Net Benefits of Wildfire Prevention Education Efforts

Jeffrey P. Prestemon, David T. Butry, Karen L. Abt, and Ronda Sutphen

Abstract: Wildfire prevention education efforts involve a variety of methods, including airing public service announcements, distributing brochures, and making presentations, which are intended to reduce the occurrence of certain kinds of wildfires. A Poisson model of preventable Florida wildfires from 2002 to 2007 by fire management region was developed. Controlling for potential simultaneity biases, this model indicated that wildfire prevention education efforts have statistically significant and negative effects on the numbers of wildfires ignited by debris burning, campfire escapes, smoking, and children. Evaluating the expected reductions in wildfire damages given a change in wildfire prevention education efforts from current levels showed that marginal benefits exceed marginal costs statewide by an average of 35-fold. The benefits exceeded costs in the fire management regions by 10- to 99-fold, depending on assumptions about how wildfire prevention education spending is allocated to these regions. FOR. SCI. 56(2):181–192.

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WILDFIRE MANAGEMENT INVOLVES deploying combinations of resources at many stages in the wildfire production process (Rideout and Omi 1990), including actions taken by individual landowners as well as public agencies. When considering wildfire management actions, land managers must contemplate the effects of phenomena not directly controlled by the managers themselves, including the provision of "free" inputs from nature—lightning strikes, weather conditions, and vegetation growth—and those provided by society—purposeful and accidental ignitions by people. One way to accommodate the natural and society-driven tendencies for wildfires to burn is to modify the landscape through fuels management and suppression. Research shows that both fuels management (e.g., Pollet and Omi 2002, Mercer et al. 2007) and suppression (e.g., Butry 2009) are effective in reducing overall wildfire damages.

Wildfire prevention education (WPE), which we define here as the avoidance of accidentally ignited human-caused wildfires through education [1], is a third method that organizations use to reduce undesired wildfire activity. And although a common belief is that WPE is worthwhile, there is a striking absence of studies documenting its effectiveness. Two studies published in the *Journal of Forestry* in the 1970s evaluated the effectiveness of personal contacts (meetings with individuals and communities to discuss means of avoiding preventable wildfires) as a WPE method (Doolittle and Welch 1974, Moak 1976), but these merely documented correlations between increased WPE activity and reduced numbers of reported wildfires and did not account for other factors that could affect those numbers. Although Sackett et al. (1967) evaluated prevention, the effect that they quantified was subsumed within a variable comprising detection, presuppression, and suppression, as well as what we have defined as prevention.

Despite the absence of recent peer-reviewed studies documenting the effectiveness of WPE, governments and other entities devote resources to educating the public about the dangers of accidental firesetting, with the expectation that these activities will lead to fewer wildfires (e.g., National Wildfire Coordinating Group 1998). Wildfires are accidentally ignited through a variety of mechanisms, including escapes from debris fires and brush-clearing fires, equipment malfunctions, campfire escapes, smoking, fire play, and vehicle sparking and crashes. Recognizing the potential damages from equipment fires, technology in some instances has been advanced to reduce their occurrence (e.g., spark arrestors on trains). Some of the accidental wildfire starts can be avoided by limiting when, where, and how people conduct certain kinds of activities and by undertaking public education programs. These programs make intuitive sense because human-caused wildfires often occur in intermixed areas of forests, high value property, and local populations (e.g., Bradshaw 1988, Butry et al. 2002), producing immediate peril to people and property. Measuring the economic or financial effectiveness of WPE requires careful statistical analysis and a comprehensive assessment of how wildfire occurrence relates to other mitigation efforts limiting wildfire occurrence, spread, and physical damages to resources and property.

The objective of this research was to quantify the effects of WPE efforts. This was achieved by analyzing statistically how WPE reduces the occurrence, area burned, and net economic losses associated with preventable wildfires. Design of a statistical approach quantifying this relationship is based on a theoretical model, which we then used in an

Jeffrey P. Prestemon, US Forest Service, Southern Research Station, 3041 Cornwallis Rd., Research Triangle Park, NC 27709—Phone: (919) 549-4033, Fax: (919) 549-4047; jprestemon@fs.fed.us. David T. Butry, National Institute of Standards and Technology—david.butry@nist.gov. Karen L. Abt, Southern Research Station, US Forest Service—kabt@fs.fed.us. Ronda Sutphen, Florida Division of Forestry, Department of Agriculture and Consumer Services—sutpher@doacs.state.fl.us.

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empirical application to test hypotheses about the efficacy of each of a variety of WPE efforts. Our theoretical model, a slight alteration from that of others (e.g., Rideout and Omi 1990, Donovan and Rideout 2003), augments the traditional cost plus loss model of wildfire program intervention to explicitly include efforts to affect wildfire ignitions. In the empirical specification, we describe wildfire area burned and damages as depending on WPE, fuels management, and suppression.

This research makes the following contributions to wildfire management and to economics. First, for one US state (Florida), we quantify the effects of alternative WPE efforts on wildfire occurrence, which, to date, have not been reported. Second, we assess the net benefits of WPE in terms of dollars of losses averted relative to the costs of aversion (costs of WPE). We show that avoided losses, including expenditures on suppression and expected economic damages from wildfire, exceed WPE program costs.

Methods

We specify a general long-run cost plus net value change model in which the land manager is assumed to maximize long-run net benefits (W) by choosing, in each location (j) and time period (t), the quantities of M alternative interventions contained in a vector $\mathbf{x} = (x_1, x_2, \ldots, x_M)'$. The effect of these interventions is distributed in some manner across I preventable wildfire causes. The programmatic costs of these interventions are subtracted from the observed wildfire damages for each wildfire cause, location, and time period ($D_{i,j,t}$) and then discounted to the present:

$$\max_{\mathbf{x}} W = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} \left\{ \left(D_{i,j,t} - \sum_{m=1}^{M} x_{i,m,j,t} w_{i,m,j,t} \right) e^{-rt} \right\} \quad (1)$$

$$D_{i,j,t} = y_{i,t} N_{i,j,t} A_{i,j,t}$$

$$N_{i,j,t} = f(\mathbf{x}_{i,j,t-k}, \mathbf{z}_{i,j,t}, \varepsilon_{i,j,t})$$

$$A_{i,j,t} = g(\mathbf{x}_{i,j,t-k}, \mathbf{z}_{i,j,t}, \nu_{i,j,t})$$

where $y_{i,t}$ is the net value change of a unit area of wildfire (defined here as losses net of benefits) of cause i common to all J locations [2] in period t, $N_{i,j,t}$ is the count (number) of wildfires for i, j, t, $A_{i,j,t}$ is an average wildfire size for i, j, t, $\mathbf{w}_{i,j,t-k}$ is a conformable m-dimensional vector corresponding to m-dimensional vector $\mathbf{x}_{i,j,t-k}$ that gives the unit costs of the m interventions, $\mathbf{z}_{i,j,t}$ are free inputs (that is, inputs provided by nature or society that are not intended to manage wildfire) to wildfire production, $\varepsilon_{i,j,t}$ and $\upsilon_{i,j,t}$ are random disturbances for i, j, t, e is the exponential operator, and r is the discount rate. In Equation 1, we assume that the net value change per unit area of wildfire is constant across t and that the intervention unit costs are constant across space in a given period; both of these assumptions could be relaxed, but we maintain them for expositional simplicity. The damage component of Equation 1 ($D_{i,j,t}$) is the product of the net value change per unit area of wildfire, the number of wildfires, and the average area of each wildfire. This provides the total damages from all of the wildfires of a given cause, in a certain location, and in a particular period. This average is calculated from a historical distribution of wildfire areas burned—another assumption that could be relaxed and re-specified as a draw from a prespecified empirical wildfire-size frequency distribution. The statistical tasks, therefore, are to (1) identify the average wildfire size ($A_{i,j,t}$), (2) quantify a wildfire net value change per unit area ($D_{i,j,t}$), (3) quantify the WPE input cost per unit of intervention type ($\mathbf{w}_{i,j,t-k}$), and (4) estimate a model predicting the number of wildfires for each wildfire cause across all locations as a function of WPE efforts and other variables specified in 1 as $N_{i,j,t} = f(\mathbf{x}_{i,j,t-k}, \mathbf{z}_{i,j,t}, \varepsilon_{i,j,t})$.

Wildfire occurrence from any cause can be represented by Poisson type processes (e.g., Gill et al. 1987, Martell et al. 1987, Prestemon and Butry 2005). Typically, these have been described as functions of weather, climate, socioeconomic factors, fuels or ecological factors, seasonality of different forms, and interventions such as fuel treatments or WPE efforts. The exact specification depends on the possibility that occurrences are autoregressive processes and on the temporal scale of the analysis. Whereas Prestemon and Butry (2005) found autoregression lasting up to 11 days in the count on a daily time scale for arson wildfires, for periods longer than that, the count of wildfire occurrences of cause i in location j in period t may be described as a nonautoregressive Poisson or negative binomial process:

$$N_{i,j,t} = \exp(\boldsymbol{\beta}_{i,j}' \mathbf{Y}_{i,j,t} + \varepsilon_{i,j,t}), \quad (2)$$

where exp is the exponential operator, $\mathbf{Y}_{i,j,t} = (1, \mathbf{x}_{i,j,t-k}, \mathbf{z}_{i,j,t})'$, and $\boldsymbol{\beta}_{i,j}$ contains parameters associated with a constant, the interventions, and the free inputs, respectively. Equation 2 is the classic Poisson model, which assumes mean–variance equivalence; a negative binomial counterpart to Equation 2 relaxes the mean–variance equivalence assumption.

In an economic assessment about whether WPE yields positive net benefits, one way to describe the magnitude of the net benefits is to calculate marginal benefit/cost ratios (the change in benefits produced divided by the cost of the added input needed to achieve the change). With a statistical estimate of 2 made over all J locations and I wildfire causes, the short-run marginal benefit/cost ratio, MBC, the additional benefits obtained from a change in wildfire damages of wildfire cause i in period t divided by the additional input costs incurred by a small change in the mth WPE activity in period t is

$$\mathrm{MBC}_{i,m,t} = \frac{-y_{i,t} \bar{A}_{i,t} \, \mathrm{d}\hat{N}_{i,t} / \mathrm{d}x_{m,i,t}}{w_m \, \mathrm{d}x_{m,i,t}}. \quad (3)$$

Here, $\hat{N}_{i,t}$ is the predicted number of wildfires of cause i in period t, $A_{i,t}$ is the average area burned by an averted wildfire of cause i in year t, and “d” indicates a small change. The negative in the numerator is indicated because y is defined as per unit damages. Not knowing how spending is distributed among different WPE efforts, the ratio of the short-run benefits to additional costs of changing all M WPE inputs by a small amount, could be calculated across all interventions simultaneously. For a single period t, this is

$$\mathrm{MBC}_{i,t} = \frac{-\sum_{m=1}^{M} y_{i,t}\bar{A}_{i,t}\,\mathrm{d}\hat{N}_{i,t}/\mathrm{d}x_{m,i,t}}{\sum_{m=1}^{M} w_m\,\mathrm{d}x_{m,i,t}}. \tag{4}$$

Finally, assuming that WPE efforts are distributed in their effects across all causes of wildfires and that these distributive effects are constant, a short-run marginal benefit/cost ratio could be calculated for the program as a whole, across all preventable wildfire causes. This would then be expressed for period t as

$$\mathrm{MBC}_{t} = \frac{-\sum_{i=1}^{I}\sum_{m=1}^{M} y_{i,t}\bar{A}_{i,t}\,\mathrm{d}\hat{N}_{i,t}/\mathrm{d}x_{m,i,t}}{\sum_{i=1}^{I}\sum_{m=1}^{M} w_m\,\mathrm{d}x_{m,i,t}}. \tag{5}$$

An empirical question with respect to wildfire occurrence is whether management variables affecting the number of wildfires on the landscape affect the probability of wildfires of all sizes or damage levels equally. We do not know whether a wildfire averted is a random draw from the wildfire size-frequency or damage-frequency distribution. For example, if wildfires averted are less damaging or smaller than those that occur, then an estimate of the marginal benefit/cost ratio in 5 that is based on a constant reflecting the average area of the wildfire (e.g., $A_{i,t}$) would be biased upward [3].

Short-Run Versus Long-Run

Research by Prestemon et al. (2002), Mercer and Prestemon (2005), and Mercer et al. (2007) showed that wildfire area burned in the current year is a negative function of historical years' wildfire area burned and that this suppression or "fuel treatment" effect of wildfires lasts many years (up to 11), at least in Florida. This negative autocorrelation implies that the long-run (multiyear) effects of any activity (e.g., WPE, fuels management, and suppression) that reduces the area burned by wildfire on a landscape are smaller than their short-run (current year) effects. Although not extensively described in these or any study, the effect of reducing the occurrence of (and hence area burned by) a subset of wildfire causes is complex. As shown in Prestemon et al. (2002), the area burned by one cause of wildfire (e.g., lightning) depends on lagged areas burned by its own cause as well as other causes. In other words, given the negative relationship between areas burned created by both preventable causes, for which WPE efforts might be effective, and other causes, the area burned by wildfires from these other causes would be expected to increase in periods subsequent to successful WPE. This interlocking negative feedback is difficult to describe mathematically, but it bears general description. Furthermore, as far as we know, a mathematical description of the nonlinear dynamics associated with wildfire is essential to understanding why short-run success in management of one kind of wildfire in the current period is not equivalent to long-run success. Equations 6–14 quantify the distinctions, which are necessary for correctly quantifying the net benefits of management.

First, specify two wildfire-cause equations, one of which (preventable wildfire ignitions) responds directly to WPE in the current period. If a_t^p is the area burned by preventable wildfires, a_t^n is the area burned by other causes, a_0^p and a_0^n are constants, $\mathbf{z}_t$ are the nonmanagement inputs to wildfire processes, $x_{M,t}$ is a WPE variable that affects wildfire occurrence and extent, and $\mathbf{x}_{M-1,t}$ is a vector of the other wildfire management inputs, then

$$a_t^p = \alpha_0^p + \boldsymbol{\alpha}_1'^p\mathbf{a}_{t-k} + \boldsymbol{\alpha}_2'^p\mathbf{z}_t + \boldsymbol{\alpha}_3'^p\mathbf{x}_{M-1,t} + \alpha_4^p x_{M,t} + \varepsilon_t^p$$

$$a_t^n = \alpha_0^n + \boldsymbol{\alpha}_1'^n\mathbf{a}_{t-k} + \boldsymbol{\alpha}_2'^n\mathbf{z}_t + \boldsymbol{\alpha}_3'^n\mathbf{x}_{M-1,t} + \varepsilon_t^n \tag{6}$$

and

$$\mathbf{a}_{t-k} = (a_{t-1}^p, a_{t-2}^p, \ldots, a_{t-k}^p, a_{t-1}^n, a_{t-2}^n, \ldots, a_{t-k}^n)'$$

Here, the effect of a marginal change in WPE in period t, measured by $x_{M,t}$, on wildfire area is

$$\frac{\partial a_t^p}{\partial x_{M,t}} = \alpha_4^p, \quad \frac{\partial a_t^n}{\partial x_{M,t}} = 0. \tag{7}$$

This result indicates that preventable wildfires are reduced in the current period, but other wildfires are not changed in the current period. Multiplying α_4^p by $y_t\,\mathrm{d}x_{Mt}$ (where y is the net value change per unit area of wildfire, as in Equations 1–5) would yield the benefit of the current period in terms of reduced preventable wildfire damages. In period $t+1$, the effects of a marginal change in WPE in period t now yield effects on both wildfire causes, owing to the lag structure of wildfire activity shown in Equation 6,

$$\frac{\partial a_{t+1}^p}{\partial x_{M,t}} = \alpha_{1,1}^p\alpha_4^p, \quad \frac{\partial a_{t+1}^n}{\partial x_{M,t}} = \alpha_{1,1}^n\alpha_4^p, \tag{8}$$

where $\alpha_{1,1}^p$ is the first element of the parameter vector $\boldsymbol{\alpha}_1^p$ and $\alpha_{1,1}^n$ is analogously defined. The first term in 8 is the effect on preventable causes in period $t+1$ and the second is the effect on other causes in period $t+1$. Expressed in terms of period t, the total discounted benefits of a change in $x_{M,t}$ by $\mathrm{d}x_{M,t}$ would therefore be $\alpha_4^p y_t\,\mathrm{d}x_{M,t} + e^{-r}\alpha_{1,1}^p\alpha_4^p y_t\,\mathrm{d}x_{M,t}$, where e is the exponential operator and r is the discount rate. If WPE reduces the area burned by accidental wildfires in period t, then $\alpha_4^p < 0$. If, also, the wildfires in period $t+1$ are negatively related to the wildfires in period t, as research has shown, then both of the marginal effects shown in 8 are positive. In other words, preventing accidental wildfires in period t leads to more area burned by wildfires of both causes in period $t+1$.

This higher amount of wildfire in period $t+1$ in turn induces less area burned of both causes in period $t+2$. All of the right-hand side terms within parentheses are negative in the marginal effects:

$$\frac{\partial a^p_{t+2}}{\partial x_{M,t}} = ([\alpha^n_{1,1}]^2\alpha^p_4) + (\alpha^p_{1,2}\alpha^n_{1,1}\alpha^p_4),$$
$$\frac{\partial a^n_{t+2}}{\partial x_{M,t}} = ([\alpha^n_{1,1}]^2\alpha^p_4) + (\alpha^p_{1,2}\alpha^n_{1,1}\alpha^p_4). \tag{9}$$

The discounted benefits of a change in $x_{M,t}$ by $\mathrm{d}x_{M,t}$ would therefore be summed across three periods, as

$$\alpha^p_4 y_t\, \mathrm{d}x_{M,t} + e^{-r}\alpha^p_{1,1}\alpha^p_4 y_{t+1}\, \mathrm{d}x_{M,t} + e^{-2r} y_{t+2}\, \mathrm{d}x_{M,t}\{([\alpha^p_{1,1}]^2\alpha^p_4) + (\alpha^p_{1,2}\alpha^n_{1,1}\alpha^p_4) + ([\alpha^n_{1,1}]^2\alpha^p_4) + (\alpha^p_{1,2}\alpha^n_{1,1}\alpha^p_4)\}. \tag{10}$$

In period $t + 3$, the effects become positive once again, but the marginal effects formulas become still more complex. An oscillating pattern after a WPE change (or any shock to a wildfire process) in period t would be expected from a negatively autocorrelated data generation process, even with such feedback across parallel processes.

A numerical simulation process can determine the long-run effect across T periods (where T represents the long-run) of a marginal change in a period t WPE effort. Define

$$\frac{\partial a_{i,t+\tau}}{\partial x_{M,t}} = \Delta a_{1,t+\tau}$$

as the marginal short-run effect τ periods after a change in WPE on wildfire of cause i in period t and $\tilde{\gamma}^{\mathrm{LR}}_{i,M}$ as the long-run discounted marginal effect of this change. We therefore have

$$\tilde{\gamma}^{\mathrm{LR}}_{i,M} = \sum_{\tau=0}^{T} e^{-r\tau}\Delta a_{i,t+\tau}. \tag{11}$$

If we label the numerical simulation-based long-run marginal effect of change in WPE effort in period t as $\tilde{\gamma}^{\mathrm{LR}}_{i,M}$ and we assume that the net value change per unit area of wildfire is constant across all t, then Equation 5 becomes

$$\mathrm{MBC}^{\mathrm{LR}}_t = \frac{-\sum_{i=1}^{I}\sum_{m=1}^{M} y_i \tilde{\gamma}^{\mathrm{LR}}_{i,M}\, \mathrm{d}x_{m,i,t}}{\sum_{i=1}^{I}\sum_{m=1}^{M} w_m\, \mathrm{d}x_{m,i,t}}. \tag{12}$$

Equations 3–5 also need an adjustment using estimates of the autocorrelation parameters on area burned to accommodate the long-run impact of a change in WPE in period t. These parameters could be used in a numerical simulation to obtain the long-run marginal effect on the average size of a wildfire of cause i. The general form of such an equation, following Prestemon et al. (2002), is

$$A_{1,j,t} = f(\mathbf{A}_{1,i,t-k}, \mathbf{A}_{2,i,t-k}, \mathbf{x}_{M-1,j,t}, x_{M,j,t}, \mathbf{z}_t),$$
$$A_{2,j,t} = f(\mathbf{A}_{1,i,t-k}, \mathbf{A}_{2,i,t-k}, \mathbf{x}_{M-1,j,t}, \mathbf{z}_t). \tag{13}$$

Coefficients on the lagged terms in both equations would be used to identify, with numerical methods, the long-run adjustment parameter, $\tilde{\gamma}^{\mathrm{LR}}_M$, to use in calculating long-run marginal benefit/cost ratios for occurrence count data models such as that shown in Equation 2. For example, Equation 5 becomes

$$\mathrm{MBC}^{\mathrm{LR}}_t = \frac{-\sum_{i=1}^{I}\sum_{m=1}^{M} y_i \gamma^{\mathrm{LR}}_M \bar{A}_{i,t}\, \mathrm{d}\hat{N}_{i,t}/\mathrm{d}x_{m,i,t}}{\sum_{i=1}^{I}\sum_{m=1}^{M} w_m\, \mathrm{d}x_{m,i,t}}. \tag{14}$$

Empirical Models of Wildfire Occurrence and Damages

The statistical model quantifies the effects that WPE has on the number of preventable wildfire causes in month t, based on wildfire occurrence and WPE data in Florida in each fire management region (Figure 1) reported at that time scale. Our empirical application assumes that a fixed-effects panel representation of Equation 2, estimated across J locations reporting WPE efforts in the state is valid for wildfire occurrence; that is, $\boldsymbol{\beta}_{i,j} = \boldsymbol{\beta}_i$ for all j. Maximum likelihood estimation is used, maximizing the log likelihood based on a Poisson distribution,

$$\ln L = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} -\exp(\boldsymbol{\beta}'_{i,j}\mathbf{Y}_{i,j,t}) + \boldsymbol{\beta}'_{i,j}\mathbf{Y}_{i,j,t}N_{i,j,t} - \ln(N_{i,j,t}!), \tag{15}$$

where $\mathbf{Y}_{i,j,t} = (1, \mathbf{x}_{i,m,j,t\text{-}k}, \mathbf{z}_{i,j,t})'$, $\mathbf{x}_{i,m,j,t\text{-}k}$ is a vector of interventions occurring over the current and k previous months for i, j, $\mathbf{z}_{i,j,t}$ are free inputs to wildfire production in month t, and $\boldsymbol{\beta}_{i,j}$ contains parameters associated with a constant, the interventions, and the free inputs, respectively, $N_{i,j,t}$ is the number of preventable wildfire ignitions of cause i in location j in month t. Preventable wildfires consist of those

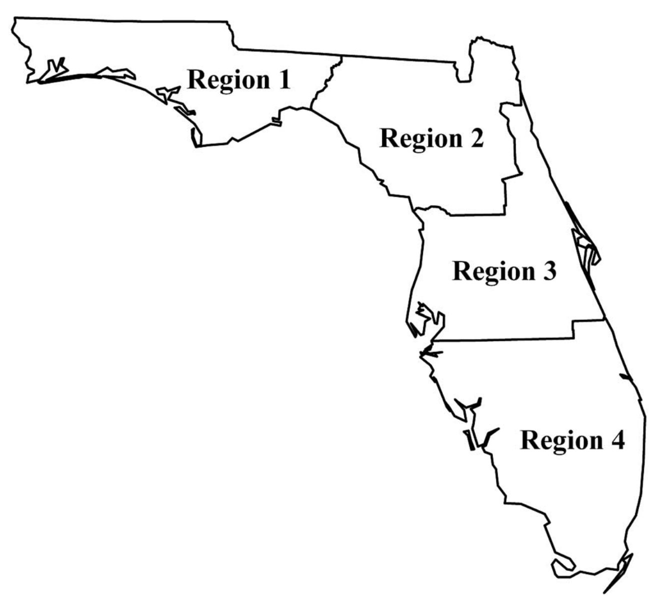

Figure 1. Fire management regions in Florida.

caused by escaped campfires, escaped debris fires, cigarettes, and children. The intervention variables, $\mathbf{x}_{i,m,j,t\text{-}k}$, include WPE variables for current and $k = 6$ lagged months (a vector that includes the individual sums of the WPE variables over the previous 6 months) and the area of prescribed fire permits issued in the previous 1, 2, and 3 years. The WPE variables include the number of media public service announcements (TV, radio, and print ads) (media), homes visited (homes), presentations given (presentations), brochures and flyers distributed (brochures), and community wildfire hazard assessments (hazard) provided in current month t and over the last 6 months (Florida Division of Forestry 2008a). Although several other WPE measures (fairs, billboards, and movie theater public service announcements) are undertaken by wildfire prevention specialists, the occurrence of such measures was too sparse in initial modeling to allow for identification of individual effects (Table 1). All WPE variables included are normalized by population, but population was included as an additional explanatory variable in the statistical models to account for the changes in the levels of the integer Poisson process. The other intervention variables include the annual area authorized for hazard removal by prescribed burning lagged up to 3 years (Florida Division of Forestry 2008b).

The vector of free inputs, $\mathbf{z}_{i,j,t}$, includes measures of fire weather (relative humidity, current month and 12-month lag), Keetch-Byram drought index (current month and 12-month lag [Keetch and Byram 1968]), fire weather index (current month and 12-month lag [Fosberg 1978]), modified fire weather index (current month and 12-month lag [Goodrick 2002]), precipitation [Goodrick 2008]), climate (the March to September monthly average and the October to February monthly average of the Niño-3 sea surface temperature anomaly in degrees centigrade [National Oceanic and Atmospheric Administration 2008]), the annual area burned (in acres) by wildfire lagged up to 6 years (Florida Division of Forestry 2008c), county population estimates (US Bureau of the Census 2008), the number of sworn full-time equivalent police officers per capita (Florida Department of Law Enforcement 2008), and dummy variables for region (region 1 is included in the intercept), season (fall is included in the intercept), and year (2002 is included in the intercept). Finally, we include a trend variable to account for the net effects of unspecified steady changes not captured by other variables.

Because of potential endogeneity between those intervention variables related to WPE efforts and ignition rates, the vector of intervention variables also includes "control" variables that capture unobserved heterogeneity exhibited between the WPE variables and $\varepsilon_{i,j,t}$ (from Equation 2). The control variables are the residuals from a set of auxiliary regressions, called "control functions":

$$x_{m,j,t} = \boldsymbol{\gamma}'_{m,i}\mathbf{h}_{m,i,t} + c_{m,i,t}, \tag{16}$$

where $\mathbf{h}_{m,i,t}$ is a vector of WPE instruments that are orthogonal to $\varepsilon_{i,j,t}$, $\boldsymbol{\gamma}_{m.t}$ contains parameters associated with a constant and the instruments, and $c_{m,j,t}$ is a normally distributed disturbance term, which also is orthogonal to $\mathbf{h}_{m,i,t}$ and contains all unobserved heterogeneity that causes the correlation between WPE effort and ignition rates. Including estimated disturbance terms, $\hat{c}_{m,j,t}$, one for each WPE variable, as additional regressors in 15 controls for any omitted variable bias that may result from the endogeneity between the WPE effort and ignitions rates (see Hausman 1978). The vector of instruments included all of the variables used in the prevention models except current WPE

Table 1. Monthly wildfire prevention education activities recorded by wildfire mitigation specialists in Florida, 2000–2007

	Region average	Maximum observed	Minimum observed	Observations
Radio PSAs	28	704	0	287
TV PSAs	47	1,630	0	287
Newspaper PSAs	41	2,031	0	287
Homes visited	29	1,923	0	287
Presentations offered	4	109	0	287
No. attending presentations	162	6,730	0	287
Arson alert signs posted	54	5,000	0	287
News releases prepared	3	36	0	287
Fliers, brochures, or CDs distributed	697	24,500	0	287
Local workshops conducted	0.7	7	0	287
No. attending workshops	46	6,500	0	287
Wildlife-urban interface hazard assessments	0.6	13	0	287
Smokey Bear programs offered to school children	4	1,000	0	287
No. of children attending programs	128	8,000	0	287
No. of wildfires with press information officer present	0.6	9	0	287
No. of wildfires with press information provided	0.7	105	0	287
Training other people	0.3	70	0	287
Firewise workshops offered	0.2	8	0	287
Firewise meetings attended	0.7	25	0	287
Homeowner/neighborhood association meetings	0.4	10	0	287
Fairs and parades where wildfire education booths were staffed	0.7	8	0	287
Local wildfire prevention team meetings	0.8	10	0	287
Training received	0.5	7	0	287
Other kinds of meetings attended or held	2	22	0	287

PSA, public service announcement.

activities (in this model the dependent variable) and also included wildfire ignitions of preventable causes (lagged 2–5 years) and the 1-year lagged value of sales tax revenues (sales tax) (Florida Department of Revenue 2008). These variables were chosen as instruments based on our assumption that they are correlated with WPE efforts but not with current wildfire behavior, except through their effect on WPE. For instance, prior wildfire behavior could influence future WPE strategies, and sales tax revenues could influence future WPE by affecting WPE budgets.

Table 1 presents summary statistics for all of the WPE activities recorded by wildfire prevention specialists in the state of Florida over the sample period. Many variables show large maxima, regional averages are often very low, and their minima are always zero. Some activities were not observed in some regions, which forced us to drop them from the fixed-effects Poisson model that we estimated.

Empirical Results

We estimated five control function models, one for each WPE activity, and the prevention model. All control

Table 2. Control function equation estimates for five prevention education variables

	Coefficient				
	Media	Homes	Present	Brochures	Hazard
Ignitions: 2 yr lag	1.32E−07	1.61E−07‡	−9.21E−10	−8.83E−08	−8.97E−11
Ignitions: 3 yr lag	1.17E−07	7.37E−08	−2.96E−10	−3.44E−08	−4.72E−10
Ignitions: 4 yr lag	1.66E−07†	9.74E−09	1.17E−09	−2.68E−07	−6.44E−10
Ignitions: 5 yr lag	1.11E−07‡	−6.41E−08	9.17E−10	−3.10E−07	−4.26E−10
MFWI: 12 mo lag	−5.44E−06	−2.73E−06	−1.31E−07	−1.24E−05	−4.98E−08
FWI: 12 mo lag	8.84E−07	6.62E−07	1.22E−07	−2.14E−05	3.61E−08
RH: 12 mo lag	1.66E−06	−3.26E−06‡	−5.38E−09	−5.32E−06	−1.40E−08
KBDI: 12 mo lag	1.03E−07	1.05E−07	8.37E−10	2.32E−07	1.81E−10
Sales tax: 1 yr lag	2.88E−14	−5.09E−15	5.64E−16	−6.91E−14	−3.56E−16
FWI: current?	−2.24E−05‡	2.03E−05	3.34E−07	2.42E−05	1.35E−07
RH	2.07E−06	8.47E−07	5.11E−08	3.23E−06	8.66E−09
KBDI	−1.57E−07	2.81E−07†	2.36E−09	7.18E−07	1.04E−09
MFWI	3.11E−05†	−1.51†05	−2.99E−07	−4.54E−06	−1.52E−07
Niño 3: Mar.–Sept.	1.82E−06	−1.39E−05	1.69E−07	−3.52E−05	−1.30E−08
Niño 3: Oct.–Feb.	−7.80E−06	−5.20E−06	2.05E−07	4.43E−05	3.02E−08
Precipitation	−1.64E−06	−2.05E−07	−6.06E−08	−7.84E−06	−1.00E−08
Rx Fire: 1 yr lag	6.37E−11	3.65E−10	−9.02E−12	2.00E−09	−2.94E−12
Rx Fire: 2 yr lag	−1.34E−10	8.17E−10*	−3.50E−12	2.18E−10	−2.72E−12
Rx Fire: 3 yr lag	1.57E−10	−1.50E−10	−4.47E−12	−1.56E−09	−1.10E−12
Fire: 1 yr lag	1.04E−10	−1.07E−10	2.92E−12	8.76E−11	9.05E−13
Fire: 2 yr lag	−7.23E−10‡	−1.01E−09†	6.83E−12	−2.86E−09‡	−1.44E−12
Fire: 3 yr lag	−4.43E−10‡	−3.52E−10	3.73E−12	−2.95E−11	3.90E−13
Fire: 4 yr lag	−3.24E−10‡	−1.39E−10	1.22E−12	1.51E−09‡	−6.89E−14
Fire: 5 yr lag	−3.25E−10	−4.37E−10‡	3.12E−12	−1.20E−10	−1.49E−13
Fire: 6 yr lag	−2.20E−10	−3.69E−10†	2.03E−12	−2.87E−10	4.25E−14
Region 2	5.50E−03†	−1.52E−03	−1.34E−05	1.69E−03	6.15E−06
Region 3	7.70E−03*	3.13E−04	−1.31E−05	2.98E−03	1.09E−05
Region 4	8.45E−03*	1.26E−03	−1.53E−05	3.97E−03	1.29E−05
Spring	5.57E−05*	−3.24E−05	6.99E−07	7.77E−05	1.02E−07
Summer	2.40E−05	4.60E−05	4.73E−07	5.40E−05	2.11E−07
Winter	−2.10E−06	−1.04E−05	4.00E−07	1.19E−04	−1.61E−07
Population	−5.69E−10†	−3.90E−10	−5.92E−13	−3.42E−10	−9.10E−13
Police per capita	1.75E+00†	−6.56E−01	−3.84E−03	7.56E−02	1.59E−03
2003	−3.19E−06	3.08E−05	−9.35E−07	−4.11E−06	−1.53E−07
2004	3.65E−05	5.48E−05	−1.49E−06	3.19E−04	−5.47E−08
2005	3.99E−05	7.80E−05	−1.72E−06	1.01E−03*	−3.13E−07
2006	6.75E−05	8.69E−05	−6.14E−07	1.02E−03†	−1.55E−07
2007	7.56E−05	1.70E−04	−3.12E−07	1.30E−03†	3.72E−07
Trend	1.25E−05†	−1.79E−06	7.08E−08	−3.39E−05	6.58E−09
Media: 1–6 mo prior	−2.55E−01*	−8.91E−03	−6.60E−04	5.13E−01†	−7.61E−04‡
Homes: 1–6 mo prior	−2.06E−01	4.52E−01*	6.18E−04	1.09E+00‡	4.75E−04
Presentations: 1–6 mo prior	−4.15E+00‡	−3.61E+00	−4.21E−02	2.59E+00	−5.77E−04
Brochures: 1–6 mo prior	−1.74E−03	2.02E−03	3.42E−05	−1.39E−01*	−9.76E−05‡
Hazard: 1–6 mo prior	4.13E+01*	−1.05E+01	−4.44E−02	2.55E+01	−5.42E−02
Intercept	−8.76E−03†	3.43E−03	1.62E−05	6.19E−04	−3.35E−06
Probability $> F$	0.0000	0.0000	0.0671	0.0000	0.0000
R^2	0.5155	0.3742	0.2471	0.4367	0.3973

MFWI, modified fire weather index; FWI, fire weather index; RH, relative humidity; KBDI, Keetch-Byram drought index.
* Significance at 0.01 level.
† Significances at the 0.05 level.
‡ Significances at the 0.10 level.

function models were significant, with the WPE variables explaining from 25 to 52% of the variation (Table 2). The prevention model, which included the residuals from the equation estimates shown in Table 2, was also significant. Variables included explained 72% of the variation in preventable ignition rates (Table 3), as defined by the increase in the value of the log-likelihood function compared with an intercept-only null model. The 6-month aggregates of the WPE variables were negative and significant for media, presentations, and brochures. Neither the 6-month aggregates of home visits nor community hazard assessments were significant, however. Current month WPE efforts were statistically significant and negatively related to the number of preventable wildfires for all the WPE variables except home visits. The control variables were all significant and, as expected, positively related to preventable ignitions. In other words, failing to control for the simultaneous determination of current-period WPE and accidental wildfire ignitions would have produced biased estimates of the effects of each modeled type of WPE, and would have underestimated the size of the effects [4].

Other variables were correlated with preventable ignitions as expected or were insignificant. Relative humidity, precipitation, prescribed fire (lagged 2 and 3 years), lagged

Table 3. Poisson model estimate of the count of preventable wildfires, 2002–2007, and associated elasticities, calculated at the mean of the data

	Coefficient	SE	z	Pr > z	Elasticity
FWI	1.46E−01	6.11E−02	2.39	0.017	1.06
RH	−3.32E−02	8.72E−03	−3.80	0	−1.70
KBDI	1.66E−03	5.72E−04	2.90	0.004	0.41
MFWI	−5.25E−02	5.96E−02	−0.88	0.379	−0.32
Niño 3: March	2.98E−02	5.82E−02	0.51	0.609	−0.01
Niño 3: October	4.41E−02	5.49E−02	0.80	0.422	0.02
Precipitation	−1.21E−01	1.33E−02	−9.13	0	−0.55
Rx Fire: 1 yr lag	−1.41E−06	1.40E−06	−1.01	0.311	−0.18
Rx Fire: 2 yr lag	−2.44E−06	1.44E−06	−1.70	0.089	−0.26
Rx Fire: 3 yr lag	−3.66E−06	9.96E−07	−3.67	0	−0.34
Fire: 1 yr lag	2.57E−06	7.79E−07	3.30	0.001	0.12
Fire: 2 yr lag	−7.03E−06	1.36E−06	−5.15	0	−0.35
Fire: 3 yr lag	−2.17E−06	8.37E−07	−2.59	0.010	−0.14
Fire: 4 yr lag	1.42E−07	8.99E−07	0.16	0.875	0.01
Fire: 5 yr lag	−1.88E−06	6.72E−07	−2.80	0.005	−0.21
Fire: 6 yr lag	−1.60E−06	4.34E−07	−3.69	0	−0.18
Region 2	2.85E+01	1.03E+01	2.77	0.006	7.01
Region 3	4.62E+01	1.42E+01	3.25	0.001	11.94
Region 4	5.34E+01	1.58E+01	3.37	0.001	13.11
Spring	9.24E−01	1.37E−01	6.76	0	0.24
Summer	6.59E−01	1.18E−01	5.60	0	0.15
Winter	5.09E−01	1.10E−01	4.61	0	0.13
Population	−4.53E−06	1.20E−06	−3.78	0	−19.95
Police per capita	8.12E+03	3.21E+03	2.53	0.011	22.17
2003	6.71E−01	1.56E−01	4.29	0	0.14
2004	2.18E+00	1.94E−01	11.25	0	0.45
2005	3.31E+00	3.37E−01	9.81	0	0.68
2006	4.81E+00	3.73E−01	12.87	0	0.99
2007	6.26E+00	4.53E−01	13.84	0	0.65
Trend	−4.28E−02	1.88E−02	−2.28	0.023	−1.26
Media: 1–6 mo prior	−1.34E+03	5.87E+02	−2.29	0.022	−0.26
Homes: 1–6 mo prior	4.50E+02	7.02E+02	0.64	0.521	0.04
Presentations: 1–6 mo prior	−4.89E+04	8.69E+03	−5.63	0	−0.22
Brochures: 1–6 mo prior	−2.15E+02	4.66E+01	−4.62	0	−0.24
Hazard: 1–6 mo prior	6.54E+04	5.03E+04	1.30	0.194	0.07
Control variable: media	3.59E+03	1.35E+03	2.66	0.008	0.00
Control variable: homes	1.43E+03	8.45E+02	1.70	0.090	0.00
Control variable: presentations	3.14E+05	1.06E+05	2.96	0.003	0.00
Control variable: brochures	5.26E+02	3.08E+02	1.71	0.087	0.00
Control variable: hazard	6.64E+05	3.02E+05	2.20	0.028	0.00
Media: current month	−4.12E+03	1.34E+03	−3.08	0.002	−0.17
Homes: current month	−1.29E+03	8.41E+02	−1.53	0.125	−0.03
Presentations: current month	−2.97E+05	1.06E+05	−2.82	0.005	−0.23
Brochures: current month	−6.62E+02	3.03E+02	−2.18	0.029	−0.14
Hazard: current month	−6.35E+05	3.00E+05	−2.11	0.035	−0.12
Intercept	−2.97E+01	1.46E+01	−2.03	0.042	
Log likelihood	−890.5587				
Probability > χ^2	0.0000				
Psuedo-R^2	0.7193				

FWI, fire weather index; RH, relative humidity; KBDI, Keetch-Byram drought index; MFWI, modified fire weather index.

Table 4. Elasticities of the count of preventable wildfires with respect to the prevention education variables, calculated at the mean of the data

Intervention variables	Coefficient	SE	z	Pr > z
Media: 1–6 mo prior	−0.26	0.11	−2.29	0.02
Homes: 1–6 mo prior	0.04	0.06	0.64	0.52
Presentations: 1–6 mo prior	−0.22	0.04	−5.63	0.00
Brochures: 1–6 mo prior	−0.24	0.05	−4.62	0.00
Hazard: 1–6 mo prior	0.07	0.06	1.30	0.19
Media: current month	−0.17	0.05	−3.08	0.00
Homes: current month	−0.03	0.02	−1.53	0.13
Presentations: current month	−0.23	0.08	−2.82	0.01
Brochures: current month	−0.14	0.06	−2.18	0.03
Hazard assessments: current month	−0.12	0.06	−2.11	0.04

area burned by wildfire (lagged 2, 3, 5, and 6 years), and population were negatively related to preventable ignitions. Although it might be expected that population increases should be positively related to preventable, human-caused ignitions, our findings may capture the effects of losses of vegetation associated with population growth. The fire weather index, Keetch-Byram drought index, area burned by wildfire in the previous year, police per capita, region dummies, season dummies, and year dummies are significant and positively related to preventable ignitions. The dummy variables (all else equal) imply that regions 2, 3, and 4 had more preventable ignitions than region 1, spring, summer, and winter seasons tended to have more ignitions than the fall season, and years 2003 through 2007 had more preventable ignitions than 2002.

Table 4 presents the elasticities of the WPE variables, all calculated at their means. The total effect (combined 6-month aggregate and current month effect) of presentations (−0.45), media (−0.42), and brochures (−0.38) are the largest of the WPE variables. These elasticities imply that for a 10% increase in presentations, media, and brochures distributed over the last 7 months (i.e., a 10% increase in effort over the last 6 months and a 10% increase in current month efforts), we would expect 4.5, 4.2, and 3.8% declines in preventable wildfire ignitions due to presentations, media, and brochure distributions, respectively. As a whole, the elasticities associated with the significant 6-month WPE effort aggregates are larger than the significant current month variables, which makes some sense because we are comparing 6 months worth of effort with 1 month. But timing is important, as the current month elasticities are nearly the same size. Thus, it seems that increases in WPE activities can be used to respond to outbreaks of accidental wildfire. For instance, WPE efforts could be used to offset increased risks posed by extreme fire weather. However, not all WPE activities are equally successful. Although presentations, media, and brochures appear to limit preventable ignitions both in current and subsequent months, wildfire hazard assessments appear to have no lasting effect beyond the current month and home visits do not appear to be related to preventable ignitions at all.

Benefit-Cost Analysis

Calculation of benefits and costs of WPE activities requires an assessment of the long-run number of preventable wildfires prevented, the long-run area of wildfire averted due to WPE, the net value change per unit area of wildfire (losses net of benefits), and the costs of WPE activities. The effect of small WPE changes on the number of preventable wildfires was calculated by observing the change in the expected count of wildfires, produced by applying the equation reported in Table 3, compared with the number observed. The small WPE change was applied across all WPE variables and all months of the 2002–2007 data simultaneously. It was assumed that a prevented wildfire in a region in a month is of the same average size as the observed preventable wildfires that occurred in that region in that month. The change in expected area burned accruing from a WPE budget change was then summed across all months and regions to yield a state total change in area burned. The formula shown in the numerator of Equation 12 indicates how the long-run effect of the WPE effort was calculated. The long-run effect of the change was based on the lagged effects of wildfire of all causes on current area burned for wildfire of each cause, as found by Mercer et al. (2007). The net value change per unit area of wildfire (y in our equations) that we adopted is from Mercer et al. (2007), $3,129/ha (in 2007 dollars; US Department of Commerce 2008) [5]. The numerator of Equation 14, the value of damages averted from the imputed WPE change, was then calculated as the long-run area of wildfire averted by all causes (preventable and nonpreventable) times the net value change per unit area. Costs of WPE were obtained by one of the authors from historical budget records.

Results (Figure 2) show that statewide net benefits of WPE efforts significantly outweigh their costs, producing a marginal benefit/cost ratio of 35 [6]. For an additional dollar spent on WPE programs in the state, a $35 reduction in wildfire damages is expected. Because wildfire suppression comprises 15.3% of this $35 reduction, an additional dollar of WPE reduced suppression expenditures by $5.32. The economic performance of WPE varies by region. Unfortunately, the exact allocation of WPE funds is not known by region. As a sensitivity analysis, we evaluated WPE effectiveness as if it were either allocated equally across the regions or allocated proportionally according to the share of long-run preventable wildfire area burned in the state. Conversations with managers (e.g., R. Rhea, pers. comm., Florida Division of Forestry, Oct. 24, 2008) indicate that such spending is best described as being equally allocated. If

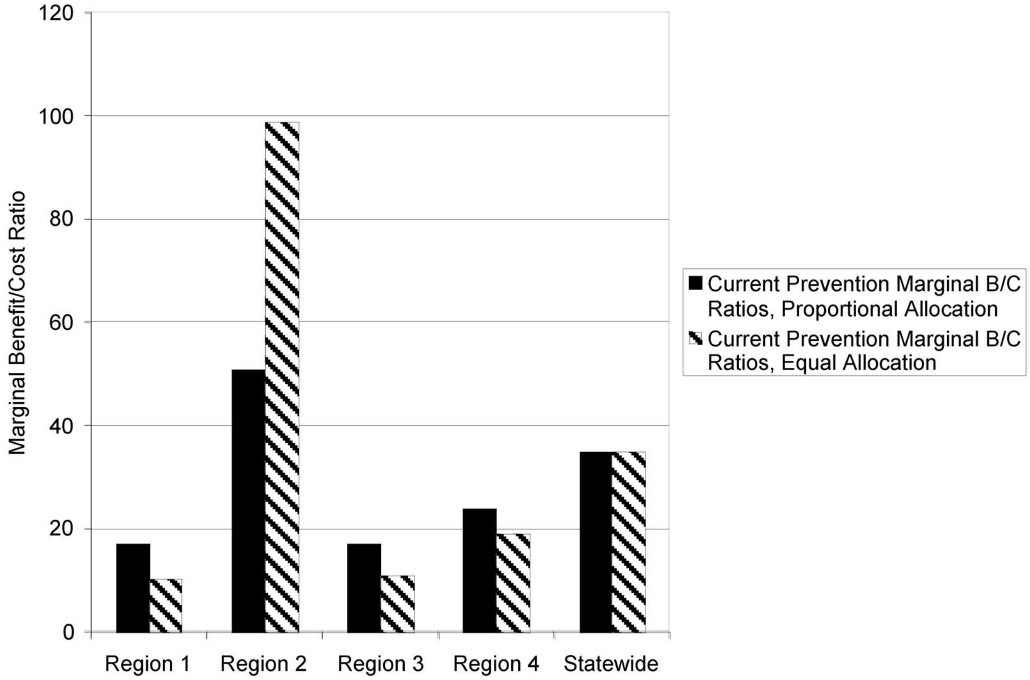

Figure 2. Wildfire prevention education marginal benefit/cost (B/C) ratios, calculated by changing all wildfire prevention education efforts from current levels simultaneously by 0.0001%, by fire management region and statewide in Florida.

equal allocation is assumed, region 2 shows the largest marginal benefit/cost ratio (99) with the ratios for the rest of the regions ranging between 10 and 20. When a proportional funding allocation is assumed, region 2 still yields the largest marginal benefit/cost ratio (51) although it is substantially smaller than that when an equal allocation is assumed. This difference is due to the higher assumed funding level for region 2 under a proportional allocation scheme. Region 2 experiences more preventable ignitions per year than the remaining three regions. The remaining regions yield marginal benefit/cost ratios ranging from 17 to 24, slightly larger than those in the equal allocation. These large marginal benefit/cost ratios imply that optimal levels of WPE activities would be substantially higher than current levels.

Figure 3 shows how variations in WPE efforts across the four regions of the state and statewide would affect both the long-run area burned by wildfire of all causes and the number of preventable wildfires. The diagram shows that increasing statewide WPE efforts would reduce the number of and area burned by wildfires, but at a decreasing rate. The average number of preventable wildfires observed per year was 1,311 and the average area burned by wildfires of all causes was 98,541 ha. For a 10% increase in WPE spending, distributed evenly over all types of activities (media, presentations, home visits, and others), the expected number of preventable wildfires per year drops to 1,131 and the statewide area burned by all wildfires falls to 98,075 ha per year; a 50% increase in spending yields 707 preventable wildfires and 96,950 ha burned per year. A doubling of WPE spending (100% increase) reduces the number of preventable wildfires to 462 and area burned to 96,387 ha.

Figure 4 presents the net benefits of independently doubling the amount of each individual WPE activity. Doubling media efforts would avert \$4.1 million in expected wildfire damages. Presentations given, brochures distributed, and community hazard assessments follow with \$3.3 million, \$2.5 million, and \$1.4 million in expected wildfire damages averted, respectively. The expected benefits from increasing home visitations are small (home visits were not significant in the statistical model). Taken together, an additional \$0.5 million investment into WPE would avoid an estimated \$11.4 million in wildfire damages.

Discussion and Conclusions

Our research yields several overall findings. First, we have shown that WPE efforts in Florida are statistically negatively related to the number of wildfires of preventable causes. The effects are economically as well as statistically significant, and our economic assessment shows that, based on our equation estimates, the expected benefits in terms of damages averted are 35 times greater than the additional WPE spending needed to avert them (at the margin). These findings account for the negative feedback on wildfire that would occur from successful WPE in the current period. Because WPE efforts are mainly controlled by the state, an implication of our study is that decisions by government to modestly alter spending on WPE could have immediate consequences, especially in the parts of the landscape where preventable wildfires occur most commonly. Since 2004, the state of Florida has increased the number of wildfire mitigation specialists active in the state. The number of such specialists rose from 5 for the period 1999 through 2003 to 12 as of early 2008. In effect, the state has already more than doubled its efforts. An expansion of that scale, we find, is likely to have already yielded positive net benefits for residents of Florida.

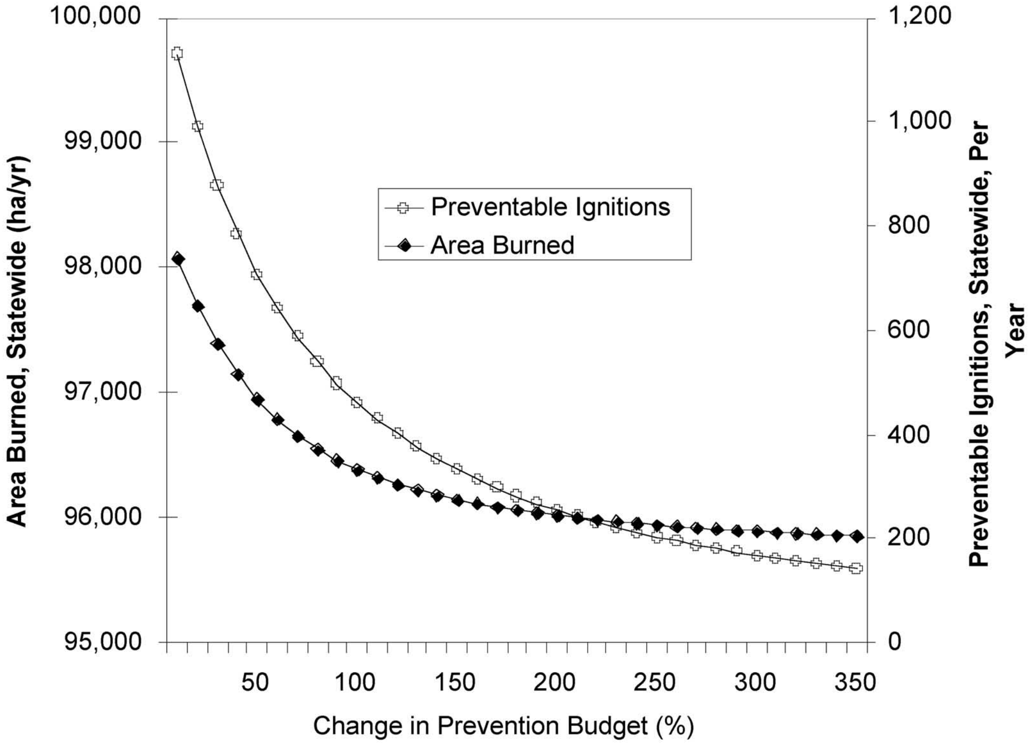

Figure 3. Counterfactual effects on annual area burned and the annual number of expected wildfires obtained by simultaneously changing all wildfire prevention education efforts statewide in Florida, 2002–2007, across a range of possible percentage increases.

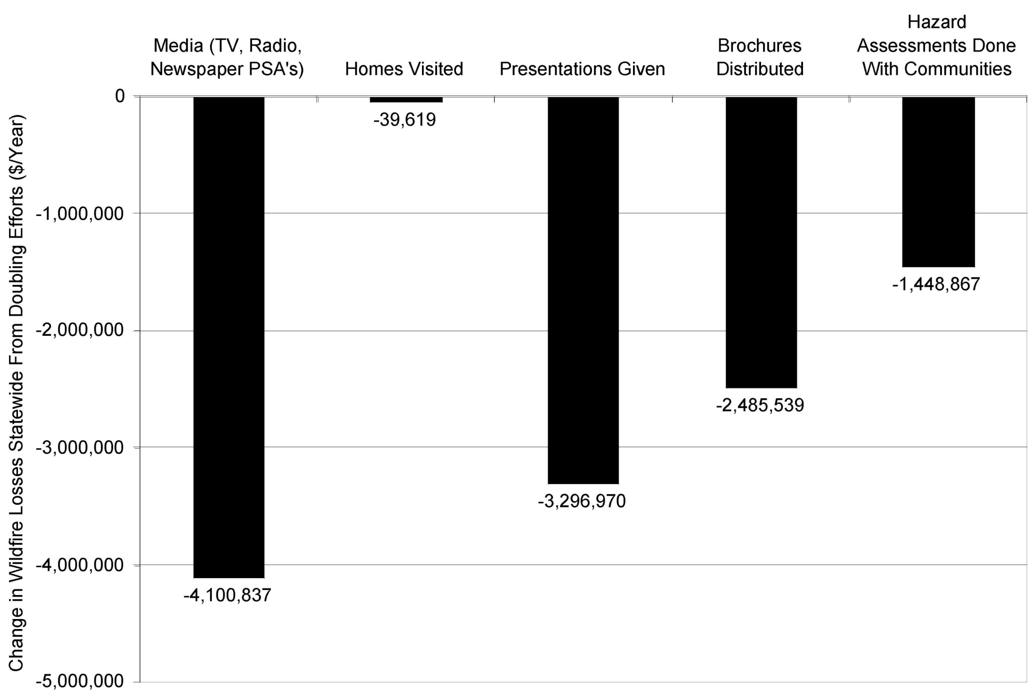

Figure 4. Counterfactual assessment of the annual wildfire-related economic losses (damages) observed by doubling individual wildfire prevention education efforts, statewide, 2002–2007.

Second, we find that there is spatial variation in the net benefits of WPE efforts. Changing the share of spending devoted to each fire region could yield positive net benefits. Devoting more of the increased WPE efforts toward region 2 in the state, for example, would appear to yield greater benefits than an increase spread equally across all regions. Some spatial variation across regions, we should note, is due to variations across regions in the absolute levels of WPE efforts, combinations of the many kinds of WPE activities, existing levels of fuels management, and endemic levels of wildfires of all causes.

Third, our analysis shows that the marginal effects of changes in individual WPE activities vary across activities. This finding implies that there might be additional potential economic gains to altering the mix of WPE activities. Media are found, at least statistically, to yield the largest net benefits per unit. Media efforts have the additional advantage that some of their costs are paid for by broadcasters, not the state. Presentations, we find, may be another way to effectively distribute the prevention message to the public [7], and focusing WPE resources on these could yield larger net benefits than increasing all other WPE activities in an equal manner. Although we did not find statistically significant effects of some WPE efforts, such as home visits (e.g., Doolittle and Welch 1974), further analyses, perhaps focused on individual preventable wildfire causes (e.g., debris fire escapes), may yield results and justify further refinement in the allocation of WPE activities.

Fourth, we have shown that education efforts appear to have persistence in the target population. We included lagged WPE efforts in the modeling and found that such efforts occurring up to 6 months in the past have statistically negative effects on preventable wildfire occurrence. A potential additional component of persistence of WPE efforts may be contained in the long-run negative trend in these preventable wildfire ignitions in the state (Table 3). Although we were not able to identify the actual source of this negative trend, it is plausible that it may partially capture even longer run effects of WPE efforts on wildfire occurrence in Florida.

Fifth, we found that statistically quantifying the effects of WPE requires attention to the potential endogeneity of current period WPE efforts and wildfire activity. In Florida, WPE efforts are ramped up when fire danger is higher. Using the control function approach, we were able to statistically factor out any simultaneity bias in parameter estimates and reveal the large effects of current-period WPE efforts.

We can identify several avenues for further research that could enhance understanding of WPE. First, we did not evaluate the specific effects of WPE efforts on individual causes of wildfire, e.g., debris escapes, campfire escapes, cigarettes, and children. Preventable wildfires are a small share of all wildfires in the state of Florida, and the data demands of statistical models are large. This unfortunate combination of factors limited our ability to draw some statistical inferences. Longer time series of WPE efforts and wildfire, however, could enable such specific analyses. Second, our spatial resolution was at the region level because WPE data were only reported consistently at this level. Finer spatial resolution could allow an analyst to develop statistical models that would identify specific locations on a landscape that would most benefit from altered WPE efforts. Third, we lacked specific information about the amount of money spent on each WPE activity in each location. Data on this spending would allow for an economic assessment of the types of WPE efforts that yield the greatest dollar benefit per dollar spent. Fourth, because of a lack of data (long enough time series or frequent enough wildfires), we were unable to determine whether there is a specific decay structure in the effects of WPE. Future research, using, for example, longer time series, could explicitly model the lag structure of WPE efforts and reveal this decay structure with greater precision. A better understanding of this structure could allow wildfire mitigation specialists in Florida or elsewhere to better time their efforts to yield maximum net benefits.

Endnotes

[1] These include debris fire escapes, campfire escapes, and fires caused by discarded cigarettes and by children. We ignore other kinds of accidental fire starts because they are not the focus of wildfire prevention education, and we ignore arson because its occurrence may be affected by a different combination of managerial (and law enforcement) actions (e.g., Prestemon and Butry 2005).

[2] Later in this research, we assume that fires of all causes produce the same expected damages per unit area burned. We maintain this distinction of damages that could vary by cause in this article because this is a testable assumption, which merits further investigation.

[3] Tests of the hypothesis that the size of a prevented fire is equal in probability to a fire that is not prevented is a hypothesis worthy of further analysis but is left for future research.

[4] Separate analyses, available from the authors but not reported here, excluded the control variables and produced what we contend are spurious positive effects of presentations and hazard assessments on the number of preventable fires.

[5] This includes losses associated with timber, the trade and tourism sector, direct community assistance (as provided by aid agencies, such as the Federal Emergency Management Agency), housing, and health, and a fixed per unit area suppression cost (Butry et al. 2001, Mercer et al. 2007). Suppression costs comprise approximately 15% of the net value change per unit, and these include the initial attack resources used in firefighting.

[6] A negative binomial version of Equation 15, which is available from the authors by request, resulted in a marginal benefit/cost ratio of 18.

[7] Presentations are often accompanied by demonstrations, which also occur at fairs. We could find no significant effect of fairs in a preliminary version of the model.

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