Estimating the Avoided Fuel-Treatment Costs of Wildfire

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ABSTRACT

Although the importance of wildfire to fire-adapted ecosystems is widely recognized, wildfire management has historically placed less emphasis on the beneficial effects of wildfire. We estimate the avoided fuel treatment cost for 10 ponderosa pine (*Pinus ponderosa*) stands on the Umatilla National Forest in the Pacific Northwest. Results show that fires in stands that show the greatest divergence from the archetypical ponderosa pine stand structure (large trees in an open, parklike stand) tend to have higher avoided costs. This is a reflection of the higher cost of fuel treatments in these stands: treatments designed to restore a stand to a desired condition are normally more expensive than treatments to maintain a stand in a desired condition.

Keywords: avoided costs, wildfire benefits, Umatilla National Forest, ponderosa pine, fuel management

A century of aggressive wildfire suppression in the United States has profoundly affected some of the nation's forests. Especially in forest types with a short fire-return interval, fuel loads and stocking densities have increased, contributing to wildfires that are more damaging and expensive to control (Westerling et al. 2006). In addition, fire exclusion has allowed species that are less fire tolerant to encroach on fire-adapted ecosystems. This situation arose, in part, because land managers did not fully appreciate the benefit of wildfire to fire-adapted ecosystems, particularly in the western United States (National Association of Public Administrators 2002). In addition to the enhancement of habitat for native fire-adapted trees and plants, wildfire benefits include the reduction of fuel loads, which can make subsequent wildfires less destructive and easier to control. Although it is now widely accepted among scientists and land managers that wildfires can have beneficial as well as undesirable effects, we could find no studies that have made monetary estimates of wildfire benefits, with one notable exception. Several studies have estimated the impact of wildfire, either positive or negative, on recreation values (for example, Englin et al. 2001, Loomis et al. 2001).

Directly estimating wildfire benefits, particularly the ecological benefits, is a daunting if not impossible task. Therefore, we consider an alternative approach: estimation of the costs that are avoided by letting a wildfire burn. For a forest with an active fuel management program, a wildfire may significantly change a stand's structure and thereby make some planned fuel management activities unnecessary or at least delay their implementation. The cost savings from avoiding or delaying these treatments may be considered a benefit of wildfire. However, it is important to note that avoided fuel-treatment costs are just one component of wildfire benefits. Nonetheless, given the scarcity of information on the economic benefits of wildfire, we believe that information on avoided fuel-treatment costs will provide managers with useful information they currently do not have.

For our case study, we selected the Umatilla National Forest (NF), which covers 1.4 million acres in the Blue Mountains of northeastern Oregon and southeastern Washington. We chose the Umatilla NF for three reasons. First, the Umatilla NF has large areas of dry-type forest with relatively short fire return intervals, the kind of forest where wildfire exclusion has had the greatest impact [1]. Second, the Umatilla NF has extensive stand inventory data, which were needed to develop fire management plans and simulate stand growth. Third, and perhaps most important, the Umatilla NF has established criteria for determining when and how to apply fuel management treatments to a stand. As will become clear in the following sections, determining when and how managers treat a stand is central to estimating the effect that a wildfire has on a stand's fuel management program.

Avoided Cost Approach

The avoided cost method (also known as the alternative cost method) has been around for 40 years—the method was first rigorously presented by Steiner (1966) and later by Herfindahl and Kneese (1974)—and is still recognized as a legitimate method for estimating project benefits when direct measurement is not practical (Young 2005). However, the method is not without controversy, in part because it does not actually measure the value of the benefit being assessed. Indeed, it measures a cost, not a benefit. Nevertheless, under certain conditions, an avoided cost can be a useful proxy for the benefit at issue.

To more fully explain how the avoided cost approach is typically used, consider two substantially different ways of achieving the same goal: option 1 and option 2, each with associated costs (C_1 and C_2) and benefits (B_1 and B_2). When the benefit of one option, for example, B_2, cannot be directly measured, then the avoided cost method uses the cost of the other option, C_1, as a measure of B_2. Although the avoided cost C_1 is not a measure of B_2, C_1 can be considered a lower bound on B_2 if the following two conditions

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hold: (1) $B_1 \leq B_2$ and (2) $C_1 \leq B_1$. If these conditions hold, clearly $C_1 \leq B_2$.

Consider a well-known example involving New York City's water supply (Daily and Ellison 2002). The goal is potable water, where option 1 is the addition of a filtration water treatment plant, and option 2 is watershed protection, which would avoid contamination so that a filtration plant would not be needed. The cost of the filtration plant (C_1) would be a lower bound on the benefit of watershed protection (B_2) if (1) the potable water from the filtration plant were no more valuable than the water produced by watershed protection ($B_1 \leq B_2$) and (2) the costs of the filtration plant were known to be less than the associated benefits ($C_1 \leq B_1$).

Unfortunately, B_1 is also often unknown, making application of the method problematic. However, there is another circumstance under which an avoided cost is a useful quantity. As Steiner (1966) argued, when there are two substantially different options for achieving the same goal and the first option will *definitely* go forward unless the second option is implemented, the avoided cost is relevant to decisions about implementing the second option. In our case, we may use this approach if we assume that fuel treatments would be undertaken in the absence of a wildfire. Of course, because we are making no assumptions about the relative magnitudes of the costs and benefits of wildfire and fuel treatments, we can no longer claim that avoided fuel treatment costs are a lower bound on wildfire benefits. Indeed, avoided fuel treatment costs are not a benefit in the traditional benefit-cost sense. However, although avoided fuel treatment costs are not a measure of wildfire benefits, they are clearly *of benefit* because they represent funds that are freed up for other uses and thus provide useful information to those making wildfire management decisions.

Our problem has a further complicating factor. There is often not a one-to-one correspondence between the effects of a wildfire and a fuel treatment. For example, it may require several fuel treatments to mimic the effects, one wildfire. In this case, the appropriate measure of avoided costs is the difference between the discounted costs of a set of fuel treatments conducted in the absence of wildfire and the discounted costs of a set of fuel treatments conducted after a wildfire. In other words, we define avoided fuel treatment costs as the wildfire-induced change in the discounted cost of a stand's fuel management regime.

Methods

We calculated the avoided fuel treatment cost of wildfires of different intensities in 10 ponderosa pine (*Pinus ponderosa*) stands on the Umatilla NF. We selected ponderosa pine stands because concerns about fire exclusion are greatest in forest types that historically experienced frequent low-intensity fires. The Umatilla NF was selected because managers have developed explicit guidelines on how and when to treat stands to reduce wildfire risk and generate ecological benefits. The 10 example stands were selected for two reasons. First they represent a range of stand conditions (Table 1). Second, only a small proportion of stand inventory plots on the Umatilla NF include data on downed fuel, and the model we used to simulate wildfires is sensitive to downed fuel levels. We could have expanded the analysis by using the model's default fuel loads, but instead we chose to limit our analysis to stands with downed fuel data.

We conducted our analysis in three steps. First, using inventory data and a growth-and-yield model, we simulated stand growth on each site in the absence of wildfire and following simulated wildfires of different intensities. Second, in consultation with managers on the Umatilla NF, we developed four fuel management programs for each stand (one for each of the wildfire scenarios). Third, we estimated the cost of these fuel management programs. A more detailed discussion of these steps follows.

Table 1. Characteristics of study sites.

Stand no.	SDI[a]	BA[b] (ft^2)	TPA	QMD (in.)	CWD (tons/ac)
1	260	166	139	14.8	0.8
2	312	130	947	5	0.8
3	217	128	158	12.2	0.7
4	429	216	590	8.2	3.1
5	218	98	472	6.2	2.3
6	222	148	99	16.5	1.2
7	249	97	961	4.3	1.2
8	267	89	1,998	2.9	0.8
9	177	56	1,613	2.5	2.4
10	66	40	43	13.1	0.2

[a] SDI, stand density index (a relative measure of stand density in terms of TPA and QMD; for more details see Reineke [1933]).

[b] BA, basal area; TPA, trees per acre; QMD, quadratic mean diameter (diameter corresponding to mean basal area); CWD, coarse woody debris.

Wildfire and Growth Simulation

We used the Forest Vegetation Simulator (FVS) and its Fire and Fuel Extension (FFE) to model four wildfire scenarios and subsequent stand growth on each site. The scenarios were no wildfire, and wildfires burning under 50th, 75th, and 95th percentile weather conditions. To simulate wildfires, FFE requires data on temperature, wind speed, and fuel moisture [2]. These data were obtained from two weather stations (Eden and Case) on the Umatilla NF. The Blue Mountains variant of FVS, which we used for this study, does not automatically model postfire regeneration. Therefore, after consultations with Umatilla NF managers, we assumed natural regeneration of 150 viable seedlings per acre following a stand-replacing fire. If a fire was not stand-replacing, then we assumed proportionally lower regeneration based on a stand's residual stand density and a stand's pre-established stand density index (SDI) target (see the following section) [3].

Fuel Management Programs

In consultation with managers, we developed fuel management programs for each stand under the four wildfire scenarios described above. We assumed that the basic maintenance fuel management program for all stands was prescribed fire with a periodicity of 17 years (the mean of the fire return interval for ponderosa pine stands on the Umatilla NF) conducted in perpetuity. Most stands, however, required mechanical thinning before prescribed fire could safely be used. Of the 10 stands, managers decided that 9 would require mechanical pretreatment. The mechanical treatment of choice on the Umatilla NF is thinning from below to a stand density target with whole-tree removal. Logs over 7 in. are sold as saw logs, and smaller trees are chipped on site and sold as chips or hog fuel. In summary, stands were assigned one of two fuel management programs: either prescribed fire every 17 years or mechanical treatment immediately, followed by prescribed fire every 17 years (the first prescribed fire occurs in the same year as the mechanical treatment).

Having decided which of the two fuel management programs to use in a stand, managers then decided what year to start treatment. They used three criteria to help judge when a stand needed to be treated. First, they considered a stand's SDI. The Umatilla NF is

Table 2. Timing of first treatment (treat.), treatment cost, avoided cost, and damage for 10 study sites following no fire and fires burning under 50th, 75th, and 95th percentile weather conditions.

	No fire		50th percentile			75th percentile			95th percentile		
Stand no.	1st treat.[a]	Cost	1st treat.	Avoided cost	Damage	1st treat.	Avoided cost	Damage	1st treat.	Avoided cost	Damage
1	0	97	0	0	L[b]	0	0	L	0	0	L
2	0	372	0	275	L	20	329	M	15	319	H
3	0	247	30	218	L	30	218	L	30	218	L
4	0	373	0	275	L	0	275	L	0	275	L
5	0	373	0	275	L	5	293	L	15	319	H
6	0	97	0	0	L	0	0	L	0	0	L
7	0	97	0	0	L	0	0	L	0	0	L
8	0	422	0	175	L	25	387	M	15	369	H
9	0	422	5	343	L	5	343	M	0	325	H
10	20	44	25	8	M	25	8	M	25	8	H

[a] First treatment listed in years; treatment cost and avoided cost in 2005 dollars per acre discounted to year 2005.

[b] L, low; M, medium; H, high.

unusual, as managers have established and documented SDI thresholds for all its forest types (Powell 1999). These thresholds are compatible with an objective of reducing the risk of crown fire (Keyes and O'Hara 2002). A stand's susceptibility to destructive wildfire is affected by more than just stand density, however. Therefore, the second criterion managers considered was level of coarse woody debris (CWD; dead woody material greater than 3 in. in diameter). High levels of CWD can often occur after a destructive wildfire, presenting a risk of severe reburn. Managers considered treating a stand if CWD exceeded 20 tons/ac. Table 1 shows that none of the example stands have levels of CWD over 3.1 tons/ac. However, following some simulated fires, particularly fires that cause substantial mortality, this treatment threshold was breached.

Reducing wildfire risk is not always the sole motivation for treating a stand. For example, some lightly stocked stands, on particularly hot, dry sites, will likely never exceed their SDI or CWD thresholds. However, for ecological reasons, such as favoring fire-adapted trees and plants, managers still periodically treat such sites. Managers on the Umatilla NF are particularly concerned about the encroachment of grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziesii*) into ponderosa pine stands. Therefore, the third criterion managers considered was fire-return interval. Managers considered treating a site if it had not been treated for 30 years, the upper bound of the fire return for ponderosa pine sites on the Umatilla NF (Agee 1993). In addition to these three criteria, managers used their unique local knowledge to customize fuel management programs.

Treatment Costs

Prescribed fire cost data on the Umatilla NF were not readily available. Therefore, we asked a fire manager on each of the Umatilla NF's four ranger districts to estimate a representative per-acre cost for prescribed fire, obtaining a mean cost of $47.25/ac. This estimate was used for all prescribed fire treatments and includes only on-the-ground costs, not overhead costs, such as equipment and planning. In addition, we made no adjustments for topography, treatment size, fuel loads etc. Given that our goal is simply to demonstrate a method for calculating avoided fuel treatment costs, we believe this is a reasonable simplification. However, if our proposed method was applied in practice, it would not be appropriate to use a single per-acre cost. In this case, factors such as treatment size and topography should be considered when estimating prescribed fire costs.

Because mechanical treatments are usually contracted out to private firms, the US Forest Service has good cost data. The mean cost across the four ranger districts was $225/ac. (As with prescribed fire costs, this figure does not include agency fixed costs, such as administering contracts.) However, we did not apply a constant cost to all treatments for two reasons. First, mechanical treatment costs show greater variation than prescribed fire costs. Indeed, some mechanical treatments can be profitable. Second, we wished to capture the effect of fires that did not remove the need for a mechanical treatment but did reduce its cost. Therefore, we asked two managers on the Umatilla, responsible for administering mechanical treatment contracts, to estimate treatment costs on a case-by-case basis. We provided them with information on the number and size of trees to be removed and those to be retained. In some cases, managers estimated that the trees removed were of sufficient value that a stand could be treated at no net cost. We did not, however, encounter a situation among the 10 sites where managers estimated that a treatment would make a profit. If a treatment did make a profit, and if a wildfire reduced or eliminated this profit, then the avoided cost of the wildfire would be lower. The discounted cost of a fuel management program was calculated using a 4% discount rate [4]. Below, we explore the consequences of different discount rates and, as previously mentioned, different treatment periodicities.

The purpose of this study is to present a method for estimating the avoided fuel treatment costs of a wildfire. However, the net effect of wildfire depends on the magnitude of other wildfire benefits and on wildfire damages. It is beyond the scope of this study to empirically estimate wildfire damages; however, to provide some context for avoided-cost estimates, we asked managers to subjectively rate the severity of wildfire damages for each wildfire scenario (low, medium, or high).

Results

For each stand, Table 2 gives the avoided costs for wildfires that burned under 50th, 75th, and 95th percentile weather conditions. These avoided costs were calculated by subtracting the discounted cost of a stand's fuel management program following a wildfire from the discounted cost of a stand's fuel management program in the absence of wildfire. The costs of fuel management following wildfire are not shown in Table 2 to save space, but they can be easily calculated by subtracting avoided costs from treatment costs in the absence of wildfire. For example, the discounted cost of fuel management without wildfire in stand 2 is $372. Avoided costs following a 50th percentile fire are $275, which means that the discounted cost of fuel management is $97. Table 2 also provides qualitative estimates of gross wildfire damages following fires of different intensities.

Several patterns can be seen in Table 2. Perhaps the most striking is that the majority of avoided costs come from removing the need for a mechanical pretreatment. This is unsurprising, as the net present value of a series of prescribed burns costing $47.25/ac that start today and continue every 17 years is $97/ac, whereas a single mechanical treatment can cost over $300/ac. Furthermore, wildfire can only delay the need for prescribed burning, not eliminate it altogether, but a wildfire can remove the need for a mechanical pretreatment, as long as a stand is subsequently maintained with periodic prescribed fire or wildfire.

Another pattern can be seen in stands with many small trees. For example, consider the three stands with the highest number of trees per acre (2, 8, and 9). These stands also have a quadratic mean diameter (QMD) of 5 in. or less. Mechanical treatments in such stands are often expensive, and therefore, avoided costs in these stands are generally high across fires of different intensities. Undesirable fire effects in these stands, particularly after more intense wildfires, are also high. However, avoided costs are not always highest after more intense wildfires. Indeed, in stands 2 and 9, the avoided costs following a 75th percentile fire are higher than the avoided costs following a 95th percentile fire. This is because for these two stands, levels of CWD were lower after 75th percentile fires. In addition, undesirable fire effects are lower after a less intense fire. Results suggest, therefore, that in stands with many small-diameter trees, avoided costs tend to be high and that these high savings can often be achieved by relatively low-intensity fires that do not result in as many undesirable effects.

Stands with a lower number of trees per acre, and a higher QMD, exhibit a different pattern. The stands with the highest QMD (1, 6, and 10 [stand 10 is the only stand that did not require mechanical treatment]) have low or no avoided costs and low undesirable effects. This is because, if required, mechanical treatments in these stands are less expensive, and larger trees are more fire resistant. These results have a number of possible management implications. The low undesirable fire effects suggest that wildfire may be a useful management tool in stands with higher QMDs. However, lower avoided costs in these stands are less able to offset undesirable fire effects that do occur.

Two other patterns are worth noting. Three stands (1, 6, and 7) required mechanical treatments that could be carried out at no cost. Avoided costs on these three stands were zero under all three weather conditions. This is partly due to the structure of these stands (fires of different intensities did not remove the need for immediate prescribed fire), but also reinforces our finding that avoided costs are greatest when a wildfire removes the need for an expensive mechanical treatment. Undesirable effects on two stands (3 and 4) were low under all three weather conditions. Avoided costs were also high under all weather conditions, which suggests that wildfire may be a useful management tool for these stands.

Sensitivity Analysis

Results are sensitive to the various assumptions we made: treatment periodicity and discount rate, for example. Our most basic assumption is that all treatments will take place when they are scheduled. However, treatments are often delayed for budget, regulatory, or other reasons. If a fuel management program is delayed for 5 years, its discounted cost is reduced by 18%, assuming that the delay in treatment does not change the type and, therefore, cost of the treatment required. For example, stand 2 is scheduled for immediate treatment at a cost of $372/ac. Discounting this cost 5 years reduces cost savings by $67/ac.

Changing our assumption about the periodicity of prescribed fire treatments also affects avoided costs. For example, if we assume that prescribed fires are conducted every 30 as opposed to every 17 years, then the discounted cost of the treatment regime is reduced from $97 to $68/ac. The choice of discount rate also affects cost savings—a higher (lower) discount rate decreases (increases) the savings and increases (decreases) the savings from delaying treatments. For example, a 6% discount rate reduces the cost of the series of prescribed fires from $97/ac to $75/ac, whereas a 2% discount rate increases the cost to $165/ac.

Estimates of avoided costs are based on our estimates of treatment costs. We assumed a constant per-acre cost for prescribed fire. If prescribed fire costs were higher (lower), then avoided costs would also be higher (lower). Similarly, changes in our mechanical treatment cost estimates would change avoided costs. In particular, if treatments can make a profit, then avoided costs may be reduced. Avoided costs are also sensitive to our assumption of regeneration of 150 seedlings per acre following a stand-replacing fire. If regeneration is lower (higher) following a wildfire, then fuel management treatments will be started later (sooner), and avoided costs will be higher (lower).

Despite the sensitivity of results to assumptions, we have demonstrated how to calculate avoided fuel treatment, and we have identified stand characteristics that affect avoided cost. Specifically, stands scheduled for mechanical treatment tend to have high avoided costs; stands densely stocked with small trees often have high avoided costs and high undesirable effects, although lower severity fires can reduce these undesirable effects; and stands with fewer, larger trees tend to have low avoided costs and low undesirable effects.

As stated in the introduction, avoided fuel treatment costs are just one component of wildfire benefits. When making wildfire management decisions, managers would need to consider both other beneficial effects of wildfire and wildfire damages. Therefore, although our results indicate that intense wildfires can produce high avoided costs, this should not be interpreted as a recommendation that intense wildfires should always be allowed to burn. Indeed, it is not difficult to imagine wildfire scenarios with damages that are orders of magnitudes higher than the avoided cost estimates we have presented. Therefore, we re-emphasize that estimates of avoided costs are just one piece of information to help managers make balanced wildfire management decisions.

Discussion

We measured the costs avoided by wildfire in 10 ponderosa pine stands on the Umatilla NF. We argue that these avoided costs may be considered to be one component of wildfire benefits if the avoided fuel treatments would definitely have gone forward in the absence of wildfire. Despite the small number of stands, we were able to identify stand conditions that affect avoided costs. Avoided costs tend to be the highest when a wildfire makes an expensive mechanical treatment unnecessary. This situation most often arises in stands densely stocked with small trees.

The methodology presented could be adapted to other areas with different land management objectives, because it simply requires the comparison of the costs of a set of management actions in the presence and absence of wildfire. However, the methodology can only be applied to areas with an active fuel management program with established treatment thresholds. This methodology could not, for example, be used to evaluate the benefits of a wildfire burning in a wilderness area that did not have a fuel management program.

Results indicate that wildfires that burn in dense, small-diameter stands tend to produce higher avoided costs than those that burn in less dense, larger-diameter stands, although fires in dense, small-diameter stands also tend to produce higher undesirable fire effects. More generally, fires in stands that show the greatest divergence from the archetypical ponderosa pine stand structure (large trees in an open, parklike stand) tend to have higher avoided costs. This is a reflection of the higher cost of fuel treatments in these stands—treatments designed to restore a stand to a desired condition are normally more expensive than treatments to maintain a stand in a desired condition. Of course, the potential for undesirable effects (killing larger trees, destroying seed banks, soil erosion, etc.) is also higher in densely stocked stands. In addition, most managers would be more comfortable allowing a wildfire to burn in a less dense, larger-diameter stand, because the risk of undesirable fire effects is lower. We are not suggesting that that is the wrong approach. We are estimating one component of wildfire benefits, and the undesirable effects of a fire in a dense, small-diameter stand may often outweigh these higher avoided costs. We are simply suggesting that managers should consider the costs that would be avoided by letting a fire burn in a particular stand. This might help break the cycle of expensive, aggressive wildfire suppression followed by expensive fuel treatments to mitigate the effects of fire exclusion. This problem was concisely summarized by Miller et al. (1999, p. 83): "managers are locked into a reinforcing feedback cycle in that perceived risks lead to fire suppression, leading to increased risks and further fire suppression."

A limitation of this study is that it was conducted at the stand scale; we did not consider the effect that a wildfire in one stand may have on a neighboring stand. However, wildfires often burn across large, heterogeneous landscapes. Nonetheless, we believe the methodology presented here could be used to provide managers with valuable information that they currently do not have.

Endnotes

[1] It is estimated that 73 million acres of dry-type forest have significantly elevated (condition classes II and III) fuel levels (Schmidt et al. 2002).

[2] The 50th, 75th, and 95th percentile values for temperature, wind speed, and fuel moisture were calculated from 20 years of data for the period from June 1 to Sept. 30.

[3] For example, if a stand had an SDI target of 180, and its postfire SDI was 90 (half its target SDI), then we would assume postfire regeneration of 75 seedlings per acre (half of the regeneration we would assume following a stand-replacing fire).

[4] All interest rates are real.

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