Wildfire Fuel Reduction Cost Analysis: Statistical Modeling and User Model for Fire Specialists in California[1]

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Abstract

This research provides wildfire specialists with tools for estimating the cost of conducting various types of wildfire fuel treatments. The dependent variable in the cost regression is what the USDA Forest Service calls Planned Direct cost per acre. Independent variables included the setting in which the fuel treatment took place (e.g., the wildland-urban interface (WUI) and Metropolitan area), acres of the treatment and the specific fuel reduction activity. The primary data for the analysis came from the Forest Service Activities System (FACTS). Separate models were estimated for activities related to or conducted as part of prescribed burning fuel reduction projects and for mechanical fuel reduction activities. In addition, California is split into two Geographic Areas Coordination Center (GACC): Southern California and Northern California GACCs. 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 (R^2) of the models is 12% to 24%. An Excel spreadsheet program has been built to allow managers to easily use the four regression models to estimate the cost of any specific fuel treatment program on the land. The user selects up to three FACTS fuel treatment(s) being proposed, whether the fuel treatment is in Northern or Southern California GACC, then the specific county of the treatment, and whether the proposed treatment is in a WUI area. Based on this selection the spreadsheet model utilizes the respective regression model to provide an estimate of the cost per acre for each FACTS activity and the total treatment cost reflecting the number of acres of the project that the user has previously specified. The spreadsheet adds up the costs for each FACTS activity that the overall fuels treatment project would entail. The model has been "tested" with fire specialists in California who felt it was a useful tool to aid in estimating the costs of fuel reduction projects.

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Introduction and Objectives

Fuel treatments are increasing viewed as a means to reduce the severity of wildland forest fires, and make these fires easier to control and suppress. An ancillary goal is to reduce property damages and lives lost due to wildfires. While these are desirable goals of a fuel treatment program, prescribed burning and mechanical fuel reduction are costly to conduct. As such they have to be budgeted for. In order to budget for them, it is necessary to have some systematic method to estimate the costs.

The overall objective of this research project is to provide forest managers and wildfire specialists with tools for estimating the cost of conducting various types of wildfire fuel treatments. Specifically this research provides a: (a) statistical analysis of USDA Forest Service data to develop a cost estimating model; and (b) user friendly macro driven spreadsheet model based on the statistical analysis for easy USDA Forest Service field use.

Statistical Cost Analysis of Mechanical Fuel Treatment and Prescribed Burning

Since our primary objective with this model was to give managers a cost estimating tool in California, our analysis was guided by a certain degree of pragmatism. While the model had to be conceptually correct and consistent with the past literature, it also had to provide as accurate an estimate of cost per acre consistent with the USDA Forest Service data. Thus this is applied research, not an attempt at advancing the econometric methods used to estimate the fuel reduction treatment costs. The reader should keep this in mind in the discussion that follows.

Initial Model Specifications

Guided by the literature review (González-Cabán and McKetta, 1986; Rideout and Omi, 1995; Wood, 1998), an initial multiple regression model was specified. The dependent variable was what the USDA Forest Service called Planned Direct cost per acre in its data set. The independent variables included the setting in which the fuel treatment took place (e.g., WUI and Metropolitan area), acres of the treatment, and each FACTS activity.

WUI: whether the activity occurred in or adjacent to a "…area, or zone where structures or other human development meet or intermingle with undeveloped wildland or vegetative fuels" (FACTS manual, page 39). The expected sign is positive (it is more expensive to conduct activities in WUI area due to extra precaution needed). Specifically, the WUI variable 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.

Acres: The number of acres actually treated by the activity

Data

The primary data for the analysis came from the Forest Service Activities System (FACTS). This system covers all the work codes routinely used by the USDA Forest Service. From the large list of activities available in FACTS, we used the model specification above and the literature to request a subset of all the variables. Further, variables that were often coded as text were recoded to numerical values. Other variables included Work Agent and Ranger District. This resulted in 25 variables. For the preliminary analysis the following activity codes were considered fuel related in the sense that one or more of these activities were conducted as part of fuel reduction projects. Table 1 on the next page provides a short definition of the FACTS Activities in the User Model. Detailed descriptions of these variables can be found in the FACTS User Guide (USDA Forest Service, 2013; http://fsweb.nrm.fs.fed.us).

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 Thin
4530	Prune
4540	Control for Understory Vegetation
6101	Wildlife Habitat RX Burn
8000	Insect & Disease Activities
10100	Other activities

Detailed descriptions of these variables can be found in the FACTS User Guide (USDA Forest Service, 2013; http://fsweb.nrm.fs.fed.us)

After reviewing the initial data sets there was a significant amount of discussion about a few concerns with the data. Some costs per acre were reported as zero. There was a significant amount of discussion about whether these were simply place holders entered into the program, as it did not seem likely that the particular activity had zero costs. There were also a large number of costs that were $1 per acre. The consensus was to drop these observations with zero costs and $1 per acre costs as they are not likely to reflect actual costs incurred. At the high end of the spectrum some costs per acre were more than five standard deviations. There were some costs that were even ten standard deviations from the mean costs. At five standard deviations from the mean the cost was $1818 per acre. At ten standard deviations from the mean, the cost was $3843 per acre, with the next highest cost being more than $1,000 higher than $3843. The decision was made to cut off costs at 10 standard deviations from the mean ($3843). This resulted in just 15 observations being lost (.1% of the sample).

Regression Modeling Strategies

Given the small sample sizes for some of the fuel reduction activities, there was exploratory analysis on whether to estimate separate regressions for the FACTS activities for which there were minimum sample sizes (e.g., $n \geq 20$) or pool the data on various activities and estimate one model with intercept shifters for each activity. Only four FACTS activities had a sample size over 100 (piling of fuels, pre-commercial thin, rearrangement of fuels and crushing of fuels) and only four had sample sizes between 77 and 99 (site preparation, tree release & weed, yarding and chipping of fuels). If individual activity level regressions were to be run, it was felt there were not enough degrees of freedom to include activities with much smaller samples. Thus, estimating one model with all the activities included and distinguishing the activities by intercept shifters had several advantages: (a) initially allowing for inclusion of all activities; (b) testing for whether there was statistically difference in the cost per acre by activity; (c) higher R2 explanatory and predictive power. Given these advantages it was decided to go with the pooled model.

Two separate pooled models were estimated. One for activities related to or conducted as part of prescribed burning fuel reduction projects and one for mechanical fuel reduction activities. In addition, California is split into Southern California GACC and Northern California GACC geographic areas (GACC stands for Geographic Area Coordination Centers, each responsible for leading wildfire efforts in their respective regions). A statistical analysis of a single state model versus splitting the state into north and south showed the separate models were statistically superior. Thus, the costs of treatment varies systematically between Northern and

Southern California. Therefore we have a total of four individual regressions: two for Northern GACC and two for Southern GACC. Each region has a model for prescribed fire fuel reduction and a model for mechanical fuel treatment.

In the fire fuel treatment model, FACTS Activity 1111 Broadcast Burning is used as the reference activity and a separate coefficient is not explicitly estimated. However, as there is no constant in the model, Broadcast Burning is essentially the constant. Thus, all the FACTS Activity cost coefficients are measured relative to Broadcast Burning. The user model automatically adds or subtracts (depending on the sign of the other FACTS Activity coefficient) the cost of that particular activity from the default average cost of Broadcast Burning ($231 Planned Cost per acre).

Statistical Results

Table 2 presents the results for the four models that correspond to Southern California (Models 1 and 2 for prescribed burning and mechanical fuel reduction, respectively) and Northern California (Models 3 and 4 for prescribed burning and mechanical fuel reduction, respectively).

The dependent variable is the natural log of the costs per acre to allow for non-linearity in costs per acre. The base case for prescribed burning models 1 and 3 is FACTS activity 1111 (broadcast burning). So when all the other activity variables are set to zero, the model estimates the cost per acre of broadcast burning (the spreadsheet program in Section 3 accounts for this automatically).

Likewise the omitted activity for mechanical fuel reduction is FACTS activity 1130 (burning piled material).

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 does fall slightly as the number of acres treated increases. Thus there is a slight degree of economies of scale for prescribed burning and mechanical fuel reduction in Northern California. 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 that .1% of observations with costs more than 10 standard deviations from the mean, the data 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. 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

significant at the 99% level, ** is significant at the 95% level,
* is significant at the 10% level.

User Cost

Estimating Program

An Excel (version 2007 or later) spreadsheet program has been built to allow managers to easily use the four models estimated above to estimate the cost of a fuel treatment program.

To start the analysis, first step is to open Excel and do File Open the Fire Treatment Cost Estimator file. Once the file has loaded the user should have a spreadsheet that looks like Figure 1 on the next page. In general the **white areas are what the user fills in using drop down menus on the right side of each cell).** The gray shaded area below the white input cells is the results area showing Per Acre Cost and Total treatment costs. In the example, the fuel treatment being proposed is in the Southern California GACC geographic region, County is Mono, and the proposed treatment is not in a WUI. In this example, three FACTS fuel treatment activities have been selected, each with different acres. Given this input, the costs are calculated and displayed in the gray cells.

Region 5: California	Regression Model

START HERE (Enter these fields first)

↓↓↓↓

GACC	South
County	Mono County
Wildland Urban Interface	No

	Activity Name	Acres Treated
Activity Treatment #1	1113 Underburn, Low Intensity	200
Activity Treatment #2	1136 Pruning to Raise Canopy Height	1000
Activity Treatment #3	4521 Precommercial Thin	10

	Per-Acre Costs:	Total treatment costs:
Activity Treatment #1	$134	$26,758
Activity Treatment #2	$389	$389,273
Activity Treatment #3	$274	$2,742
All treatments	$797	$418,773

Figure 1. Screen shot of the R5 Fuel Treatment Cost Estimator Spreadsheet Interface

To set the input values, the fire specialist uses the drop down on the right side of each white cell. In order to get the drop down menu indictor to be visible, the user must click on that input cell, then on the right of the cell, the drop down menu indicator triangle will appear. The drop down is indicated by a square box with a downward facing triangle in it (▼). The drop down triangle only appears when you click on the cell, otherwise it is not visible. There are six input cells. These area:

- whether the project is in Northern California or Southern California GACC. The drop down menu has North or South as the choices.
- what county. The drop down is a list of counties in that GACC. The program then automatically (without any separate display) links to whether the county in that GACC is considered a metropolitan county or not.
- whether the project is in a Wildland Urban Interface (WUI) area or not. The drop down menu is simply Yes or No
- Then the user specifies up to three fuel treatment activities from a drop down list of FACTS activities.

These activities can be all prescribed fire, all mechanical or a combination of both. The program selects the appropriate set of FACTS activity variable coefficients to bring in to perform the calculations on.
- Then the user provides the number of acres that each FACTS Activity will be performed on. Each activity can have a different number of acres.

Based on this selection the spreadsheet model selects the appropriate coefficient from the appropriate statistical model to provide an estimate of the cost per acre for each FACTS activity and the total treatment cost reflecting the number of acres of the project that the user has previously specified. The spreadsheet adds up the costs for each FACTS activity that the overall fuels treatment project would entail.

Conclusion

The objective of this research was to provide wildfire manages with a simple tool for estimating the cost of fuel treatments. To achieve this objective, we developed a spreadsheet cost estimator, the foundation of which is a multiple regression model. To develop the regression model of the costs of fuel treatments in California we obtained USDA Forest Service FACTS fuel treatment cost data for California. This data was first "cleaned" of obvious errors such as fuel treatments whose costs were reported as zero or one dollar per acre. At the other extreme was some fuel treatment costs per acre that were reported to be more than 10 standard deviations from the mean (e.g., about 10 observations had costs slightly more than $4,000 an acre). With a clean data set we estimated four pooled fuel treatment cost models:

- Northern California prescribed burning
- Southern California prescribed burning
- Northern California mechanical fuel treatment
- Southern California mechanical fuel treatment

Overall these models are reasonably good statistical models of the factors influencing costs of prescribed burning and mechanical fuel reduction. In particular, in all four models treatment costs increased in WUI and metropolitan counties (i.e., higher labor costs). There was a slight degree of economies of scale as the cost coefficient was negative and statistically significant in three of the four cost regressions.

Each of these equations were programmed into one macro driven Xcel (2007 or later) spreadsheet that was designed to be easy for fire specialists to use. The data inputs for the spreadsheet are only:

- Whether the fuels treatment would be in northern or southern California

- The county where the fuel treatment would be located (drop down list is provided)
- Whether the fuel treatment would be located in a WUI
- Up to any three FACTS fuel treatment activities. These can be any combination of three burning or mechanical treatments (a drop down list is provided)
- Acres of each treatment (these can be different or the same for each fuel treatment activity).

After these data are input, the program automatically calculates the per acre costs of each treatment activity and the total cost of each treatment activity and the total cost.

We feel this is a useable tool and a useable approach. Depending on the reception of fire specialists as to the utility of this tool, it could be improved by professional programming into a more polished program. Further, it could be expanded to other GACC's in the U.S. Our preliminary investigation into these other USDA Forest Service Regions indicates that similar FACTS data, with equivalent data quality issues, does in fact exist and is amenable to the same type of statistical analysis and hence program as performed here.

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