6669501	0.3406537	-7.829	6.79e-15 ***
activity4270	-0.0330208	0.3403509	-0.097	0.922717
activity4473	0.3799445	0.4233233	0.898	0.369510
activity4474	0.4328997	0.2388449	1.812	0.070014 .
activity4475	0.4051037	0.3093574	1.310	0.190466
activity4484	0.5052869	0.2836569	1.781	0.074961 .
activity4492	1.0110020	0.3096862	3.265	0.001109 **
activity4493	0.7076624	0.2340367	3.024	0.002518 **
activity4494	0.5408235	0.2502050	2.162	0.030735 *
activity4495	0.7046644	0.2324532	3.031	0.002455 **
activity4511	0.4362722	0.2305028	1.893	0.058495 .
activity4521	0.7748995	0.2326752	3.330	0.000878 ***
activity4530	0.1258655	0.2623480	0.480	0.631430
activity6107	0.3512916	0.2349758	1.495	0.135018
lnacres	-0.8051671	0.0135983	-59.211	< 2e-16 ***
Elevation	0.0005172	0.0001573	3.288	0.001020 **
Slope	0.0312211	0.0048347	6.458	1.24e-10 ***
Crown density	0.0550116	0.0069289	7.939	2.85e-15 ***
%low severity	-0.0074498	0.0015987	-4.660	3.30e-06 ***
Fire return Interval	0.0149143	0.0015533	9.601	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 69%

The explanatory power of the spatial model is the same as the non spatial at 69%, a slight improvement over the non spatial model. Mechanical fuel treatments in WUI areas cost slightly more than in non WUI areas. The spatial variables are all statistically significant indicating their importance in the model.

12. Eastern GACC Fire Fuel Treatment

Table 23. Eastern GACC Non-spatial fire fuel treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std. Error	t value	Probability
WUI0	4.64837	0.09237	50.322	< 2e-16 ***
WUI1	4.85132	0.07547	64.282	< 2e-16 ***
metro1	0.21467	0.07935	2.705	0.00694 **
activity1113	-0.02925	0.08395	-0.348	0.72759
activity1117	2.24914	0.29428	7.643	5.04e-14 ***
activity1130	-0.54356	0.07251	-7.497	1.46e-13 ***
activity4471	0.82569	0.58158	1.420	0.15600
activity4481	1.17772	0.22632	5.204	2.38e-07 ***
activity4491	1.24244	0.29531	4.207	2.82e-05 ***
activity6101	-0.09580	0.07257	-1.320	0.18711
lnacres	-0.86217	0.01650	-52.254	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 94%

All but three of the fire fuel activities are statistically significant. Fire fuel treatments are more expensive in WUI's (WUI1) and Metropolitan areas. What is particularly noteworthy is the very high explanatory power at 94%. This implies that only 6% of the variation of cost of fire fuel treatments is unexplained.

Table 24. Eastern GACC Spatial fire treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	**Estimate**	**Std. Error**	**t value**	**Probability**
WUI0	3.9399383	0.1344112	29.313	< 2e-16 ***
WUI1	4.0992660	0.1269346	32.294	< 2e-16 ***
metro1	0.4823268	0.0860283	5.607	2.69e-08 ***
activity1113	-0.0952970	0.0849061	-1.122	0.261978
activity1117	2.2059761	0.2893952	7.623	5.91e-14 ***
activity1130	-0.5851276	0.0778411	-7.517	1.27e-13 ***
activity4471	0.9929440	0.5645637	1.759	0.078930 .
activity4481	1.0110014	0.2236734	4.520	6.95e-06 ***
activity4491	1.1439771	0.2879702	3.973	7.64e-05 ***
activity6101	-0.0899257	0.0715241	-1.257	0.208956
lnacres	-0.8609115	0.0169049	-50.927	< 2e-16 ***
Elevation	0.0008618	0.0002004	4.300	1.88e-05 ***
Crown density	0.0440844	0.0114451	3.852	0.000125 ***
%low severity	0.0252805	0.0052104	4.852	1.42e-06 ***
%med severity	-0.0486322	0.0081559	-5.963	3.47e-09 ***
Fire return Interval	0.0236782	0.0049023	4.830	1.59e-06 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 79%

All the added spatial variables being highly significant. However, the explanatory power (R square) of this spatial model is somewhat lower than the non spatial model, a very odd result. Nonetheless, the explanatory power is still quite good with nearly 80% of the variation in the fire fuel treatment costs being explained by the model.

13. Southern Mechanical Fuel Treatment Models

Table 25. Southern Non-spatial mechanical treatment model
Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std.Error	t value	Probability	
WUI0	2.98056	0.44624	6.679	2.76e-11	***
WUI1	3.13786	0.44542	7.045	2.21e-12	***
metro1	0.28915	0.03289	8.791	< 2e-16 ***	
activity1152	3.43834	0.62880	5.468	4.85e-08	***
activity1154	1.90599	0.47029	4.053	5.17e-05 ***	
activity1160	0.65023	0.49686	1.309	0.190731	
activity1180	1.35861	0.52085	2.608	0.009132	**
activity2510	0.58350	0.54415	1.072	0.283648	
activity4113	1.65854	0.53108	3.123	0.001804	**
activity4117	1.29798	0.46173	2.811	0.004963	**
activity4131	3.12861	0.45223	6.918	5.37e-12	***
activity4132	1.35776	0.47825	2.839	0.004550	**
activity4142	0.17856	0.48746	0.366	0.714153	
activity4145	0.15472	0.48761	0.317	0.751028	
activity4146	1.46595	0.56185	2.609	0.009113	**
activity4151	-0.42291	0.51318	-0.824	0.409935	
activity4152	2.00499	0.53102	3.776	0.000162	***
activity4177	3.30680	0.54527	6.065	1.46e-09	***
activity4193	2.65045	0.49280	5.378	7.99e-08	***
activity4194	1.58796	0.53101	2.990	0.002804	**
activity4220	1.14169	0.44568	2.562	0.010456	*
activity4231	-0.56806	0.46954	-1.210	0.226422	
activity4232	1.23202	0.44952	2.741	0.006160	**
activity4241	0.87647	0.58778	1.491	0.136010	
activity4270	1.21332	0.50720	2.392	0.016797	*
activity4455	1.39143	0.51315	2.712	0.006728	**
activity4472	1.61057	0.52091	3.092	0.002004	**
activity4474	1.65220	0.45340	3.644	0.000272	***
activity4475	1.48293	0.47676	3.110	0.001882	**
activity4492	1.82193	0.47654	3.823	0.000134	***
activity4493	1.25462	0.47070	2.665	0.007723	**
activity4494	1.69583	0.45619	3.717	0.000204	***
activity4495	1.66447	0.44689	3.725	0.000199	***
activity4511	1.60492	0.44497	3.607	0.000314	***
activity4521	1.35981	0.44587	3.050	0.002306	**
activity6103	1.86680	0.46259	4.036	5.56e-05	***
activity6105	1.19883	0.52165	2.298	0.021609	*
activity6106	1.39867	0.46349	3.018	0.002564	**
activity6107	1.03151	0.44560	2.315	0.020674	*
lnacres	-0.63787	0.01147	-55.627	< 2e-16 ***	

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 61%

Obviously there are a large number of mechanical fuel treatment activities that have costs different than the baseline activity. Performing mechanical fuel treatment activities in the South is higher in WUI areas and Metropolitan counties.

Table 26. Southern Spatial mechanical treatment model

Variable	Estimate	Std. Error	t value	Probability
WUI0	2.612e+00	4.423e-01	5.905	3.83e-09 ***
WUI1	2.755e+00	4.415e-01	6.240	4.86e-10 ***
metro1	2.508e-01	3.273e-02	7.661	2.35e-14 ***
activity1152	3.584e+00	6.167e-01	5.812	6.68e-09 ***
activity1154	2.006e+00	4.611e-01	4.350	1.40e-05 ***
activity1160	6.823e-01	4.872e-01	1.401	0.161429
activity1180	1.563e+00	5.111e-01	3.059	0.002239 **
activity2510	4.025e-01	5.339e-01	0.754	0.450955
activity4113	1.693e+00	5.209e-01	3.250	0.001164 **
activity4117	1.428e+00	4.528e-01	3.153	0.001628 **
activity4131	2.896e+00	4.439e-01	6.525	7.74e-11 ***
activity4132	1.488e+00	4.693e-01	3.171	0.001534 **
activity4142	1.555e-01	4.781e-01	0.325	0.745008
activity4145	6.157e-02	4.783e-01	0.129	0.897583
activity4146	1.502e+00	5.512e-01	2.726	0.006445 **
activity4151	-1.915e-01	5.034e-01	-0.380	0.703728
activity4152	1.902e+00	5.210e-01	3.650	0.000266 ***
activity4177	3.279e+00	5.350e-01	6.130	9.73e-10 ***
activity4193	2.568e+00	4.834e-01	5.313	1.14e-07 ***
activity4194	1.427e+00	5.212e-01	2.739	0.006197 **
activity4220	1.288e+00	4.372e-01	2.945	0.003247 **
activity4231	-4.647e-01	4.606e-01	-1.009	0.313061
activity4232	1.268e+00	4.412e-01	2.875	0.004061 **
activity4241	9.938e-01	5.764e-01	1.724	0.084735 .
activity4270	1.359e+00	4.975e-01	2.732	0.006318 **
activity4455	1.157e+00	5.039e-01	2.295	0.021770 *
activity4472	1.707e+00	5.109e-01	3.341	0.000844 ***
activity4474	1.680e+00	4.446e-01	3.778	0.000161 ***
activity4475	1.489e+00	4.676e-01	3.185	0.001459 **
activity4492	1.715e+00	4.675e-01	3.669	0.000247 ***
activity4493	1.337e+00	4.617e-01	2.897	0.003790 **
activity4494	1.750e+00	4.473e-01	3.914	9.26e-05 ***
activity4495	1.492e+00	4.384e-01	3.404	0.000670 ***
activity4511	1.516e+00	4.363e-01	3.473	0.000520 ***
activity4521	1.395e+00	4.372e-01	3.191	0.001431 **
activity6103	1.841e+00	4.540e-01	4.055	5.12e-05 ***
activity6105	1.246e+00	5.115e-01	2.436	0.014897 *
activity6106	1.521e+00	4.546e-01	3.347	0.000824 ***
activity6107	1.112e+00	4.370e-01	2.544	0.010990 *
lnacres	-6.219e-01	1.162e-02	-53.515	< 2e-16 ***
Elevation	3.697e-04	6.281e-05	5.885	4.33e-09 ***
Slope	1.055e-02	2.677e-03	3.939	8.33e-05 ***
Crown density	6.927e-02	1.350e-02	5.131	3.04e-07 ***
%low severity	-6.404e-03	3.393e-03	-1.887	0.059173 .
Fire return Interval	1.386e-02	2.578e-03	5.375	8.11e-08 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 63%

The explanatory power of the spatial model is slightly higher than the non spatial and the spatial variables are statistically significant.

14. Southern GACC Fire Fuel Treatment

Table 27. Southern CACC Non-spatial fire treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std.Error	t value	Probability	
WUI0	3.503803	0.028017	125.060	< 2e-16	***
WUI1	3.596527	0.025288	142.224	< 2e-16	***
Metro1	0.124055	0.012576	9.864	< 2e-16	***
activity1112	-0.117544	0.182595	-0.644	0.52	
activity1113	0.156349	0.015490	10.094	< 2e-16	***
activity1117	1.053029	0.069886	15.068	< 2e-16	***
activity4471	0.643673	0.043465	14.809	< 2e-16	***
activity4491	0.834865	0.043499	19.193	< 2e-16	***
activity4541	0.502105	0.075487	6.652	3.29e-11	***
activity6101	0.310350	0.021095	14.712	< 2e-16	***
lnacres	-0.766403	0.003958	-193.619	< 2e-16	***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 93%

This compact model performs very well, with all but one variable statistically significantly different than the baseline activity, broadcast burning. Costs are slightly higher in WUI areas and significantly higher in metropolitan areas. The explanatory power is quite strong with 93% of the variation in the cost per acre explained by the model.

Table 28. Southern GACC Spatial fire treatment model

Dependent variable is the natural log (ln) of Cost of per acre for the activity.

Variable	Estimate	Std.Error	t value	Probability
WUI0	3.080e+00	2.994e-02	102.876	< 2e-16 ***
WUI1	3.149e+00	2.816e-02	111.823	< 2e-16 ***
metro1	1.446e-01	1.175e-02	12.309	< 2e-16 ***
activity1112	-2.073e-02	1.651e-01	-0.126	0.90009
activity1113	9.584e-02	1.446e-02	6.629	3.82e-11 ***
activity1117	9.498e-01	6.345e-02	14.970	< 2e-16 ***
activity4471	6.329e-01	3.932e-02	16.096	< 2e-16 ***
activity4491	8.462e-01	3.947e-02	21.438	< 2e-16 ***
activity4541	5.715e-01	6.837e-02	8.360	< 2e-16 ***
activity6101	2.955e-01	1.940e-02	15.235	< 2e-16 ***
lnacres	-7.455e-01	3.719e-03	-200.464	< 2e-16 ***
Elevation	6.383e-04	5.029e-05	12.692	< 2e-16 ***
Slope	5.399e-03	2.023e-03	2.668	0.00765 **
Crown density	5.923e-02	4.695e-03	12.617	< 2e-16 ***
%med severity	-2.173e-02	2.684e-03	-8.097	7.39e-16 ***
Fire Return Interval	2.285e-02	2.608e-03	8.763	< 2e-16 ***

*** significant at the 99.99% level; ** significant at the 99.9%; * significant at the 99% level; + significant at the 95% level; . significant at the 90% level. R square: 95%

All the spatial variables are statistically significant and the explanatory power increases slightly over the non spatial model.