Forest Policy and Economics 50 (2015) 249–258

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Development and application of a probabilistic method for wildfire suppression cost modeling

Matthew P. Thompson [a,1], Jessica R. Haas [a], Mark A. Finney [b], David E. Calkin [a], Michael S. Hand [a], Mark J. Browne [c], Martin Halek [d], Karen C. Short [b], Isaac C. Grenfell [b]

[a] Rocky Mountain Research Station, US Forest Service, 200 E Broadway, Missoula, MT 59807, USA
[b] Rocky Mountain Research Station, US Forest Service, 5775 Highway 10 West, Missoula, MT 59808, USA
[c] School of Risk Management, Insurance and Actuarial Science, St. John's University, 101 Murray St 426, Manhattan, NY 10007, USA
[d] Department of Actuarial Science, Risk Management and Insurance, University of Wisconsin, 975 University Ave, Madison, WI 53706, USA

ARTICLE INFO

Article history:
Received 18 February 2014
Received in revised form 24 September 2014
Accepted 9 October 2014
Available online 4 November 2014

Keywords:
Fire economics and policy
Financial risk
Actuarial science
Incentives
Performance measurement

ABSTRACT

Wildfire activity and escalating suppression costs continue to threaten the financial health of federal land management agencies. In order to minimize and effectively manage the cost of financial risk, agencies need the ability to quantify that risk. A fundamental aim of this research effort, therefore, is to develop a process for generating risk-based metrics for annual suppression costs. Our modeling process borrows from actuarial science and the process of assigning insurance premiums based on distributions for the frequency and magnitude of claims, generating parameterized probability distributions for fire occurrence and fire cost. A compound model of annual suppression costs is built from the coupling of a wildfire simulation model and a suppression cost model. We present cost modeling results for a set of high cost National Forests, with results indicating variation in expected costs due to variation in factors driving financial risk. We describe how our probabilistic cost models can be used for a variety of applications, in the process furthering the Forest Service's movement towards increased adoption of risk management principles for wildfire management. We review potential strengths and limitations of the cost modeling process, and conclude by discussing policy implications and research needs.

Published by Elsevier B.V.

1. Introduction

Wildfire activity and escalating suppression costs continue to threaten the financial health of federal land management agencies, in particular the U.S. Department of Agriculture Forest Service (Forest Service). Again in 2013 the Forest Service faced emergency budget funding transfers to allow the agency to continue to suppress fires because fire suppression funds were exhausted. Transferring funds from multiple critical budgets (timber, recreation, research, etc.) can be highly disruptive (U.S. Government Accountability Office, 2004; U.S. Government Accountability Office, 2007; Peterson et al., 2008), even for fire-related programs such as hazardous fuels management (Stephens and Ruth, 2005). High inter-annual variability in large fire suppression costs leads to reliance on the use of a 10-year rolling average for budgetary purposes, and increasing suppression expenditures have led to decreasing budgets for non-fire programs. In both 2012 and 2013 the proportion of the Forest Service's budget associated with wildfire has approached 50% of total discretionary funds; whereas in 2000 allocation represented less than 20% (Abt et al., 2009a; U.S. Department of Agriculture, 2009). Including emergency budget transfers, in 2012 and 2013 wildfire suppression expenditures exceeded 50% of the Forest Service's total budget. Collectively these financial impacts constrain the ability of the Forest Service to achieve land and resource management objectives.

The high variability of annual suppression costs and associated impacts to program budgets creates financial risk for the Forest Service. In order to minimize and effectively manage the cost of that financial risk, the agency needs the ability to quantify that risk. A fundamental aim of this research effort, therefore, is to develop a process for generating risk-based metrics for annual suppression costs. With risk monetized, it becomes possible to better monitor fire manager performance and to put incentives in place that encourage sound risk management. Our process is also intended to provide an improved ability to understand variation in factors driving financial risk, in order to identify efficient risk mitigation and cost containment actions.

Our work builds from research aimed at better understanding suppression expenditures, as well as better understanding how various wildfire management activities may affect future suppression costs (Taylor et al., 2013; Thompson et al., 2013d). A growing body of work attempts to use mid-range climate forecasts to project fire season costs, and thereby improve predictive power relative to a 10-year

E-mail address: mpthompson02@fs.fed.us (M.P. Thompson).
[1] Research Forester, Rocky Mountain Research Station, US Forest Service, 200 E Broadway, Missoula, MT 59807, USA. Tel.: +1 406 329 3383; fax: +1 406 329 3487.

http://dx.doi.org/10.1016/j.forpol.2014.10.001
1389-9341/Published by Elsevier B.V.

moving average (Prestemon et al., 2008; Abt et al., 2009b; Preisler et al., 2011). However, these models have a limited ability to compare projected costs against actual fire workload, and do not have the spatial resolution to estimate costs of specific fires in specific geographic areas. By contrast, most of the existing work has more refined spatial resolution but limits the focus to understanding factors affecting the costs of individual incidents (Gebert et al., 2007; Liang et al., 2008; Yoder and Gebert, 2012; Gude et al., 2013). Econometric analyses of historical per-fire suppression costs have identified a number of environmental and socioeconomic factors that influence suppression costs, principal among which are final fire size, ownership, and the presence of populated areas proximal to the fire. However, the fire-by-fire nature of these cost analyses provides only a limited ability to assess the cumulative impacts of fire management decisions and associated suppression costs across multiple fires and across multiple fire seasons.

In this paper, we review major developments and improvements in suppression cost estimation based on actuarial science principles. Our modeling process is built from the coupling of a wildfire simulation model and a suppression cost model, and is based on recent work estimating suppression costs on National Forest System lands (Thompson et al., 2013a; Thompson et al., 2013d). Relative to earlier work, the key advancement here is the generation of parameterized probability distributions for fire occurrence and fire cost, leading to a compound model of annual suppression costs. This approach leverages advancements in spatial, stochastic wildfire simulation to better capture geographic variation in wildfire ignition probability and growth potential, and further to better account for current landscape conditions resulting from past management activities and disturbances (insect outbreak, wildfire, etc.). This latter component allows for an extension of the cost analysis framework to consider not just suppression response alone but rather the entire spectrum of land and fire management activities (e.g., fuel treatment), and thus periodic re-estimation of suppression cost distributions could reflect expected cost reductions due to past investments in risk-mitigation activities. Similarly, the framework could account for changes in factors likely to increase suppression costs, such as expanded residential development in fire-prone areas or increased fire spread potential due to accumulation of fuels. Combined with a suppression cost model that incorporates geographic information such as ownership at ignition, fuel type, topography, and proximal values-at-risk, this new modeling approach can generate annual forecasts of suppression expenditures while capturing fine-scale spatial variation in factors influencing fire growth and suppression costs, all within a probabilistic framework.

As a demonstration of our novel, actuarially-based annual suppression cost estimation process we present cost modeling results — expected values and compound probability distributions — for a set of identified high cost National Forests. To clarify, this is not a retrospective analysis of historical costs, but rather a forward-looking forecast based on current conditions, using models parameterized from historical data. We describe how our probabilistic cost models can be used for a variety of applications, in the process furthering the Forest Service's movement towards increased adoption of risk management principles for wildfire management. We review potential strengths and limitations of the cost modeling process, and conclude by discussing policy implications and research needs.

2. Development of a probabilistic model for annual suppression costs

In this section we develop a compound model of aggregate suppression cost for annual large fire suppression costs. The compound model is based on the joint estimation of the distribution of the number of escaped large wildfires per year, and the distribution of the per-fire suppression cost. Application of the model is premised on the geographic delineation of a land management unit of interest and their respective areas of responsibility for managing ignitions. In effect this model is identical to a compound model of aggregate loss used by actuaries to develop insurance premiums, for instance in the health insurance arena actuaries estimate distributions for the annual number of claims and the amount per claim to derive a distribution for the total annual claim amount.

Consider a given National Forest F, and let S represent the total annual suppression costs for F in a given fire season. Our ultimate aim is the identification of a probability distribution for S. Next, let N represent the number of escaped large wildfires in a given fire season, and X_k the total suppression expenditures for fire k in F. Eq. (1) presents derivation of S as a function of N and X. For our purposes here we assume independence between N and S, which may not strictly hold under rare circumstances where high synchronous fire load leads to scarcity of available firefighting resources. Turning to a probabilistic framework, the derivation of the expected value ($E(S)$) and variance ($Var(S)$) for total annual suppression expenditures are presented in Eqs. (2) and (3), respectively.

$$S = \sum_{k=1}^{N} X_k \quad (1)$$

$$E(S) = E(N)E(X) \quad (2)$$

$$Var(S) = E(N)Var(X) + [E(X)]^2 Var(N) \quad (3)$$

To illustrate application of the suppression cost estimation process we identified a set of 25 high cost National Forests to study, all of which are located in the western United States, selected on the basis of mean annual suppression costs over the period 2000–2012. We obtained suppression cost information from the Foundation Financial Information System,[2] a system used by the Forest Service to track wildfire suppression expenditures. Table 1 provides summary information for each National Forest, including historical mean annual suppression costs $\left(\overline{S}_h\right)$.

There are a number of compelling reasons to turn to a compound loss model rather than estimate the distribution of S directly from historical costs. From a practical perspective, the historical record has limited utility to directly estimate S due to prior cost accounting practices that made it difficult to comprehensively link suppression costs to specific fires (Gebert et al., 2007). Further, decoupling annual suppression expenditures (S) allows for a more refined ability to model spatiotemporal variation in the underlying factors driving fire occurrence (N) and cost (X). Fire occurrence patterns, for instance, can range from almost exclusively lightning-caused to strongly human-influenced. Landscape changes due to vegetative growth, previous wildfires, other disturbances (e.g., insect and disease), and land management activities (e.g., hazardous fuel reduction) can directly influence fire growth potential and area burned, key variables influencing suppression costs.

To generate frequency distributions for N we queried a historical (1992–2011) nationwide fire occurrence database (Short, 2013), filtering fires on the basis of size (≥300 acres, a "large" fire for cost accounting purposes), reporting unit (individual National Forest preparing the fire report), and owner (Forest Service, agency responsible for managing the land at the ignition location). We tested three parametric frequency distributions (Poisson, negative binomial, and geometric), and selected a model for each National Forest based upon the criterion of the lowest value of the χ^2 goodness-of-fit test statistic.

To generate severity distributions for X we combined a suppression cost model (Gebert et al., 2007) with FSim, a stochastic fire simulation system (Finney et al., 2011), using a similar process to that outlined in (Thompson et al., 2013a; Thompson et al., 2013d). The cost model is a statistical regression model based on historical costs, and provides

[2] The Foundational Financial Information System is being replaced by the Financial Management Modernization Initiative (FMMI), available at http://info.fmmi.usda.gov/.