

An Alternative Incentive Structure for Wildfire Management on National Forest Land

Geoffrey H. Donovan and Thomas C. Brown

Abstract: Wildfire suppression expenditures on national forest land have increased over the last 35 years, exceeding US\$1 billion in 2000 and 2002. These increases in expenditure have been attributed, in part, to a century of aggressive wildfire suppression, resulting in a buildup of fuel on the nation's forests. The efficiency of the current incentive structure faced by Forest Service fire managers is analyzed. An alternative incentive structure is presented that encourages fire managers, as they work to limit wildfire damages, to contain costs and consider the beneficial effects of wildfire. FOR. SCI. 51(5):387–395.

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EXPENDITURES ON WILDFIRE SUPPRESSION by the USDA Forest Service have increased steadily over the last 35 years, drawing scrutiny from, among others, Congress and the Office of Management and Budget. For example, between the periods 1970–1974 and 1998–2002, the Forest Service's average annual expenditure for wildfire suppression rose in nominal dollars from US\$69 million to US\$666 million (Schuster et al. 1997 updated). Despite this increase in expenditure, the average number of burned hectares increased between the two periods from 1.2 million to 2.2 million (NIFC; <http://www.nifc.gov/stats/wildlandfirestats.HTML>. Mar. 15, 2004).

These increases in suppression costs and burned area have been attributed, in part, to a century of aggressive wildfire suppression [1]. Before large-scale wildfire suppression, consumption of fuels by wildfire largely offset fuel accumulation. However, suppression activities—plus, to a much lesser extent, reductions in harvest levels—have allowed fuels to accumulate more quickly than they are being consumed. Consequently, subsequent wildfires are both more destructive and more expensive to control (Arno and Brown 1991). Numerous studies have suggested that the implementation of a large-scale fuels-management program will be required to restore—and maintain—the equilibrium between fuel accumulation and consumption on the nation's forests (National Association of Public Administrators 2002).

Aside from wildfire, land managers have two main fuel management tools at their disposal: mechanical treatment, such as thinning, and prescribed (i.e., intentionally set) fire. The 2003 healthy forests initiative has focused attention on the former as a safe way to reduce wildfire risk. However, unless the trees removed are of significant commercial value—and in most locations they are not—mechanical treatment can cost

roughly from US\$500 to US\$1,000 per acre (USDA 2003a). With 30 million hectares of national forest currently thought to be in need of treatment in forests that have historically had frequent low-intensity fires (Schmidt et al. 2002) [2], it is clear that the use of mechanical treatment must be restricted to a small percentage of the areas at risk.

The other option, prescribed fire, reduces downed fuel loads, mimics some of the ecological effects of wildfire, and is typically cheaper than mechanical treatment, costing roughly US\$100 per acre (Cleaves et al. 2000). However, prescribed fire faces other problems. First, the weather and fuel moisture conditions for a successful prescribed burn occur only intermittently. Second, concerns about smoke and risk to houses limit the areas in which it can be applied. Furthermore, well-publicized examples of prescribed fires escaping management control and becoming destructive wildfires have placed additional restrictions on its use.

In light of the increased scrutiny of Forest Service suppression costs, and of the costs and difficulties of fuels management, a thorough review of the current incentive structure faced by fire managers is warranted. It is these incentives that have caused the widespread accumulation of fuels and contributed to the escalation of suppression costs. Without a change in the incentives, containment of suppression costs is unlikely. After all, as Steven Lansburg pointed out in *The Armchair Economist*, “People respond to incentives; all the rest is commentary.”

We realize that incentive structures are not easily changed. The status quo reflects existing laws, institutions, and political and social pressures. However, it is always useful to examine the cost of existing practices and the incentives that shape them, and to consider alternatives that may improve efficiency.

Several authors have studied the effect of incentives on

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forest management, focusing on the USDA's forestry incentive program (Steigner 1984, Nodine 1993), the effect of changes in European Union policy on afforestation in Scotland (Tyler et al. 1996) and Ireland (Gillmor 1998), forestry incentives in Chile (Amacher et al. 1998), and the effect of the Indian Self-Determination and Education Assistance Act of 1975 on timber harvests from Native American land (Krepps and Caves 1992). However, we found no evidence in the economics literature of studies addressing the incentives faced by USDA Forest Service fire managers.

Although the question of how incentive structures affect wildfire suppression costs has not been explicitly addressed in the literature, several authors have studied the effect of other factors on the cost of wildfire suppression and prescribed burning. For example, in a series of studies Gonzalez-Caban developed models to predict the cost of initial attack and large fire suppression (Gonzalez-Caban 1983), the cost of suppression forces using a cost-aggregation approach (Gonzalez-Caban and McKetta 1984, Gonzalez-Caban et al., 1984), and the cost of wildfire mop-up (Gonzalez-Caban 1984). The studies found significant regional variation in costs, and that site-specific factors had a significant impact on costs. Other authors have identified variables that affect the cost of prescribed fire. Gonzalez-Caban and MacKetta (1986) analyzed prescribed fire costs on two national forests. They found that managerial factors and organizational constraints influenced treatment costs more than physical site characteristics. Rideout and Omi (1995) used a National Park Service database to develop a constant elasticity of declining unit cost model to predict prescribed fire costs. They found that both physical site characteristics and managerial factors influenced treatment costs, and that treatments whose primary purpose was ecological restoration exhibited greater variation in costs. Gonzalez-Caban (1997) used a questionnaire to estimate the cost of a series of hypothetical prescribed burns. As with previous studies, he found that treatment size and managerial factors affected treatment costs. He also showed that a manager's level of risk aversion had the potential to affect treatment costs. A timely review of the economics of prescribed burning was provided by Hesseln (2000). A common theme running through many of these studies is that physical site characteristics do not fully explain the observed variation in suppression and prescribed fire costs. Rather, to fully understand fire costs, the attitudes of individual fire managers also need to be considered.

Economics of Wildfire Management

For a given area of land and set of fire-behavior conditions, the most efficient level of fire management expenditure minimizes the sum of all fire-related costs and net damages (Donovan and Rideout 2003). Typically, fire-management expenditures are broken down into two categories: presuppression and suppression. Definitions of the two terms are not consistent [3], but essentially spending before the outbreak of a wildfire is a presuppression expenditure, whereas direct firefighting costs are suppression expendi-

tures. For example, the purchase of a fire engine is a presuppression expenditure, whereas the cost of operating the vehicle during a fire is a suppression expenditure.

Wildfires can have both negative and positive effects. Negative effects may include loss of timber, damage to structures, and temporary reduction in water and air quality. Positive effects may include ecosystem benefits, such as favoring native fire-adapted trees and plants, and a reduction in fuel loads. A wildfire that reduces fuel loads reduces the severity of future wildfires, thereby reducing future wildfire-related damages and suppression costs. Conversely, wildfire suppression allows fuel loads to increase, thereby increasing the sum of future wildfire damages and suppression costs. Simply put, the more successfully current suppression efforts exclude wildfire, the more expensive and damaging future wildfires will be, all else equal.

The present value of all wildfire-related damages minus the present value of all wildfire-related benefits is known as net value change (NVC) [4]. The relationship among presuppression, suppression, fire damage, and fire benefits can be represented graphically by holding presuppression fixed; the optimal amount of suppression minimizes the sum of all fire-related costs (C) and NVC ($C + NVC$) (Figure 1).

This minimization problem may be represented mathematically as (Donovan and Rideout 2003)

$$\text{MIN: } C + NVC = W^P P + W^S S + NVC(P, S), \quad (1)$$

where P denotes presuppression, S denotes suppression, W^P denotes the wage of presuppression, and W^S denotes the wage of suppression. Differentiating with respect to P and then S gives the following first-order conditions:

$$\frac{\partial(C + NVC)}{\partial P} = W^P + \frac{\partial NVC}{\partial P} = 0, \quad (2)$$

$$\frac{\partial(C + NVC)}{\partial S} = W^S + \frac{\partial NVC}{\partial S} = 0. \quad (3)$$

Rearranging the terms yields

$$-\frac{\partial NVC}{\partial P} = W^P, \quad (4)$$

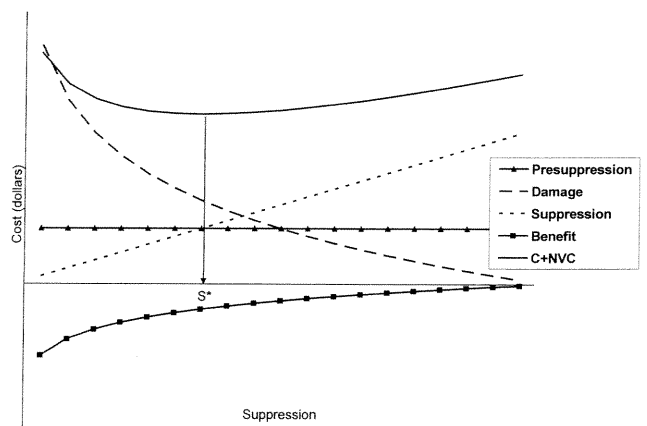


Figure 1. The $C + NVC$ model.

$$-\frac{\partial \text{NVC}}{\partial S} = W^S. \quad (5)$$

Wildfire management is characterized by uncertainty about fire behavior, suppression effectiveness, and resource damages. Therefore, fire managers have to base their decisions on less information than is implicitly contained in Figure 1. However, Figure 1 and Equations 4 and 5 do provide a rule of thumb: An additional dollar should only be spent on presuppression or suppression if it averts at least one dollar of NVC.

Current Forest Service Wildfire Budgeting Policy

The Forest Service funds presuppression and suppression efforts in different ways. Presuppression budgets are developed using the National Fire Management Analysis System (NFMAS), a simulation model that allows users to compare the effect of alternative suppression strategies on historical wildfires. The NFMAS architecture has both theoretical and practical problems (Donovan et al. 1999); however, its stated purpose is to identify the level of presuppression expenditure that minimizes $C + \text{NVC}$. In contrast, suppression budgets are not determined in advance. Since 1908, the Forest Service has had the authority to engage in deficit spending to fund wildfire suppression (Pyne et al. 1996). Deficits are typically made up by a supplemental appropriation at the end of a fire season.

Most wildfires are contained by suppression efforts within the first 12-hour burning period. Those that are not are considered "escaped fires." Although escaped fires constitute a small proportion of all wildfires, they account for the majority of suppression expenditures. For example, in 2002 less than 2% of wildfires became escaped fires. However, those escaped fires that exceeded 120 hectares accounted for 95% of total hectares burned and 85% of total suppression expenditures (USDA 2003).

The suppression of large, escaped wildfires is undertaken jointly by local land managers and incident command teams. Incident command teams assume responsibility for tactical wildfire suppression decisions, although local land managers provide overall strategic guidance. To determine the appropriate suppression strategy, local land managers are required to perform a wildland fire situation analysis (WFSA). Although software exists for preparing a WFSA, it is not a prescriptive model; rather it is a decision-analysis process (NIFC. <http://www.fs.fed.us/fire/wfsa/index.htm>. Mar. 15, 2004). A WFSA requires a manager to consider different suppression strategies, associated costs and damages, probability of success, and the compatibility of these strategies with established land management objectives. For example, in a situation where significant volumes of commercial timber are at risk and the weather forecast predicts hot, dry, windy weather, a manager may recommend that the incoming incident command team use an aggressive suppression strategy. However, if a wildfire does not significantly threaten resources of particular management con-

cern or the weather forecast is favorable, a less aggressive strategy may be recommended.

A WFSA provides the incoming incident command team strategic guidance and a nonbinding estimate of suppression cost, which can be reassessed when fire conditions change. When preparing a WFSA, managers are directed not to consider the potential beneficial effects of wildfire. Incident commanders also are directed not to consider beneficial fire effects when planning or executing suppression activities. However, even if land managers and incident commanders were allowed to consider the beneficial effects of wildfire, it would likely be difficult for them to give wildfire benefits the correct weight, because wildfire damages are immediate, and both land managers and incident commanders face intense pressure to minimize these damages. In contrast, the beneficial effects of wildfire are only partially understood, and they occur in the future.

Disregard for the beneficial effects of wildfire creates an incentive to increase suppression expenditures beyond the efficient level shown in Figure 1. Figure 2 contrasts the optimal level of suppression when wildfire benefits are considered (S^*) versus the optimal level of suppression when the beneficial effects of wildfire are ignored (S') (for clarity, presuppression and suppression are not shown). The magnitude of the difference between S^* and S' will depend on the functional relationship between wildfire damages and benefits and suppression expenditures.

Funding wildfire suppression with an emergency suppression budget provides fire managers with an additional incentive to overuse suppression resources, because the opportunity cost to fire managers of suppression expenditures is zero. If fire managers were to forgo some increment of suppression spending, this savings could not be used for another purpose. Therefore, fire managers would continue to spend on suppression as long as these expenditures decreased damage by even a small increment. Therefore, the primary constraint on suppression expenditure is resource availability. If all needed resources are available, suppression expenditures may approach S'' (Figure 2).

In summary, the current Forest Service mechanism for

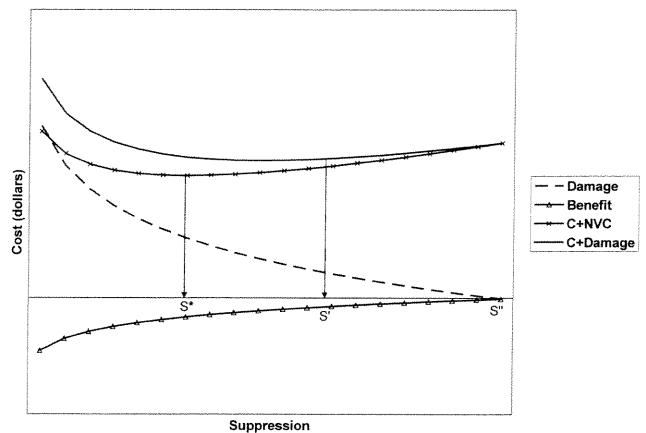


Figure 2. A comparison of optimal suppression expenditure and suppression expenditure under current incentive structure.

funding wildfire suppression has two related problems. First, the benefits of wildfire are ignored. Second, the costs of wildfire suppression are not fully considered. Both problems encourage fire managers to use inefficiently high levels of suppression expenditure.

The current Forest Service incentive structure may be analyzed by using a utility maximization framework. We assume that two factors affect a fire manager's utility: resource damage (D) and firefighter safety (F). For a specified wildfire, a fire manager's utility maximization problem may be stated as

$$\text{Max}_S U = E[U(D(S), F(S))]. \quad (6)$$

Note that neither wildfire benefits nor suppression costs appear in the fire manager's utility function. We assume D is dependent on both presuppression and suppression. However, as the scope of the following analysis is a fire season, and presuppression is fixed within a fire season, we exclude presuppression from the fire manager's utility function for simplicity. Later, we discuss the consequences of relaxing this assumption. Equation 6 denotes an expected utility maximization problem, because the fire manager would not know the exact functional relationship between suppression and damage, and between suppression and firefighter safety.

It is assumed that

$$\begin{aligned} \frac{dU}{dD} < 0, \quad \frac{d^2U}{dD^2} > 0, \quad \frac{dU}{dF} > 0, \quad \frac{d^2U}{dF^2} < 0, \\ \frac{dD}{dS} < 0, \quad \frac{d^2D}{dS^2} > 0, \quad \frac{dF}{dS} < 0, \quad \frac{d^2F}{dS^2} > 0. \end{aligned}$$

Differentiating Equation 6 with respect to S yields the first-order condition,

$$\frac{dU}{dS} = \frac{dU}{dD} \frac{dD}{dS} + \frac{dU}{dF} \frac{dF}{dS} = 0 \quad (7)$$

Equation 7 implies that, given sufficient resource availability, fire managers will continue to spend on suppression until the increase in utility from decreasing damage equals the decrease in utility from decreasing firefighter safety. The influence of firefighter safety on suppression decisions will vary between fires. On wildfires with moderate fire behavior, firefighter safety will likely have less influence on the fire manager's choice of suppression level than on wildfires with severe or unpredictable fire behavior.

Equation 7 shows that the fire manager's utility maximization problem is not budget-constrained, and is not dependent on the beneficial effects on wildfire. Furthermore, the fire manager's choice of suppression on one fire is independent of the manager's suppression decisions, or expected suppression decisions, on all other fires during the fire season. Therefore, the current incentive structure provides fire managers with no incentives to consider the marginal tradeoff between suppression costs and wildfire damages and benefits.

Our intention is not to imply that all fire managers

completely ignore costs, clearly this is not the case. However, it is our contention that the current incentive structure provides little or no incentive for fire managers to consider the costs of suppression resources or the beneficial effects of wildfire. The challenge, then, is to design an incentive structure for an uncertain fire season that encourages fire managers to act as if suppression costs and wildfire benefits appeared in their utility function.

Alternative Incentive Structure

Before developing an alternative incentive structure, we define several terms:

K = Initial annual budget.

E = Emergency funding.

C = Net budget carryover (budget carryover, either positive or negative, from the current year to the future minus budget carryover, positive or negative, from the previous year, or $C_0 - C_{-1}$).

A = Hectares burned.

q = The number of hectares a wildfire would burn in the absence of any suppression, so $A \leq q$.

The current funding mechanism for wildfire suppression may be represented as

$$W^S S \leq K + E. \quad (8)$$

Because E is unbounded, funding wildfire suppression in this way provides fire managers with no incentive to consider the cost of suppression resources.

Alternatively, fire managers could be given a fixed suppression budget,

$$W^S S \leq K. \quad (9)$$

Under this funding mechanism, if K is low enough to constrain suppression expenditure, the fixed budget provides fire managers with an incentive to consider the tradeoff between suppression costs and suppression benefits (i.e., damage averted); managers would seek to use limited funds where they were most effective. However, uncertainty about the severity of a fire season would make it impossible to set the optimal level of K in advance.

One solution to the problem of determining a suppression budget for an uncertain fire season is to allow fire managers to carry over surpluses and deficits from year to year [5]. Therefore, savings from a moderate fire year could be used to supplement suppression expenditure in a severe fire year:

$$W^S S \leq K - C. \quad (10)$$

As long as managers expected their base funding (K) to remain constant (in real terms) from year to year, this funding mechanism would provide an incentive to consider the tradeoff between suppression costs and benefits, and would address the issue of budgeting for an uncertain fire season. However, it would not correct the other deficiency of the current system, the lack of an incentive to consider

the beneficial effects of wildfire. Therefore, we propose supplementing this funding mechanism with a severity adjustment based on the number of hectares burned in a fire season:

$$W^S S \leq K - C + bA, \quad (11)$$

where b is a constant and

$$A(\bar{P}, S). \quad (12)$$

It is assumed that

$$\frac{dA}{dS} \leq 0. \quad (13)$$

This severity adjustment would provide an incentive to consider the beneficial effects of wildfire. To illustrate this point, consider the fire manager's suppression cost (TC) [6] function (i.e., the reduction in budget due to fire suppression activities) for a specified wildfire implied by Equation 11,

$$TC = W^S S + b(q - A). \quad (14)$$

Equation 14 shows that, as suppression expenditures reduce the number of burned hectares, the fire manager's budget is reduced by the amount $b(q - A)$. For example, consider a forest with a base suppression budget of US\$50,000. A wildfire starts that would burn 1,000 hectares in the absence of suppression. If b were chosen to equal the per hectare benefit of wildfire, in this case we assume US\$50, then the fire manager's maximum suppression budget would be US\$100,000 (US\$50,000 + [1,000 · US\$50]). If the manager spent US\$20,000 suppressing the wildfire, reducing the total number of burned hectares to 900, the manager's total suppression budget would be reduced to US\$75,000. Therefore, the cost of suppressing the wildfire would be US\$25,000: US\$20,000 in direct suppression costs and US\$5,000 in reduced budget. The reduction in budget of US\$5,000 is a proxy for the wildfire benefits that were forgone by protecting 100 hectares of forest from wildfire. Therefore, although the fire manager does not directly consider the benefits of wildfire, the manager does consider the reduction in budget from reducing the number of burned hectares.

To illustrate this point more formally, consider the fire manager's benefit function for a specified wildfire,

$$TB = c(q - A), \quad (15)$$

where c denotes the per-hectare value of resources at risk. Differentiating Equations 14 and 15 with respect to S yields the following expressions for marginal cost and marginal benefit of suppression:

$$MC = W^S - \frac{dA}{dS} b, \quad (16)$$

$$MB = -\frac{dA}{dS} c. \quad (17)$$

Equating Equations 16 and 17 and rearranging terms yields the equilibrium condition,

$$\frac{dA}{dS} c - \frac{dA}{dS} b = -W^S. \quad (18)$$

The first term on the left-hand side of Equation 18 is the product of the marginal physical effectiveness of suppression and the per-hectare value of resources at risk, and is, therefore, the marginal benefit of suppression. Now consider the second term on the left-hand side of Equation 18. If b is chosen to be the per-hectare benefit of wildfire, then this expression, with its negative sign, becomes the marginal loss of wildfire benefits, and the left-hand side of Equation 18 becomes the marginal effect of suppression on NVC. Therefore, if b is set to equal the per-hectare benefit of wildfire, Equation 18 is the same as Equation 5—the first-order condition for optimal level of suppression expenditure—and, at the margin, the proposed incentive structure will promote an efficient level of suppression expenditure. (The efficiency of the incentive structure also depends on the accuracy of fire managers' estimates of wildfire damages). Under the budget constraint of Equation 13, fire managers would—through the incentive to maintain budget for suppressing future, potentially more destructive fires—essentially consider the wildfire benefits they are forgoing each time they prevented a hectare of land from burning. That is, when the value of the potential damage was judged to be less than direct suppression costs plus the value of the funds that suppression would remove from future suppression activities, managers would avoid the cost and let some hectares burn.

The proposed incentive structure may also be analyzed using a utility maximization framework. Under the current incentive structure, the choice of suppression on a given fire is essentially independent of the choice of suppression on all other fires of the season. In contrast, the proposed incentive structure imposes a finite annual budget cap, and consequently, the choice of suppression on one fire is no longer independent of the suppression choices on other fires. Therefore, we model the fire manager's utility maximization problem one fire at a time, starting with the first fire of the season.

When the first fire of the year occurs, the fire manager must decide what level of suppression to use. The choice of this level, S_1 (where the subscript indicates the first fire), depends on the fire manager's expectation of the severity of the first fire of the season and on the manager's expectation of the severity of the remainder of the fire season [7]. These expectations are based on different types of information. At the time of the first fire, a manager knows the location of the fire, weather conditions, and resources currently threatened. Although this is insufficient information to allow the manager to predict the outcome of a fire with certainty, it is more information than is available for wildfires that have yet to start. Nevertheless, based on current weather and fuel conditions, and past wildfire occurrence data, a manager can at least estimate the number of fires that will occur during the remainder of the fire season ($E_1[n]$) and the mean

suppression requirement across these fires ($E_1[S']$). The product of these two terms and the wage of suppression is the expected suppression expenditure for the rest of the fire season.

As with suppression, a fire manager is better able to estimate the number of hectares the current fire will burn, $E_1[A_1(S_1)]$, than the number of hectares that future wildfires will burn. The total number of hectares that will burn during the rest of the fire season is estimated as the product of the estimated number of fires that will occur during the remainder of the fire season ($E_1[n]$) and the mean number of hectares burned across these fires ($E_1[A']$).

The choice of S_1 also depends on a fire manager's expectation of carryover ($E_1[C]$), which in turn depends on a fire manager's expectation of the relative severity of the current fire season. If a fire manager believes that the current fire season will be less severe than average, then the manager may plan to carry over a surplus to the following year. Conversely, if a fire manager believes that the current fire season will be more severe than average, then the manager may plan to carry over a deficit to the following year. The fire manager's utility maximization problem at the time of the first fire may, therefore, be represented as

$$\begin{aligned} \text{Max}_{S_1} E[Z] = E_1[U_1(D_1(S_1), F_1(S_1))] & \quad (19) \\ - \lambda(W^S(S_1 + (E_1[n] * E_1[S']))) - K & \\ - E_1[C] - b * (E_1[A_1(S_1)] + (E_1[n] * E_1[A']))) & \end{aligned}$$

Differentiating with respect to S_1 yields the first-order conditions,

$$\frac{\partial Z}{\partial S_1} = \frac{dD_1}{dS_1} \frac{\partial U_1}{\partial D_1} + \frac{dF_1}{dS_1} \frac{\partial U_1}{\partial F_1} - \lambda * W^S + b * \frac{dA_1}{dS_1} = 0, \quad (20)$$

$$\frac{\partial Z}{\partial \lambda} = W^S(S_1 + (E_1[n] * E_1[S'])) - K - E_1[C] \quad (21)$$

$$- b * (E_1[A_1(S_1)] + (E_1[n] * E_1[A'])) = 0.$$

Because S_1 enters Equation 21 directly and indirectly, we cannot solve explicitly for the optimal level of S_1 . However, inspection of Equation 21 shows that the optimal level of S_1 is dependent on the wage of suppression, the base budget, the expected budget carryover, b (a proxy for wildfire benefits), and the manager's expectations concerning the remainder of the fire season. Therefore, we have addressed the two shortcomings of the current incentive structure by making the fire manager's utility dependent on the cost of suppression resources and the beneficial effects of wildfire. Equation 20 can be solved for the optimal level of λ ,

$$\lambda^* = \frac{\frac{dD_1}{dS_1} \frac{\partial U_1}{\partial D_1} + \frac{dF_1}{dS_1} \frac{\partial U_1}{\partial F_1}}{W^S + b * (dA_1/dS_1)}. \quad (22)$$

Equation 22 represents the benefit–cost ratio of an additional unit of suppression. The numerator denotes the in-

crease in utility from an additional unit of suppression. The denominator has two components, the wage of an additional unit of suppression, and the decrease in budget that results from a unit of suppression decreasing the number of burned hectares.

The fire manager's utility maximization problem on the second fire of the season may be represented as

$$\begin{aligned} \text{Max}_{S_2} E[Z] = E[U_2(D_2(S_2), F_2(S_2))] & \quad (23) \\ - \lambda(W^S(S_1 + S_2 + (E_2[n] * E_2[S']))) - K & \\ - E_2[C] - b * (A_1 + E_2[A_2(S_2)] + (E_2[n] * E_2[A']))) & \end{aligned}$$

On the second fire of the season, a manager's choice of suppression level (S_2) is constrained not only by expectations about the remainder of the fire season, but also by the suppression expenditure and hectares burned on the first fire. During the early part of the fire season, the manager's choice of suppression level is largely constrained by his or her expectations concerning the rest of the season. However, as the season progresses, the fire manager's choice of suppression level is increasingly constrained, not by expectations concerning the rest of the season, but by expenditures on previous fires. This iterative and adaptive utility maximization process continues, one fire at a time, for the rest of the fire season. A general form of the fire manager's utility maximization problem, for the k th fire of the season, may be expressed as

$$\begin{aligned} \text{Max}_{S_k} E[Z] = E[U_k(D_k(S_k), F_k(S_k))] & \quad (24) \\ - \lambda \left(W^S \left(\sum_{i=1}^k S_i + (E_k[n] * E_k[S']) \right) - K \right. & \\ \left. - E_k[C] - b * \left(\sum_{i=1}^{k-1} A_i + E_k[A_k(S_k)] + (E_k[n] * E_k[A']) \right) \right) & \end{aligned}$$

We have shown that, if b is chosen to be the per-hectare benefit of wildfire, then, at the margin, the proposed incentive structure promotes the efficient use of suppression resources. However, the benefits of wildfire are difficult to quantify accurately, and in any case, because they are in part nonmarket goods, they are difficult to value. A practical approach to setting b is to determine how much it would cost to achieve these benefits by different means. The two main management tools for mimicking the beneficial effects of wildfire are prescribed fire and mechanical treatment. As described in the introduction, the cost of these tools can vary from less than US\$100 per acre for prescribed fire to over US\$1,000 per acre for mechanical treatment. Therefore, the optimal value for b varies by site depending on whether prescribed fire is an option and on the difficulty of applying whichever treatment is chosen. The utility maximization model presented can be modified to account for different values of b on different areas of land. Although this complicates the model, it does not change the basic results.

The proposed incentive structure encourages fire managers to make efficient trade-offs between the costs and benefits of suppression, subject to the base budget K . Because it is not possible to determine the optimal level of K before the fire season begins, we suggest that K be determined either by reference to previous suppression budgets or some desired target for suppression expenditure, remembering that this budget will be supplemented by additional funds based on burned hectares, the size of the supplement depending on the severity of the fire year. Although it is not possible to determine the optimal level of K , the proposed incentive structure, including allowing an annual carryover, would encourage fire managers to spend available resources where most effective.

To demonstrate how the proposed incentive structure would be applied, we contrast actual annual suppression expenditures (in constant 1994 dollars) over the period 1994–2002 with annual suppression budgets that the proposed incentive structure would generate. We make the simplifying, and unrealistic, assumption that the proposed incentive structure would not change the number of burned hectares or the mean annual suppression expenditure. For one alternative, we arbitrarily set b at US\$75, requiring that K be set at US\$129M so that the annual suppression budget under the proposed structure equals the mean historical suppression expenditure (Figure 3) [8]. The other alternative sets b at US\$25 and K at US\$375M. Figure 3 shows that the proposed incentive structure results in more stable annual suppression budgets, with the variance in annual budget decreasing as b decreases. These changes in budget structure leave managers with fewer funds in a severe fire year, and more funds in a moderate fire year, requiring them to carry over funds from year to year. To decrease annual suppression budgets, either K or b could be reduced.

A logical extension to this incentive structure would be to remove the artificial delineation between wildfire and fuels management. In this case, the budget constraint would apply to both wildfire and fuels management (so that A represents burned hectares plus treated hectares). Therefore, if the increase in budget from burning or treating an addi-

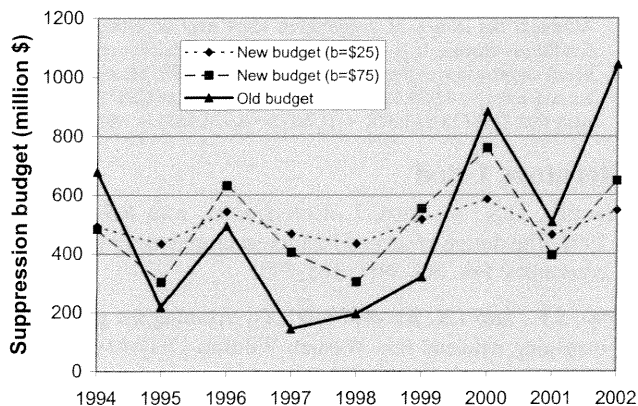


Figure 3. A comparison of annual suppression budgets under the proposed incentive structure and actual suppression expenditures 1992–2002 (in 1994 dollars).

tional acre (b) were larger than the sum of the treatment cost and the disutility of any damages caused, the manager would treat that acre of land. Another extension to the model would be to remove the distinction between presuppression and suppression budgets. Fire managers would receive a single fire management budget, which could be used to finance suppression, presuppression, or fuels management. These extensions can be incorporated into the utility maximization model presented. Although they do make the model somewhat cumbersome, they do not fundamentally change the results.

An incentive structure that encourages fire managers to increase the number of burned hectares would increase the possibility of wildfires or prescribed fires escaping management control and causing unexpected damage. Measures may need to be taken to encourage fire managers to accept this increased risk. Managers should not face undue consequences if a wildfire or prescribed fire they are managing causes unexpectedly high damages.

Implementing the proposed incentive structure would also require institutional changes. Currently, the local land manager cedes tactical fire management decisions to the incoming incident command team. But for the proposed incentive structure to work, the local land manager must maintain control over suppression decisions. However, incident command teams have far more experience than local land managers in managing large wildfires. Therefore, the proposed incentive structure would require establishing some form of principal–agent relationship between the local land manager and the incident command team.

Discussion

Two problems with the current incentive structure faced by Forest Service fire managers are identified, both of which encourage inefficiently high suppression expenditures, and thus contribute to the problem of excess fuels on national forestland. First, fire managers do not consider the potential benefits of wildfire. Second, there is no compelling incentive to consider the true cost of suppression expenditures. Encouragements or admonishments to contain costs have not been very effective in the past, most likely because they are insufficient to change behavior in an organization with a strong culture of aggressive fire suppression.

An alternative incentive structure is proposed in which fire managers are given a base budget that is supplemented by a variable component, the magnitude of which depends on the severity of a fire season. Uncertainty about the severity of an upcoming season means that the optimal value of the base budget K cannot be determined in advance. However, the proposed incentive structure does encourage fire managers to use available resources efficiently.

This article presents an alternative incentive structure that would encourage fire managers to suppress some wildfires less aggressively, resulting in an increase in burned area. If this policy, or one like it, were implemented, it would require a fundamental shift in public expectations of

fire suppression on national forests. There needs to be recognition that complete wildfire exclusion is neither desirable nor possible. A century of aggressive wildfire suppression has demonstrated the consequences of such a policy. In addition, political leaders need to accept the fact that maintaining forest health and controlling suppression expenditures necessitates burning significant areas of forested land annually, either by wildfire or prescribed fire. Such a policy would inevitably result in more short-term resource damage.

Wildfire is an emotive topic, and any attempt to change significantly the way wildfire is managed will likely meet political resistance. For example, few people would argue with the general proposition that wildfire suppression should be economically efficient. However, the reality of suppressing wildfires less aggressively is unpalatable to many people and their political representatives. For this reason, budget considerations seldom significantly limit wildfire suppression. This situation is summarized by Pyne et al. (1996), "... no federally managed fire has been abandoned for lack of funds; no American fire regime has been withdrawn from protection because of strict economic analysis." Therefore, it is unrealistic to suggest the wholesale adoption of an alternative wildfire management incentive structure. However, the proposed incentive structure could be adopted in stages. For example, it would be less contentious to first allow managers to carry over credits and deficits from one year to the next, delaying adoption of the burned area severity adjustment until later. In addition, the proposed incentive structure could be tested and refined in one region of the country before being adopted nationally.

The objectives of containing costs and considering the benefits of fire along with the damages will of course result in letting some fires burn. However, it is not our intention to imply that the decision about letting a wildfire burn is a binary choice, with a wildfire either suppressed as aggressively as possible or left to burn unattended. Rather, fire managers make incremental judgments, weighing the cost of an additional suppression resource against the damage it is expected to avert. For example, a fire manager may decide not to aggressively suppress a fire with expensive aerial resources, but rather let the fire burn a larger area and eventually contain it by using less expensive ground-based resources. Similarly, a fire manager may allow a wildfire to burn some areas to achieve fuels-reduction objectives while suppressing it in others to protect private structures. This is in contrast to the Forest Service's Wilderness Prescribed Natural Fire Program, which since 1972 has allowed 4,000 wildfires to burn to achieve ecological objectives (Trachtman 2003). Under this program, which applies to only a small proportion of Forest Service land, a binary decision is made whether or not to classify a wildfire as a prescribed natural fire.

There are also problems determining the base budget K . Basing it on historical suppression budgets may not be appropriate, because we have shown that the current incentive structure encourages fire managers to use inefficiently high levels of suppression expenditure. In addition, the

values at risk from wildfire are changing. In particular, increased development in the wildland-urban interface means that more private structures are at risk from wildfire.

The success of the incentive structure depends on fire manager's perceptions of government behavior. If fire managers believe that emergency suppression funds will be provided in a severe fire year, there will be a reduced incentive to limit suppression expenditure. Similarly, if fire managers believe that their base budget will be reduced if they carry over large annual surpluses, there will be reduced incentive to limit spending in moderate fire years for use in a later, more severe fire year. Any incentive structure is only as good as the confidence of the participants that it will be enforced.

Endnotes

- [1] Increases in suppression costs have also been attributed to extensive residential development in the wildland-urban interface. We do not address issues specific to the wildland-urban interface.
- [2] These areas are in historic fire regime groups I and II (those lower elevation zones of fire-adapted species, i.e., with a fire recurrence interval of under 35 years) and in current condition classes 2 and 3 (those areas with relatively large departures from the historic fire regime and resultant fuel loads).
- [3] For example, some authors consider initial attack to be a presuppression expenditure. This analysis is not dependent on a particular definition; all that is required is that some distinction is made between presuppression and suppression expenditures.
- [4] Typically, total damages are assumed to be greater than total benefits. Although this need not be the case, situations where total benefits exceed total costs are of less interest to the current analysis, because in these cases the optimal amount of suppression expenditure is zero.
- [5] This has been suggested before, including by the Forest Service in its report "Fire Suppression Costs on Large Fires: A Review of the 1994 Fire Season" released August 1, 1995.
- [6] The total cost function considers only monetary costs, not reductions in utility resulting from reductions in firefighter safety.
- [7] We are representing the fire manager's choice of suppression level as a discrete as opposed to a continuous process. Within hours of a wildfire escaping initial attack, a fire manager must make a series of decisions that will, along with fire behavior, largely determine total suppression expenditures. For example, the fire manager must decide how many crews, engines, and aerial resources to order. Once a resource is ordered, most of its cost must be paid irrespective of whether it is used. In addition, once resources are ordered, support services such as caterers, showers, and communications equipment must also be ordered. However, this decision process may occur more than once on a large fire. For example, a wildfire may significantly exceed a manager's initial expectations. The manager must then reassess the situation, and decide whether to order more resources. Although the choice of suppression level may be changed as fire conditions change, it is still largely a discrete decision process.
- [8] Mean suppression expenditure = US\$498,179,990. Mean number of burned acres = 4,924,488. Therefore, K was set at US\$128,843,373, such that $\text{US\$128,843,373} + (\text{US\$75} \cdot 4,924,488) = 498,179,990$.

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