Estimating Timber Harvesting Costs For Fuel Treatment in the West: Preliminary Results

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Abstract

Preliminary of estimates of harvesting costs for forest fuel reduction treatments in the West are presented. Cost estimates were made for typical stands based on Forest Inventory and Analysis (FIA) plots that represented forest stands in 12 western states, using the ST Harvest spreadsheet system. Costs were estimated for a range of harvesting systems, forest conditions, and harvest intensity levels. The approach is described, functional form of the cost equation is presented and discussed, and initial average costs are summarized based on a small sub-sample of the data.

Introduction

Concerned with the rising damages and suppression costs associated with catastrophic wildfire, the United States General Accounting Office called for a cohesive strategy of fuel reduction treatments to control excessive losses to wildfires. The federal Comprehensive Strategy and Implementation Plan were the two principal USDA Forest Service and Department of Interior responses. In addition, the president and Congress have encouraged fuel treatments through the Healthy Forests Restoration Act, National Fire Plan, and Healthy Forests Initiative. All of these initiatives propose greatly increasing the amount of fuel reduction treatments, including prescribed fire and mechanical approaches. In some cases, mechanical fuel treatments involve the removal of marketable timber products.

Mechanical fuel treatments are different from typical harvests because they involve partial cutting, with small diameter materials requiring the most effort and larger diameter materials the least; in that sense, they are similar to thinning operations. Many of the proposed mechanical treatments may be on steep sites, so their expense per unit of material removed is likely to be different from typical silvicultural treatments. This will affect the net costs of these treatments. The removal of products also will result in impacts on the local and regional timber markets by potentially increasing the supply of some products to mills. This will influence the price of products at the mill, which will in turn affect the net returns to the landowner.

As part of a large research project, the USDA Forest Service Southern Research Station is developing a model that will determine the optimal allocation of fuel treatments across fire prone regions of the United States. This model is estimating the appropriate mix of treatments across space and over time and the amount of subsidy that the government will need to provide to

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reduce forest fuel loads and their eventual wildfires. Determining harvest costs for these treatments for all regions and forest types of the U.S. is part of this larger project.

Previous studies of products available from fuel treatments (Fried 2003) have focused on very specific locations (SW Oregon, Sierra Nevada). These projects all used FIA data at the plot level combined with the use of the Forest Vegetation Simulator and either assumptions or the use of ST Harvest to develop harvest costs for each plot and treatment type. Given the scope of the proposed work (all FIA plots in the West), this approach was not feasible. Instead, we developed a new approach described below.

Methods

Harvesting costs are affected by many factors, including tree species, terrain, tree size, stand volume, equipment type, and labor skills (Cubbage et al.1989, Carter et al. 1994, Kluender et al. 1998, Keegan et al. 2002). There are several harvest cost models in use for different regions of the country and different types of timber and harvesting techniques. For the purposes of this study, ST Harvest was used to estimate fuel treatment costs.

This research investigated the effects of several factors, including tree size, tract volume and removal intensity on harvesting costs for applying fuel treatments to Forest Inventory and Analysis (FIA) plots in 12 states located in the Western United States. Ground and cable-based harvesting systems were included and their costs were estimated using ST Harvest (Hartsough 2001). Regression analysis was then used to develop cost equations to predict harvesting costs for each system as a function of tree size, location, tract volume, tree density and removal intensity.

Both whole-tree (WT) and log-length systems were included in the empirical analysis of the harvesting costs for applying fuel treatments to FIA plots using ST Harvest. The six harvesting systems included in this analysis are shown in Table 1 together with the conditions under which they customarily operate. In the whole-tree harvesting method, the tree is felled and delivered to the landing with limbs and tops attached to the stem. In the short-wood or log-length method, trees are processed at the stump. Figure 1 illustrates the steps and activities at each phase of harvesting for both systems.

ST Harvest (Hartsough et al. 2001) was used to estimate production and costs of the six harvesting systems shown in Table 1. The ST harvest computer application is Windows-based, public-domain software used to estimate costs for harvesting small-diameter stands or the small-diameter component of a mixed-sized stand (Fight et al. 2003). This program estimates costs of harvesting small trees in stands in the interior Northwest. ST Harvest provides production functions for harvesting as part of the simulation package, and allows users to use the default costs or update those costs. Equipment prices in the model were updated with current prices from the Green Guide (2005). Table 2 shows the assumptions included in ST Harvest to estimate harvesting costs in this study.

Table 1. Ground-based or cable systems and condition to operate

Tree size and slope	**Manual Felling**			**Mechanical felling**		
	Ground based		**Cable**	**Ground based**		**Cable**
	Whole tree length	**Log length**	**Log length**	**Whole tree length**	**Log length**	**Log length**
Maximum tree size (ft^3)	150	150	150	80	80	80
Minimum tree size (ft^3)	1	1	1	1	1	1
Maximum slope (%)	<40	<40	>40	<40	<30	>40

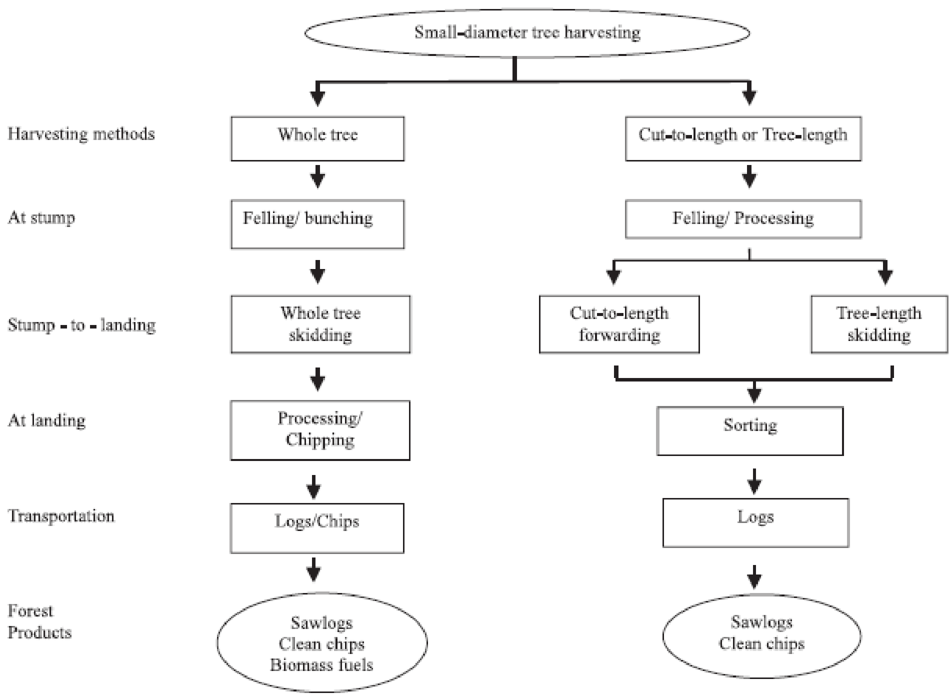

Figure 1. Flow chart of small wood harvesting in whole-tree and cut-to-length/tree-length operations (Han-Sup et al. 2004)

The FIA data plots represented typical forest conditions in the West. The harvesting scenarios for these plots were based on research by colleagues at the USDA Forest Service Southern Research Station and Pacific Northwest Research Station. The Forest Service researchers developed forest harvesting rules that would be appropriate for reducing the risk of forest fires, by limiting spread along the crown and crowning--the spread of fires from the ground to the crown of the trees. They then provided these harvesting rules and scenarios to us, along with sets of summarized FIA plot level data (Huggett 2005, personal comm.). We then used the ST Harvest spreadsheet simulator to estimate harvesting costs for these FIA plots based on tree density conditions, the amount of material to be harvested, and the harvesting systems that would be appropriate for the slope conditions of that FIA plot. We had more than 30,000 FIA plots so needed automated methods to run all the harvest simulations. We were able to obtain a ST Harvest front-end simulator from Bruce Hartsough (personal comm. 2005; Chalmers et al. 2003), which was then used to be able to run the 30,000+ FIA plot harvest simulations swiftly.

Table 2. Assumptions used in ST Harvest to estimate harvesting costs for applying fuel treatments to FIA plots

Variable	Unit	Value
Logging system	---	Whole-tree and log-length harvesting methods, ground based and cable yarder
Cut type	---	Partial cut
Yarding distance	Feet	800
Slope	%	Range from -1% to 85%
Move-in distance	Miles	50
Harvested area	Acres	50
Removal intensity	Cut trees/acre	Range from 0 to 4,682
Tree size	DBH class	d3 < 5" d6 = 5"-6.9" d8 = 7"-8.9" d10 = 9"-10.9" d12 = 11"-12.9" d14 = 13"-14.9" d15 = 15"+"

The FIA plots provided a large sample of conditions in the West and an excellent means to estimate basic regression equations of timber harvesting costs by important variables. Once production rates and costs were estimated using ST Harvest a set of regression equations were estimated to develop an average of harvest costs for the 12 states included in this study. The method of least squares was used to fit a prediction equation of harvesting costs to the data.

Selection of functional form for the timber harvesting cost equations was based on knowledge of timber harvesting operations, past studies, and statistical procedures. In general, timber harvesting is very expensive for small stands and small stems, since it takes many actions with expensive equipment and labor to harvest a small amount of volume. This characteristic has been estimated quantitatively in several studies, which have found that timber harvesting costs are much greater for small stems and for small tracts, and decline asymptotically to a minimum level at large stem size and tract size.

We estimated harvesting costs per dbh class using the following functional form:

$$\begin{aligned}
&\ln(\text{harvesting cost per acre and per dbh class}) = \beta_0 + \beta_1\,\text{DBHSm} + \beta_2\,\text{DBHMed} + \beta_3\,\text{Arizona} + \\
&\beta_4\,\text{California} + \beta_5\,\text{Colorado} + \beta_6\,\text{Idaho} + \beta_7\,\text{Montana} + \beta_8\,\text{Nevada} + \beta_9\,\text{New Mexico} + \\
&\beta_{10}\,\text{Oregon} + \beta_{11}\,\text{South Dakota} + \beta_{12}\,\text{Utah} + \beta_{13}\text{Washington} + \beta_{14}\ln(\text{total volume per acre}) + \\
&\beta_{15}\ln(\text{trees removed per acre}) + \beta_{16}\ln(\text{trees per acre}) + \beta_{17}\,\text{Slope} + \\
&\beta_{18}\ln(\text{trees removed per acre}) * \ln(\text{trees per acre}) + \varepsilon
\end{aligned}$$

where ln is the natural log, harvesting cost is measured in $US per acre, per plot and per dbh, DBHSm is a dummy variable taking on the value of one for trees with DBH less than 6.9 inches, DBHMed is a dummy variable taking on the value of one for trees with DBH between 7 and 12.9 inches and total volume removed per acre is measured in cubic feet. The western states included in the data frame were Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington and Wyoming. Table 3 shows the descriptive statistics of the variables included in this analysis.

Table 3. Descriptive statistics of independent variables included in cost analysis

Variable	Description	Mean*	Standard deviation	Coefficient of variation (%)
TOTVOL	Total volume removed per acre (ft^3/acre)	546.45	706.63	129.20
TREEACRE	Number of trees per acre	147.60	222.69	150.86
TREEREM	Number of trees removed per acre	86.67	147.26	169.89
SLOPE	Slope (%)	25.43	21.93	86.23
DBHSM	Dummy variable for small trees = 1 if DBH is less than 6.9 inches	0.43	0.49	---
DBHMED	Dummy variable for medium trees = 1 if DBH is between 7 and 12.9 inches	0.42	0.49	---
ARI	Dummy variable for region = 1 if state is Arizona	0.017	0.129	---
CAL	Dummy variable for region = 1 if state is California	0.172	0.377	---
COL	Dummy variable for region = 1 if state is Colorado	0.208	0.406	---
IDA	Dummy variable for region = 1 if state is Idaho	0.086	0.280	---
MON	Dummy variable for region = 1 if state is Montana	0.096	0.294	---
NEV	Dummy variable for region = 1 if state is Nevada	0.001	0.033	---
MEX	Dummy variable for region = 1 if state is New Mexico	0.033	0.179	---
ORE	Dummy variable for region = 1 if state is Oregon	0.185	0.388	---
SDA	Dummy variable for region = 1 if state is South Dakota	0.002	0.053	---
UTA	Dummy variable for region = 1 if state is Utah	0.022	0.147	---
WAS	Dummy variable for region = 1 if state is Washington	0.140	0.347	---

* Including 34,595 records of 12,039 plots located in twelve states in the West

This functional form allows one to use the results without needing to know the units of measurement of variables appearing in logarithmic form, because the slope coefficients are invariant to rescaling. Moreover, by using ln(harvesting cost per acre and per dbh class) as the dependent variable we can satisfy the Classical Linear Model (CLM) assumptions more closely. Strictly positive variables (as is the case for harvesting costs) often have conditional distributions that are heteroskedastic or skewed; taking the log can mitigate both problems. There are also some standard rules of thumb for taking logs. When a variable is a positive dollar amount, the log is often taken.

A high coefficient of variation was associated with total volume removed per acre, number of trees per acre, and number of trees removed per acre as related to the different fuel treatment scenarios and the different geographical locations of the 12,039 FIA plots. This permitted us to estimate a robust and very representative harvesting cost function that can be applied to different treatment scenarios and locations.

For the case of the dependent variable, harvesting costs in dollars per acre were estimated for the 34,595 records, which included the six ground-based and cable harvesting systems included in this analysis. Table 4 shows the harvesting costs included in this study as the dependent variable, which were obtained using ST Harvest. Table 4 shows high coefficient of variations for all harvesting systems given that dbh classes go from small diameter trees to larger diameter tress which affects fuel treatment costs. The variation is also explained for the application of different harvesting systems under different conditions of tree density and with different harvesting intensities. And again, as was the case for the independent variables shown in Table 3, the high coefficient of variation of harvesting costs shown in Table 4 is also explained by different slope conditions and plot location.

Table 4. Descriptive statistics of harvesting costs per acre and per dbh class obtained with ST Harvest and included in cost analysis

Variable	Description	Mean	Standard deviation	Coefficient of variation (%)
MANWT	Cost of ground-based manual whole tree harvesting system ($/acre/dbh)	1,274(1)	1,029	80.77
MANLOG	Cost of ground-based manual log harvesting system ($/acre/dbh)	1,905(1)	1,450	76.12
MECHWT	Cost of ground-based mechanical whole tree harvesting system ($/acre/dbh)	1,032(1)	1,110	107.56
CTL	Ground-based cut to length harvesting system ($/acre/dbh)	1,364(2)	1,287	94.35
CABLEMAN	Cost of cable manual log harvesting system ($/acre/dbh)	5,876(3)	6,412	109.12
CABLECTL	Cost of cable cut to length harvesting system ($/acre/dbh)	5,250(3)	5,691	108.40

(1) Including 26,319 records of 9,466 plots located in twelve states in the West
(2) Including 22,306 records of 8,178 plots located in twelve states in the West
(3) Including 8,275 records of 2,573 plots located in twelve states in the West

Results

Using functional form presented in (1) and the information on harvesting costs obtained from ST Harvest and shown in Table 4, Table 5 shows the results of the parameter estimates of the harvesting cost function for fuel treatments of FIA plots for a ground-based manual whole-tree harvesting system. We also have preliminary results for five other harvesting systems listed in Table 4, but so not have space here to summarize them all. Thus this system is used to illustrate the approach, and details on the other systems will be published later or become available from the authors as final results are estimated.

Table 5 shows that the dummy variable for Arizona (ARI), California (CAL), Idaho (IDA), Nevada (NEV), New Mexico (MEX), Utah (UTA) and Washington (WAS) were not significant at the 5% level. All the rest of the independent variables were significant at least at the 5% confidence level after correcting for heteroskedasticity. These dummy variables thus shift the intercept of the cost equations up or down by state. When log(y) is the dependent variable in a model, as it is the case for the functional form presented in (1), the coefficient on a dummy variable, when multiplied by 100, is interpreted as the percentage difference in y, holding all other factors fixed.

We used three broad DBH classes in estimating the regressions of harvesting costs, by collapsing the 7 original classes described in Table 2 into only three dummies: small, medium, and large. To avoid problems with rank conditions in the regression estimation, the effect of the large tree dbh class is contained in the constant of the regression, which is significant. The coefficients on dbh class β_1 and β_2 gives the approximate proportional difference in harvesting costs per acre for those small trees (dbh less than 6.9 inches) and medium trees (dbh between 7 and 12.9 inches), respectively. This implies that the coefficient on DBHSM gives the approximate proportional differential in harvesting costs between those who are and are not small trees. In this case, the coefficient on DBHSM is .064, thus the harvesting costs are 6.4% higher for small trees than large trees, holding medium size tree, state, total volume, removal intensity, trees per acre and slope constant. Similarly, for this case harvesting costs are 8.1% lower for medium size trees than large trees, holding small tree size, state, total volume, removal intensity, trees per acre and slope constant. This indicates that both small and large trees are more costly to harvest given the typical equipment used in ground-based manual systems for fuel treatment harvests.

Table 5. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a ground-based manual whole tree harvesting system

Independent variables	**Parameter**	**Estimated coefficient (OLS)**	**Standard error**	**P-value**
Constant	β_0	2.484	0.023	0.000
DBHSM	β_1	0.064	0.013	0.000
DBHMED	β_2	-0.081	0.007	0.000
ARI	β_3	-0.006	0.008	0.442
CAL	β_4	-0.003	0.006	0.625
COL	β_5	0.032	0.005	0.000
IDA	β_6	0.005	0.006	0.395
MON	β_7	-0.034	0.006	0.000
NEV	β_8	0.020	0.022	0.363
MEX	β_9	-0.009	0.007	0.171
ORE	β_{10}	-0.011	0.005	0.029
SDA	β_{11}	-0.046	0.013	0.001
UTA	β_{12}	-0.016	0.009	0.071
WAS	β_{13}	0.003	0.005	0.598
LNTOTVOL	β_{14}	0.408	0.005	0.000
LNTREEREM	β_{15}	-0.486	0.003	0.000
LNTREEACRE	β_{16}	0.515	0.006	0.000
SLOPE	β_{17}	0.006	0.000	0.000
LNTREEACRE*LNTREEREM	β_{18}	0.050	0.000	0.000
N	26,319			
R^2	0.969			
Adjusted R^2	0.969			
F-value	45,492			0.000

The coefficients on the different states included in this study give the proportional change in harvesting costs per acre between those trees that are and are not located in each one. For the case of Colorado for example (COL), harvesting costs per acre are 3.2% higher holding constant dbh class, other states, total volume per acre, removal intensity, trees per acre and slope. Coefficients on LNTOTVOL, LNTREEREM and LNTREEACRE were very significant in predicting harvesting costs per acre. For these cases β_{14}, β_{15} and β_{16} represent the elasticity of harvesting costs per acre with respect to total volume per acre, removal intensity and number of trees per acre respectively. According with Table 5, when TOTVOL, TREEREM and TREEACRE increases by 1%, harvesting costs increase by approximately 0.41%, decrease by 0.49%, and increase by 0.52% respectively holding constant tree size, state and slope.

The coefficient β_{18} measures the impact on harvesting costs per acre based on the interaction between trees per acre and number of trees removed per acre. In this case, the interaction was very significant. One would expect this result since the interaction variable is measuring the fuel treatment effect on the selection of removal intensity. In this case, the effect of one unit change in trees per acre will depend on the level of number of trees removed per acre and vice versa. When trees per acre or removal intensity changes by 1%, the interaction term makes increase harvesting cost per acre by 0.050%. β_{17} is the semi-elasticity of harvesting costs per acre with respect to slope. When slope increases by 1%, harvesting costs per acre increases approximately by 0.60%.

The model estimated and presented in Table 5 was very significant (P-value < 0.000) and explained 96.9% of the variation in harvesting costs per acre for applying fuel treatments to FIA plots. Much of the significance can be attributed to the large sample size, but the large coefficient of determination also indicates the model fit the harvesting cost data well. The results for the calculations shown in Table 5 were illustrative of the process, but may need adjustment for move-in costs in future research. ST Harvest gives cost estimates for specific combinations of removal intensities and tree volume. For complete estimates of costs per plot, one has to weight the different combinations of tree removal intensity and tree volume for every plot. These weights were proxied by the ratio between trees removed per dbh class and total number of trees removed for each plot included in this study. The comparative findings about the importance of the variables affecting costs remain unchanged. Preliminary results for other timber harvesting systems and equipment configurations were calculated, although revisions remain in progress. To provide more accessible results of the weighted costs for this paper, a sample of 20 plots was used and the mean and standard deviations of timber harvesting costs were calculated (Table 6).

Table 6. Sample Fuel Harvesting Cost Calculations per Acre for FIA Plots for Four Ground-Based Systems in the West, U.S. Dollars, 2005

System	Mean ($/acre)	Standard Deviation	Coefficient of Variation (%)
Manual Whole-Tree	740	455	61.49%
Manual Log	1,136	748	65.85%
Mechanical Whole-Tree	552	278	50.36%
Cut-to-Length	699	351	50.21%

Conclusions

For our preliminary results from the 20 plot samples, the mean fuel harvesting costs based on our regression equation estimates ranged from $552 per acre to $1,136 per acre. Mechanical whole-tree harvesting operations were cheapest on average, followed by cut-to-length and manual-whole tree. Variations in the cost estimates are again partly explained by the different harvesting system applied, slope condition, plot location, tree density condition and removal intensity defined for every dbh class.

Several preliminary conclusions can be made as a result of this study. Considering a ground-based manual whole tree harvesting system, dbh class, state (Colorado, Montana and South Dakota), tract volume, trees per acre and removal intensity appear to be the most statistically significant variables that explain the variation in harvesting costs per acre. Regarding with a ground-based manual log harvesting system, dbh class, state (Colorado, Montana and Washington), tract volume, trees per acre and removal intensity were the most statistically significant variables that explain the variation in harvesting costs per acre. For the case of a ground-based mechanical whole tree harvesting system, dbh class, state (Colorado, Montana and Oregon) were the most statistically significant variables in explaining cost variation.

For the cut to length harvesting system, small trees size (dbh < 6.9"), state (Colorado and Montana), tract volumes, trees per acre and removal intensity were the most statistically significant variables that explain the variation in harvesting costs per acre. For the case of the cable-based harvesting systems, only small trees size (dbh < 6.9"), tract volumes, trees per acre and removal intensity were the most statistically significant variables to help to explain the variation in harvesting costs per acre. For these harvesting systems plot location was not significant.

Slope was statistically significant no matter which harvesting system was selected, although its impact on costs was small. The impact of slope on cost was large only for the case of a ground-based mechanical whole tree harvesting system, where a 1% increase in slope caused a 1.3% increase in harvesting cost per acre. Regardless of harvesting system, costs tend to decrease when total tract volume and removal intensity increase. The opposite trend is observed when initial trees per acre increase.

This research provides considerably more information about timber harvesting costs for fuel reduction treatments. It developed a method to estimate timber harvest costs for fuel treatments in the West based on existing harvesting technologies, an existing western timber harvesting simulation package, and extensive FIA plot level data for 12 western states. Our results are preliminary since this is still a work in progress. The results do indicate that fuel harvesting costs are expensive. Fuel reduction harvests take out a large share of small stems, using either expensive equipment or lots of manual labor, often on steep terrain. This is far less economically efficient than harvesting fewer large trees with much more volume, which is typical of normal sawtimber harvests in the West.

Providing much better estimates of these fuel reduction harvest costs can help managers plan how to allocate their budgets and forest and homeowners decide how to protect their property. We will continue these analyses and discuss their implications more as this research proceeds.

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