CHAPTER 15: ECONOMIC ANALYSIS OF FUEL TREATMENTS

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Abstract—Economical management of wildfire through interventions is a growing literature containing three main themes: factors affecting the cost of fuels management, the effects of fuels management on wildfire processes, and using fuels management to achieve management and policy objectives. We review the research into each of these thread, summarize a case study of the third kind of theme, deciding on the economically best long-run level of prescribed fire in Florida. The chapter concludes with recommendations for additional research.

INTRODUCTION

Economical management of wildfire is complicated because wildfire processes look different, depending on the spatial and temporal scale at which decisions are being made, and because there is considerable uncertainty of how management actions result in changes Interventions through fire prevention programs, suppression, and fuels management, like the wildfire processes they seek to manage, will have effects that are scale dependent and temporally and spatially dynamic.

The objective of this chapter is to describe the state of the research into the economics of fuels management. We review studies describing the economic question of fuel treatment choices in wildfire management. We then discuss the importance of how the question or the issue is framed. Framing can be defined in space and time, and it could depend on how the wildfire process is defined. Finally, we offer a case study that provides one example of how researchers have evaluated the economics of fuel treatments.

Approaches to Economics of Wildfire Management

Initial studies into the economics of wildfire management expressed the problem simply, while research in more recent years has described the problem closer to its full complexity. Headly (1916) and Sparhawk (1925) expressed the economic problem as one where a fire boss or agency seeks to minimize the sum of wildfire losses (damages) and the costs of fire suppression for a single fire. Forty years later, Davis and Cooper (1963) and Davis (1965) recognized that fire managers could alter the distribution and quantity of fuels on a managed landscape, not just suppress fires, creating a multi-input problem with greater spatial complexity. The task of the manager was to find that level of fuels management that would alter the likelihoods that fires reach particular sizes. The economic problem, then, was to minimize the sum of fuels management costs, the costs of suppressing fires that do occur, and the losses created by the wildfires on the landscape in a fire season.[1]

Subsequent to these pioneering analyses, authors have begun to describe the problem more broadly. Rideout and Omi (1990), Prestemon and others (2002), Donovan and Rideout (2003), and Mercer and others (2007) have identified the problem of wildfire management as one in which a wildland manager can do any number of things to affect the fire regime in order to achieve overall wildfire program or social welfare objectives. These include preventing fire ignitions, managing fuels, building fire breaks, pre-positioning firefighting resources before fire seasons begin, suppressing fires, evacuating local residents, and taking actions such as timber salvage and site rehabilitation after wildfires to reduce total damages. The problem can be specified either as (i) maximizing values protected minus the costs of protection, or (ii) minimizing the sum of losses and costs of actions taken to affect those losses. Further, many authors have properly described the problem as a long run dynamic optimization problem in which management actions and wildfire in previous periods affect wildfire in the current period. For example, fuel treatments, including fuel breaks, prescribed fire, and mechanical removals, may have long run or multi-season effects on many measures of fire activity and therefore affect the levels of expected damages over many years (Mercer and others 2007).

Given any of the available objectives of wildland management, how much wildfire managers intervene into wildfire processes will depend on the costs of those interventions and on the degree, duration, and spatial extent of their effectiveness. For example, if the per-unit area cost of prescribed fire on a given landscape is greater than the value of the expected wildfire damages produced per unit area, then prescribed fire would not, from the perspective of

wildfire alone, be an economical option for management. A key objective of wildfire managers using fuels management is to maximize its effectiveness and/or reduce its cost—i.e., apply it efficiently. Maximizing effectiveness can mean applying it in the places likely to do the most "good," and reducing its cost means doing it in places where it is inexpensive relative to values at risk and in ways that require fewer or cheaper inputs.

The question of fuel treatment efficiency and the role of treatments in wildland management become more complicated when considering other costs and benefits derived from the treatment itself. For example, fuel treatments can provide many benefits that could be accounted for when evaluating different treatment options. Prescribed fire may reduce vegetative competition and therefore enhance the growth of residual trees (see Crow and Shilling [1980]), enhance production of nutritious forage for livestock, and provide habitat for fire-dependent species (González-Cabán and McKetta 1986). Mechanical fuel treatments offer benefits similar to those of prescribed fire but also produce wood that can be sold (Abt and Prestemon 2006, Rummer and others 2005). Fuel treatments applied in one location, or to one property, can offer benefits in other locations or properties. These benefits, in terms of reduction of wildfire risks, occur because treatments may break up fuel contiguity, slowing the spread of wildfires or enhancing the efficiency of fire suppression activities for fires that occur. Consideration of these benefits can lower the overall per-unit area net costs of implementation, viewed from the broader perspective of the landscape or society.

At the same time, treatments may carry costs that go beyond their explicit implementation costs. For example, treatments can negatively affect environmental attributes and other environmental values important to society and may produce risks for neighboring landowners. Prescribed fire, by altering vegetative cover, can affect water quality (González-Cabán and others 2004), and it produces smoke that reduces air quality, affecting humans (e.g., Martin and others 1977). Mechanical treatments can increase siltation, and the equipment used to conduct them can compact the soil, reducing productivity and damaging residual trees and other plants. Chemical methods for reducing fuels also may have negative environmental impacts that should be considered when evaluating treatment costs.

PUBLISHED STUDIES ON THE ECONOMICS OF FUEL TREATMENTS

Economics studies of fuel treatments can be divided into three broad classes: (i) those focused on the factors that affect the costs of fuel treatments, (ii) those concerned with how fuel treatments can lead to changes in wildfire processes, and (iii) those evaluating how fuel treatments can be applied to achieve societal or managerial goals. Some studies straddle all classes, correctly recognizing that choices about the best locations, timing, and amounts of fuel treatments to apply depend on their costs and whether, where, and when fuel treatments are effective. These studies sometimes also quantify how their location and characteristics affect their costs and hence their net contributions to achievement of desired goals.

Factors Affecting the Costs of Fuel Treatments

The literature on the costs of fuel treatments is difficult to summarize in a few paragraphs, but our review will be brief, focused on some of the more influential studies. Thorough reviews are offered by Hesseln (2000) and Kline (2004), and most of the research we describe in this section is more thoroughly described in those documents.

Perhaps the first refereed journal article on prescribed fire costs in the southern U.S. was by Vasievich (1980), who emphasized the roles of vegetation characteristics and the scale of activity in influencing costs. Vasievich found that the thicker the vegetation, the higher the cost, because of higher labor, capital, and materials requirements with denser undergrowth and ladder fuels. Recognizing the importance of fixed and variable costs in fuels management, the study showed that prescribed burns greater than 2,000 acres cost nine times less per acre than 50-acre burns. Because all treatment actions must contend with fixed costs such as burn management and because larger fires require less perimeter management relative to area contained within the perimeter, greater efficiencies in the use of labor, capital, and other inputs can be achieved. This effect is termed in economics as an "economy of scale."

The earliest published research into the costs of fuel treatments in the western U.S. that we could identify was by Jackson and others (1982). These analysts focused not on prescribed fire intended to change wildfire risk but instead on how prescribed fire could enhance wildlife habitat. This analysis of treatments occurring on national forests contained in U.S. Forest Service Region 1 (Montana and northern Idaho) was one of the first modern studies to document that there are economies of scale to prescribed fire in the western U.S.—larger treatments are less costly per unit area treated, a central focus of the analysis.

The first study we found published in a refereed journal about prescribed fire reducing fire risk was by González-Cabán and McKetta (1986). These authors focused on prescribed fire or mechanical plus prescribed fire fuel treatments occurring on two U.S. national forests in Montana and Oregon. Linear regression quantified the average effect of the fuel treatment method used and site factors on the per-acre cost of these activities. To identify fuel treatment effects beyond reducing fire probabilities and damages, surveys of fire managers indicated how to allocate the costs of treatments to all other benefits; managers allocated 45 and 36 percent of the treatment cost to the goal of reducing wildfire damage risks on the Lolo and the Willamette National Forests, respectively. Fuel treatment costs were found to be influenced slightly by the size of the treatment (indicating economies of scale) but more significantly by the type of treatment, the type of stand, the initial fuel conditions in the stand, primary managerial objective for the treatment (fuel reduction versus silviculture), and seasonal variables which may partially account for weather. The authors conclude that an important factor influencing costs are managerial objectives of the treatment. It appears that treatments that are focused on reducing wildfire risk are significantly more costly than those focused on achieving silvicultural objectives. Presumably, this is because risk reduction treatments are designed to decrease fuel contiguities and reduce crowning and torching potentials, which require significantly more handling and post-thinning fire treatment of downed woody debris.

A subsequent study by González-Cabán (1997) focused on the role that managerial and institutional factors play in the cost of prescribed burning. Based on a survey of U.S. Forest Service managers in the western U.S., González-Cabán found that efforts to reduce the negative impacts of prescribed fire—including escape risk and smoke emissions—led to higher per-unit area costs, indicating that an important cost-escape risk and cost-smoke risk tradeoff existed. The size of burn was a significant explainer of costs, with larger burns associated with lower per-unit costs. Site factors also mattered (e.g., slope) but managerial objectives did not. In conclusion, it appears that efforts to minimize the externalities from risk reduction lead to increases in costs but that these costs can be reduced by treating large areas simultaneously.

Cleaves and others (2000) conducted a nationwide survey of national forests in the U.S. that sought to quantify the variability of prescribed fire costs. The study, based on a survey of managers, illustrates the combined importance of variations across the forests in the availability of prescribed fire services, managerial objectives, site factors, prescribed fire escape risks, and other constraints. Nationwide, over the period 1985-1994, the costs of prescribed fire were found to vary by an order of magnitude, with some of the most expensive prescribed fire occurring in mountainous regions of the West (more than $300 per acre) and the cheapest in the South ($20 per acre). Mercer and others (2007) used the same basic dataset to further explore the factors influencing these prescribed fire costs on national forests. Mercer and others showed that part of the differential in costs across national forests is due to differences in labor costs. Average cost per unit area in each national forest was positively related to statewide costs of labor, but significant cost differences existed by region and according to the amount of forest available for treatment, indicating the importance of other influences on the costs of treatments.

Rideout and Omi (1995) concentrated their analysis on understanding how the scale of operations affects the cost of fuels treatments on U.S. Park Service lands. They found strong economy of scale effects on prescribed burn costs, with lower per unit area costs associated with larger burn areas. Rideout and Omi also found that costs are higher when managers take additional steps to reduce prescribed fire escape risks or protect key resource values or if they accompany the treatment with mechanical, chemical or biological pre-treatments. Significant effects of ecosystem structure or other factors related to location within the U.S. were also found. In short, efforts to protect valuable resources, property, and people from the dangers of using prescribed fire to treat landscapes tend to drive up costs. This implies that ecosystem restoration and fire risk reduction activities may occur more frequently in areas where there are fewer values at risk, an unfortunate situation that complicates actions and economic analyses of where best to place treatments.

The importance of managerial constraints is also highlighted in a study of the role of private property protection by Berry and Hesseln (2004). This analysis found that mechanical and prescribed fire treatment costs per unit area in the National Forests of the Pacific Northwest were higher in the wildland-urban-interface (WUI) than in non-WUI areas. Size of treatment was negatively related to cost, confirming once again that economies of scale exist when conducting treatments. As requirements for handling fuels grow with denser stands, treatment costs also grow, as expected. Validating other research, conducting treatments on sites with high fuels levels that are closer to values at

risk tends to carry a higher cost. Since treatment costs and risk reduction benefits appear to be positively related, careful economic and statistical analyses are required to identify where best to place treatments on landscapes.

Research into the economics of fuel treatments has also been advanced by recent studies into the costs of mechanical fuel treatments and the factors affecting them. Rummer and others (2005) quantified the costs of fire- and ecosystem-enhancing mechanical fuel treatments for all forestlands in the western U.S. Fuel treatment costs varied greatly according to the locations of treatments and stand type. Costs per acre were high, ranging from a few hundred dollars to thousands of dollars per acre, suggesting that restoring ecosystems to fire-adapted conditions may be very costly.

Abt and Prestemon (2006) took the Rummer and others (2005) analysis a step further by evaluating the timber market consequences of releasing marketable products obtained from fuel treatments into western timber product markets. Focused on federal lands, the study showed that significant revenues could be obtained from these treatments, thereby reducing their overall costs, but that unintended consequences in the market may also occur. Concentrating treatments on high-risk sites could be done with less outlay and possibly greater overall benefit than spending money on treating all risky sites without regard to degree of risk.

Prestemon and others (in press) evaluate the costs of fuel treatments in the same framework as Abt and Prestemon (2006) but using a more sophisticated model of treatment costs, consideration of how treatments would affect fire risk, and expanded the spatial scope of the analysis. Prestemon and others controlled for the effects of slope and stand conditions when conducting a modified stand density index-based or thin-from-below type treatment in fire prone stands. The main advance of this work compared to Abt and Prestemon (2006) was inclusion of the South, all federal lands, and the possibility of having to return to stands to re-treat when risky conditions return. The authors conclude that fuel treatments of these types can be less costly if marketable materials are removed and sold but that the net cost of conducting treatments is still well over $600 per acre.

Much of the historical analyses of the factors influencing treatment costs have been focused on public land management in the U.S. Only rarely have studies focused on the costs of treatment on private lands. The important influence of legal and institutional constraints in driving up fuel treatment costs on private lands is clarified in a study by Yoder and others (2003). Liability rules have an effect on how much effort a land manager puts into reducing the risks of fire escape from a prescribed burn. Strict liability laws that penalize managers for escapes tend to increase treatment costs more than those that only penalize managerial negligence. These laws vary across the U.S. and imply that the use of prescribed fire will be lower in places with strict liability compared to those with weaker rules. The strength of laws may therefore conflict with achievement of societal and managerial goals of ecosystem restoration and wildfire risk reduction. However, the empirical effect of laws has not been fully evaluated; presumably, laws are meant to reduce escapes and therefore the attendant damages occurring from wildfires caused by prescribed fires. In locations where escapes are important, strong laws would not necessarily be as much in conflict with achievement of societal objectives as they would be in places where escape risk is low.

Yoder and others' (2003) work reveals that liability laws inflict costs on society in two ways: (i) through increased treatment costs to comply with the law and (ii) the increased losses and suppression costs from wildfires that result from landowners reducing fuel treatments in response to the liability laws. However, the total of these costs should be weighed against the benefits from reducing losses and costs associated with escaped prescribed fires. Developing the socially optimal portfolio of laws requires considering all of these effects prior to enacting additional legislation.

The Effects of Fuel Treatments on Fire Processes

Since ground-breaking work by Davis (1965) and Davis and Cooper (1963), wildland managers have recognized that the economical use of fuel treatments depends on how effective they are at changing wildfire activity across broad landscapes. More recently, Prestemon and others (2002), bolstered by subsequent analyses by Butry (2006, in press), Mercer and others (2007), and Mercer and Prestemon (2005), described the importance of understanding the spatial and temporal dynamics of fuel treatments in affecting fire activity. That is, fuel treatments' effects can span large areas and long time spans, and accounting for their effects must not be limited to understanding or quantifying how actions done in one, confined location leads to changes in fire activity in the short run in that specific location.

Davis (1965) described wildfire activity as a conditional probability distribution across sizes of wildfires and their frequencies. The amount of wildfire activity is conditional on actions intended to affect fire activity. Davis (1965)

and Davis and Cooper (1963) offered some evidence on shifts in the expected amount of area burned in a management unit during a fire season in California and Florida. Prestemon and others (2002), Butry (2006), Butry (in press), Mercer and others (2007), and Prestemon and Butry (2005), instead provide evidence that prescribed fire and other treatments have long term impacts, and that their effects are felt across space and time. Generally, prescribed fire was found to reduce wildfire area burned or intensity-weighted area burned in the long run with an elasticity ranging from about -0.05 to -0.30. In other words, each percentage increase in prescribed fire is expected to yield a long-run decrease in wildfire activity by between 0.05 and 0.30 percent.

Many of the above studies used statistical techniques—i.e., actual data on wildfire and fuel treatment amounts to quantify fuel treatment effects on wildfire. In places without historical data on fuel treatments, or when treatments of new types are being considered, statistical analyses are not easily done. In these cases, simulation approaches are sometimes tested. One example by Finney and Cohen (2003) focused on how fuel treatments may affect wildfire area burned and the number of structures damaged. The authors emphasize (i) the scale of analysis for evaluating fuel treatment effects, and (ii) desired outcome measures. The Finney and Cohen (2003) simulations focused especially on how placement of treatments in the landscape may affect overall wildfire risks on the landscape. Random location of fuel treatments generates overall less beneficial outcomes in terms of total fire spread (area burned) compared to a more systematic pattern of treatment. The authors further discuss how fuel treatments can lead to a variety of potential benefits due to the treatments' effects on fire intensities as well as area burned.

Mercer and others (2007) confirm the dual effects of fuel treatments on fire intensities and area burned. The authors combine intensity and area burned data for Florida to identify the effectiveness of prescribed fire on the landscape. Their econometric results show that prescribed reduces wildfire in both the season following treatment and up to two subsequent seasons. The long-run impact of prescribed fire, however, is about 60 percent less than the short-run impact on wildfire activity because of the dynamic impacts on wildfire. Fuel treatments are found to be less effective at reducing the sizes and intensities of future wildfires than are wildfires themselves. Therefore, short-run reductions are partially offset by subsequent wildfire activity. As in Prestemon and others (2002) and Mercer and others (2007), roundwood removals have various impacts on wildfire activity, serving to increase or decrease wildfires and intensities. This result, the authors speculate, is due to temporary increases in fine fuels in the aftermath of thinning.

Fernandes and Botelho (2003) review the effectiveness of prescribed fire in achieving societal objectives. They identify studies that show that prescribed fire is quite effective at reducing fine fuels and therefore fire intensities and possibly area burned. They also find that empirical analyses by others show that prescribed fire is most effective at reducing fire intensities and areas burned only when weather conditions during fires are not extreme. They also show that strategic application of fuel treatments may be the most effective at reducing fire activity (e.g., Keeley 2002).

Much of the work cited by Fernandes and Botelho has focused on studies of Mediterranean forest types. Piñol and others (2005) offer a simulation model that documents the importance of fire weather in modifying the effectiveness of fuel treatments. An interesting finding from their analysis is that, no matter how fires are burned on landscapes, by intensity levels, fire area burned is about constant, whether or not the fire burns as a fuel treatment (prescribed fire) or as a wildfire. Although, they find, prescribed fire may be a sufficient surrogate to wildfire, prescribed fire must be done in places with high fuels levels, which can be operationally challenging.

The importance of targeting of fuel treatment location is backed up by analyses by Hof and others (2000). In a simulation model of wildfire and fuel treatments, these authors find that effectiveness of treatments at protecting valued resources or property on a landscape depends on the spatial distribution of the treatments, with layout and breaking up of the landscape important determinants. Implied here, given other research on prescribed fire and mechanical treatments (González-Cabán 1997, González-Cabán and McKetta 1986), is that a trade-off exists between costs and protection offered. Given that specific and effective treatment spatial orientations may be more costly than typical layout designs, the finding on the importance of layout, with support by Finney and Cohen (2003), also implies that there may be trade-offs between treatment design and implementation costs.

Using Fuel Treatments to Achieve Managerial and Societal Objectives

Unfortunately, the role of fuels management in achieving improved desired outcomes was barely acknowledged in the received literature, either before Davis (1965) or for at least two decades afterward. To our knowledge, the first published (in a refereed journal) assessment of the question was by Saveland (1987). But even this analysis was

based on simulation and was highly theoretical. The author was forced to make assumptions about the costs of prescribed fire and the damages from wildfire and then evaluate what level of prescribed fire efficacy would result in positive net societal benefits, in terms of reducing total fire program costs and losses. The analysis, however, advanced consideration of the long-run effects of a fuel treatment program, a major contribution to the literature.

Although analysts such as Bellinger and others (1983) and Rideout and Omi (1990) recognized the importance of the potential role of making "presuppression" interventions in a wildfire program, prescribed fire was not considered part of this. Omi and others (2000) revisited the overall problem of how to assess the cost effectiveness of fuel treatments using a simulation approach to assess how fuel treatments might affect area burned. The analysis was purely experimental, although it was based on simulations from National Park Service lands in the U.S.

It was not until Prestemon and others (2002) broached the issue of the long-run, broadscale nature of the fire-fuels management problem that analysts have attempted to evaluate the economics of fuel treatments in wildfire management using actual data. Prestemon and others (2002) showed in their statistical analysis of wildfire at the county level in Florida that prescribed fire has long- and short-run impacts and that its effects can be identified at broad spatial scales. Butry (2006) also showed how the economics of fuels management depend on the recognition of the trade-offs among fuel treatments, suppression expenditures, and wildfire damages. Mercer and others (2007) extended the Prestemon and others (2002) analysis to show how prescribed fire can lead to aggregate net benefits, in terms of reducing damages to timber, housing, and the broader economy.

Other research has addressed the problem of fuel treatments at a stand level, rather than a landscape level, while still recognizing the spatial and long-run nature of the problem. In the context of a Faustmann model of optimal timber rotation, Amacher and others (2006) describe how landowners may choose the amount of fuel treatments, recognizing the random nature of wildfire, changed intensities of wildfires due to treatments, the changed value of salvage timber due to treatments following wildfires, and the long-run nature of the problem. Rather than approach the problem of fuels management from the perspective of public lands, like nearly all previous analyses, the Amacher and others study was the first to mathematically describe the spatio-temporal complexity of the problem of fuels management in the context of a multi-ownership landscape.

Prescribed Fire and Sediment Production: Costs and Benefits

Increased soil erosion and sedimentation often result in lost reservoir water storage capacities and increased water treatment costs for municipal watersheds (González-Cabán and others 2004). A study by Wohlgemuth and others (1999) found that sediment production in areas affected by recent wildfires was about 90 to 95 percent lower in areas previously prescribed burned compared to non-treated areas.

Although wildfires are one of the main causes of accelerating sedimentation, due to increased soil erosion, the only study we could find that examined the economics of prescribed fire on sediment production was conducted by Gonzáles-Cabán and others (2004). These analysts present a methodology for estimating the costs and benefits of using prescribed fire to reduce sedimentation following wildfires and apply it in a case study of the watersheds in the Los Angeles County foothills, which encompasses the Angeles National Forest and adjacent private lands. The current wildfire interval of 22 years produced $2.5 million in sediment management and watershed rehabilitation costs for local, state and federal agencies. However, a multiple regression analysis of the impact of fire interval on sediment yield indicated that using prescribe fire that reduced the fire interval to 5 years would decrease sediment yield by 2 million cubic meters in the 86.2 square kilometer watershed adjacent to the Angeles National Forest. A 1% decrease in the fire interval was found to reduce annual sediment yield by 0.58%. Gonzáles-Cabán and others estimated that implementing a prescribed burning program on a five year interval would save $24 million per year because of the decreased debris basin clean-out costs for LA County Public Works.

CASE STUDY: DEFINING SOCIALLY-OPTIMAL FUEL REDUCTION PROGRAMS IN FLORIDA.

Defining the "best" amount of fuel treatments to apply to a forested landscape remains one of the most important and difficult issues for wildfire management because: (i) treatment effectiveness is difficult to measure and varies over time, (ii) treatment costs are variable and are influenced by the scale of operations, (iii) wildfire damages are complex and vary regionally, and (iv) future fire occurrences are inherently uncertain.

Over the past five years, US Forest Service scientists have completed a series of studies to address this large question (Butry 2006, Butry and others 2001, Butry and Prestemon 2005, Mercer and Prestemon 2005, Mercer and others 2007, Prestemon and Butry 2005, Prestemon and others 2002, Prestemon and others 2008, Pye and others

2003). Using data on forest resources, meteorology, fire occurrence, and economic impacts within a probabilistic modeling framework, Forest Service economists have built a state-of-the-science assessment of prescribed burning efficacy in Florida. Unlike previous studies, this work goes well beyond natural resource impacts to address how prescribed fire programs affect total social welfare at a broad scale.

Mercer and others (2007) applied the approach to Volusia County in Florida to evaluate the optimal prescribed burning regime for a broad range of potential fire scenarios. The results indicate that, not only does the current prescribed burning regime generate expected net gains in social welfare, but that these gains would exceed the costs of burning for a considerable expansion in the prescribed burning program. While landowners currently prescribe burn about 4 or 5 percent of forests per year, the socially optimal treatment is approximately 13 percent of forests per year.

The results provide information for forest managers in Florida but also define broader policy and program implications. Among the policy relevant findings are: (i) the available supply of fuel treatment service providers plays a key role on the ability to accomplish goals; (ii) understanding and predicting the potential fire severity and burned areas under different management regimes are crucial to identifying optimal policies; and, (ii) the use of private sector prescribed burn services by public land agencies may drive up prescribed burning costs for private forest landowners—i.e., an unintended consequence of public programs can be a reduction in beneficial activities on private land. Next we briefly describe the methods used for this analysis.[2]

The Model

In general, determining the publicly optimal amount of prescribed burning requires solving a stochastic dynamic optimization problem. Therefore, to find the optimal levels of prescribed fire (or other vegetation management) inputs for wildfire risk reduction, we maximize the sum of expected current and future net present value of welfare:

$$\max_{x_t} A = E\left\{ VW_t - \mathbf{v(x)'x_t} + \sum_{i=t+1}^{T} e^{-ri}(VW_i - \mathbf{v(x)'x_i} \right\}, \qquad (1)$$
$$\text{and} \quad W_t = W(\mathbf{Z_t}, \mathbf{W_{t\text{-}j}}, \mathbf{x_{t\text{-}k}}) + \varepsilon_t, \mathbf{x_t} \geq 0 (\forall t)$$

where A is the maximization criterion (a welfare measure), V is the net value change per unit area of wildfire, W_t is current area (acres) burned by wildfire[3] for the spatial unit of observation in year t, $\mathbf{v}$ is a vector of the prices per unit area of suppression, pre-suppression, and vegetation management inputs[4], $\mathbf{x} = (\mathbf{x_t}, \mathbf{x_{t+1}}, \ldots, \mathbf{x_T})$ is a vector of the amount of suppression, pre-suppression, and vegetation management inputs for year t through T (the planning horizon), $\mathbf{Z}_t$ are exogenous inputs to wildfire production including stochastic climate variables, $\mathbf{W}_{t\text{-}j}$ is a vector of j lags of wildfire area, and r is the discount rate. Solving this optimization problem produces a Tx1 vector of optimal input quantities and a Tx1 vector of wildfire quantities over time. The uncertainty associated with random events (errors in prediction of weather, for example) means that $W(\cdot)$ is known only with error, complicating the solution process. In the presence of such error, simulation techniques may be used to identify, for example, the amounts of prescribed burning most likely to maximize the welfare criterion. Hadar and Russell (1969) describe how to evaluate these types of uncertain prospects.

Identifying the long-run expected impact of prescribed fire requires accounting for variable weather and the uncertainties associated with the "true" form of equation (1). While equation (1) was estimated using historical data on fire output and wildfire production inputs, observed wildfire output always differs from that predicted by an empirical model because of the random nature of the phenomenon and the imprecision of statistics. To identify the "best" level of prescribed fire to apply in a fire-prone landscape, the authors first estimated two versions of equation (1)—one expressing wildfire output in area burned and one in intensity-weighted[5] area burned. Research has shown that wildfire intensity is closely related to the resulting damages to forests. So, measuring how prescribed fire affects the intensity of wildfire output should provide a more accurate prediction of the impacts of prescribed fire on wildfire damages.

Next, the results from the empirical estimates of equation (1) were used to forecast the expected damages from wildfire under different prescribed fire scenarios for Volusia County, which was representative of the fire-prone landscape of Florida. Forecasts of each year's wildfire activity were made for 100 years into the future. The 100-

year realization of wildfire output was done by (1) selecting a fixed level of prescribed fire to apply every year; (2) randomly selecting the values of two climate variables found to influence wildfire in Florida (an ocean temperature measure of the El Niño-Southern Oscillation and an index of sea level air pressure quantifying the North Atlantic Oscillation); (3) randomly selecting a forecast error for wildfire area burned and wildfire intensity-weighted area burned from the historical distribution of weather factors and from prediction errors; and then (4) calculating the total annual expected wildfire damages and suppression costs and the annual cost of applying the fixed amount of prescribed fire to the county. The final step was to vary the amount of prescribed fire chosen in step 1 and then repeat steps 2-4. This process was continued, starting from 5,000 acres prescribed burned per year, up to about 100,000 acres per year (out of 313,000 acres of forest in the county). After all of these simulations were completed, the total, long-run discounted cost plus losses associated with wildfire and prescribed fire were compared across all levels of prescribed fire to identify the acreage of annual prescribed fire where the sum of costs and losses was smallest.

Data were obtained from many state and federal agencies. The Florida fire data on state and private lands, 1981-2001, were daily records of the location and the features of the wildfire, sufficient information to construct a damage measure of fire intensity-weighted acres burned per year in each county; these data were by special request. Data on wildfires on Federal lands were obtained from the USDA Forest Service, US Fish and Wildlife Service, and the US Park Service. The prescribed fire data, 1994-2001, were permits granted by the State for prescribed fire. The National Oceanic and Atmospheric Administration (2003a) provided data on the Niño-3 SST anomaly, 1994-2001, a measure of the strength of El Nino (fires burn more in Florida when the Niño-3 SST anomaly is negative). NOAA (2003b) also provided the values of the North Atlantic Oscillation, 1994-2001, another ocean temperature measure linked to wildfire in Florida. The USDA Forest Service provided information on the amount of forest in each county. Data on annual housing counts in each county were provided by the Florida Bureau of Economics and Business Research (2002), our instrument for measuring the impact of available wildfire suppression resources. The wildfire intensity-weighted risk variable was calculated by categorizing all wildfires into intensity classes using actual observations of the average flame length for each fire, based on research by Byram (1959). The annual intensity-weighted risk was derived by summing for each county the product of the annual number of acres burned in each intensity class times the average intensity for that class divided by the county's total forest area.

Models were estimated for fire at the county level. Two county fixed-effects time series models of (i) intensity-weighted area burned and (ii) area burned were estimated. The dependent variables for the two models were: (a) intensity weighted acres per acre of forest area in the county in the year and (b) the area of wildfire area burned in the county per acre of forest area in the county.

The losses associated with wildfire were calculated based on the 1998 wildfires (Butry and others 2001). Two versions of losses were generated: one version assembled losses in terms of social welfare—consumer plus producer surplus. Another version assembled losses in terms of market values—prices times quantities. Losses accounted for timber losses from wildfire, housing losses, and suppression expenditures.

Results

The original statistical models, relating fire area burned and fire intensity-weighted area burned, show that prescribed burning at the county level has a large, statistically significant effect on both intensity-weighted area burned and on area burned in the county. The elasticity of intensity-weighted area burned with respect to prescribed fire permitted area was −0.9 in the short-run and −0.31 in the long-run. The elasticity of wildfire area burned with respect to prescribed fire permitted area was −0.72 in the short-run and −0.28 in the long-run.

We also estimated a model for the supply of prescribed fire services, which showed that prescribed fire services had a long-run supply elasticity of about +0.54. This indicates that the cost of prescribed fire per acre would increase twice as fast as the increase in the areal increase in prescribed fire. This extra cost associated with higher levels of prescribed fire was included in the cost plus loss simulations.

The simulations (see Figures 1 and 2) showed that the optimal levels of prescribed fire depend on whether wildfire is measured purely by area burned or if it is quantified by intensity-weighted area burned. Figure 1 shows the impact of prescribed fire on both wildfire intensity-weighted acres and on the losses and costs associated with wildfire and prescribed fire applied to achieve these levels of losses and costs. Figure 2 shows the same, but in terms of area burned-related losses instead of intensity-weighted area burned related losses. Figure 1 shows that the expected

value of losses plus costs is minimized when prescribed fire is set at about 19,000 acres per year in Volusia County, Florida. Figure 2 shows that the prescribed fire area of 14,000 acres per year maximizes net value change plus costs. From 1994-2001, Volusia County averaged about 13,000 acres per year, which is close to the amount justified based on the area burned effect of prescribed fire. But this is about 30 percent less than the amount that would be justifiable based on the intensity-weighted area burned measure.

SUMMARY AND CONCLUSIONS

The most striking finding from our survey of the economics of fuel treatments is mainly how little work has been done to evaluate net economic benefits. Most economic studies of wildfire management have focused on assessing wildfire economic impacts, understanding the economic questions surrounding wildfire suppression and prepositioning of suppression resources (a literature that we did not thoroughly review), and evaluating the costs of fuel treatments and the variables affecting those. Much of the economic analyses of fire suppression have been theoretical, which limits their usefulness to managers, with almost no empirical applications reported in the refereed literature.

Still less work has been published that quantifies how treatments may affect wildfire processes. Without models that can quantify the impacts of treatments on wildfire activity, answering questions about the economics of treatments is not possible. Simulation models of wildfire that can account for the effects of fuel treatments are available, but they are in early development stages (e.g., FARSIGHT; see Finney [1998] and Finney and Andrews [1999]). The only known empirical assessments in the refereed literature that we can find are analyses for Florida that we have described (e.g., Mercer and Prestemon 2005, Prestemon and others 2002). Only Davis and Cooper (1963), Davis (1965), and Mercer and others (2007) have done actual empirical analyses that place fuel treatments into the question of wildfire management economics.

Even the received literature has many information gaps that need to be addressed. For example, all of the literature ignores many of the externalities and non-market effects of fuel treatments. No study has integrated into an economic analysis of fuel treatments the possible damages associated with treatments, including (i) the risks from escaped prescribed fires, (ii) the negative site impacts from mechanical thinnings, or (iii) the smoke from prescribed fires. Similarly, no study has integrated the benefits of fuel treatments on processes other than wildfire. These benefits include ecosystem restoration and improvement of timber growing conditions.

Additionally, we found only one study that included attention to watersheds (González-Cabán and others 2004), and this has not been published in the refereed literature. These gaps in knowledge about the connections among wildfire, fuel treatments, and watersheds are not necessarily for lack of interest. We believe that the most recent advances in the science have occurred due to the availability of new historical data on wildfire and fuel treatments in the same landscapes, enhanced computational power (which allows fine-scale simulations), and the emergence and application of new statistical methods. We anticipate that future research in the area of fuel treatment economics will advance rapidly. In terms of water, the most significant research need that we see is for experimental and field experiments that measure water and watershed responses to wildfires and fuels management.

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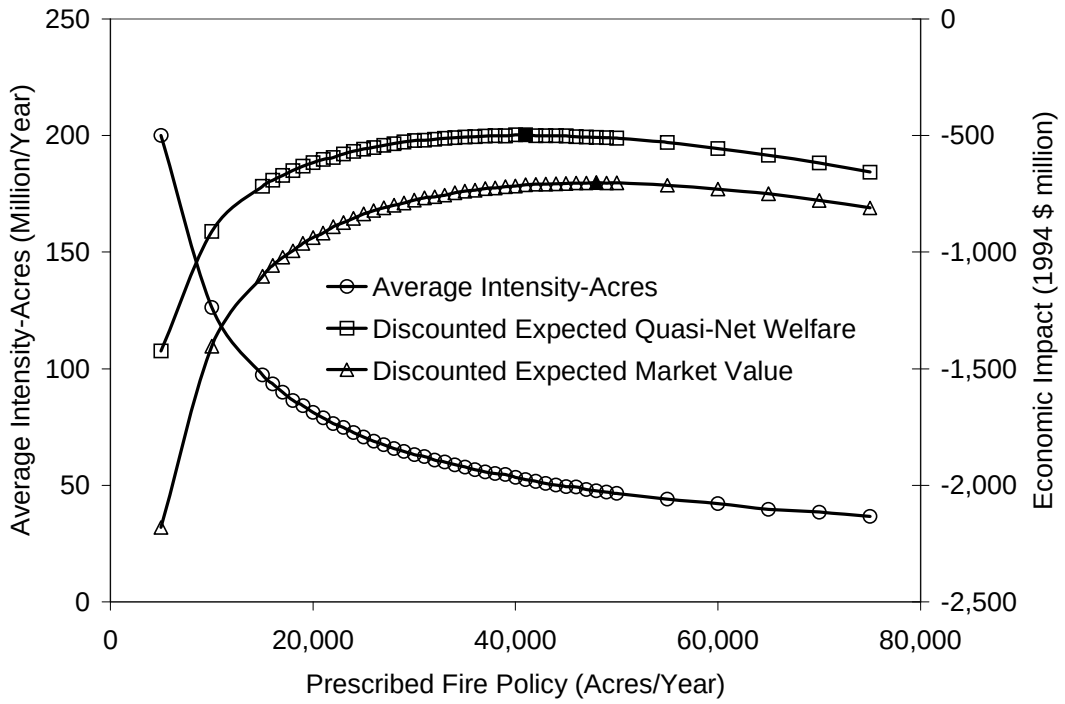

Figure 1--The simulated schedule of input-output combinations derived from the intensity-weighted risk model; amounts of prescribed burning yielding the maximum of net value change minus cost (symbols shaded black) are 19,000 acres/year for the quasi-net welfare analysis and 20,000 acres/year for the market value analysis. (Source: Mercer and others 2007).

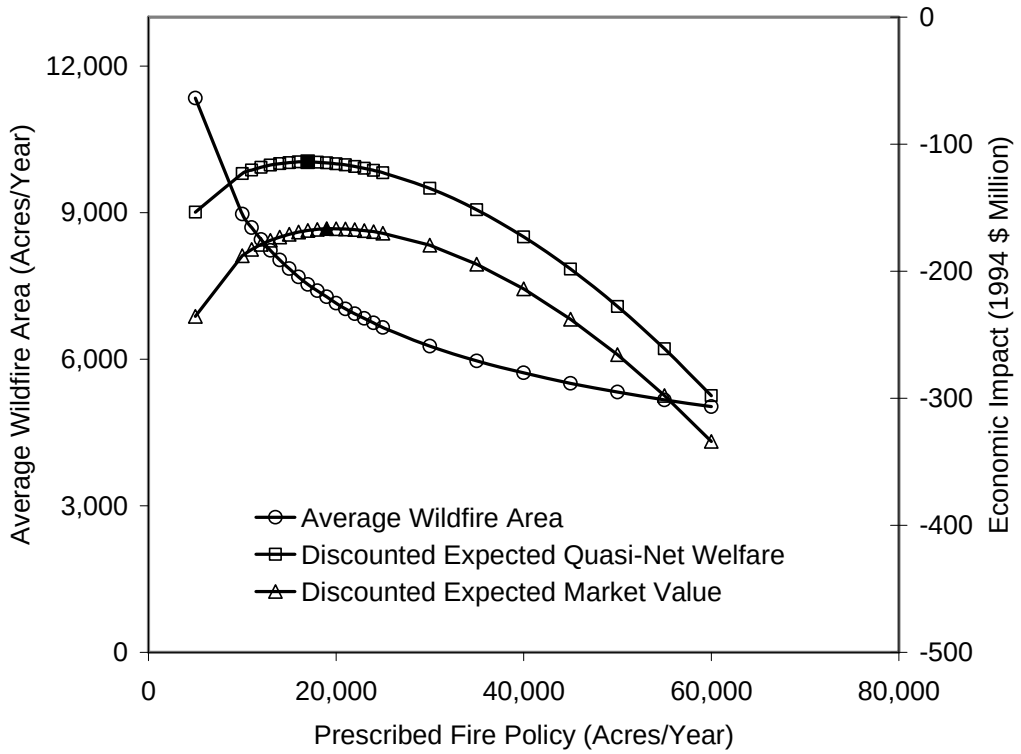

Figure 2--The simulated schedule of input-output combinations derived from the areal risk model; amounts of prescribed burning yielding the maximum of net value change minus cost (symbols shaded black) are 14,000 acres/year for the quasi-net welfare analysis and 15,000 acres/year for the market value analysis. (Source: Mercer and others 2007)

FOOTNOTES

[1] In this chapter, we conform to convention and define wildfire damages or wildfire-related losses of ecosystem goods and services as "losses" and the expenses incurred to manage wildfire on the landscape (prevention, fuels management, suppression, post-fire rehabilitation) as "costs." Hence, the economic problem is often described as minimizing the sum of costs plus losses. Losses are sometimes also described as net of wildfire-related benefits so that when a wildfire occurs, it generates net changes in values ("net value change"), so that the wildfire management economic problem is stated instead as minimizing the sum of costs plus net value change.
[2] This section is derived from Mercer and others (2007).
[3] W_t could, alternatively, be expressed as a quantity measure of resources "saved" by applying resource inputs. In that case, V would be a positive number, reflecting positive values. As currently expressed in (1), V would be a negative value per unit, measuring damages per unit of wildfire realized.
[4] The "price" to the economy would be the net welfare change arising from the diversion of resources to vegetation management and away from other economically productive activities in the economy; in other words, this is the opportunity cost of foregone uses of these resources in the economy.
[5] Wildfire intensity is defined as the rate at which a fire produces thermal energy.