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An econometric model for *ex ante* prediction of wildfire suppression costs

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ABSTRACT

This paper develops an econometric model that can provide predictions of fire suppression costs (per acre and in total) for a given large fire before final fire acreage is known. The model jointly estimates cost per acre and acreage equations via Maximum Likelihood, accounting for sample truncation based on final fire size. Formulas and results are shown for predictions of costs and fire size for wildfires in general, and for large fires in particular. Marginal effects of explanatory variables on cost and acreage are discussed. The distribution of these model predictions illustrates the importance of accounting for sample truncation when generating predicted outcomes based on *ex ante* information.

Introduction

Between 1980 and 2002, wildfires larger than 300 acres amounted to about 1.4 percent of all reported wildfires, but accounted for about 94 percent of all suppression expenditures. Large fires are responsible for the bulk of fire suppression expenditures (Strategic Issues Panel on Fire Suppression Costs, 2004). Understanding the factors that influence suppression costs and size of large fires is therefore important for both strategic fire planning and on-site fire management decisions. This paper contributes to the existing literature and modeling approaches by developing and estimating a bivariate econometric model of cost per acre and fire size that can provide statistically consistent and relatively precise predictions of fire suppression costs (per acre and in total) for a given large fire before final fire acreage is known.

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Several papers have been published that focus on estimating costs and/or acreage of individual wildland fires. The most recent and relevant include Butry et al. (2008), who estimate log-linear regression models for fire acreage based on fire characteristics, climate/weather, management and mitigation efforts, and other factors. They break their sample into two subsamples (fires > 1000 acres and fires < 1000 acres) and estimate the same regression equation on each sample separately to allow flexibility to account for structural differences between large and small fire regimes. However, they do not statistically account for truncation of their subsamples (limited to 1000 acres or larger), which may introduce bias and inconsistency in parameter estimates and model predictions.

Gebert et al. (2007) estimate suppression costs per acre for individual wildland fires of 100 acres or more. The paper focuses specifically on costs per acre, and does not estimate a fire size equation to address sample truncation based on fire size. Currently, models such as this are being used for forecasting during the fire, but with reliance on ad hoc estimates of final fire acreage. Holmes et al. (2008) estimate a set of models for fire size based on an extreme value threshold model based on a generalized Pareto distribution to allow for relatively heavy tailed distributions. One distinction of this approach is that it calls for the explicit selection of a fire size threshold for including an observation in the sample for estimation.

The primary contribution of this present paper is the development and estimation of a model of suppression costs for individual fires that accounts for sample truncation inherent in our data, and is useable for forecasting prior to knowing final fire characteristics.

We estimate acreage and cost per acre equations as a bivariate system of equations. This allows us to better utilize information about the relationship between acreage and costs, thereby improving forecasting precision while allowing early cost predictions (prior to knowing acreage). Addressing sample truncation based on acreage addresses potential statistical inconsistency and bias in parameter estimates and predictions, for both acreage and cost equations, that would likely exist if truncation were ignored. We use new data from the Department of Interior for 2004 through 2009, for a total of 2061 available observations on fires of 300 acres or more.

Although the modeling framework of Holmes et al. (2008) is a reasonable approach, we rely on lognormal disturbances for modeling because it provide a more stable and manageable framework for joint estimation of costs and acreage with a relatively large number of covariates. We contend that this distributional assumption is a reasonable approximation and worth the benefits in terms of practical estimation and forecasting. We also found in preliminary analysis that applying the threshold selection approach used by Holmes et al. (2008) would call for substantial data and information loss (up to 95% of our observations).

The next section provides the theoretical foundation for the empirical model, followed by data descriptions, estimation results, cost and fire size prediction summaries, and a conclusion.

Model and estimation

As motivation for the bivariate regression equations for cost per acre and fire acreage, suppose a fire suppression manager allocates resources to balance suppression costs against wildfire damage losses. Consider two types of suppression inputs: s_a is productive for limiting acreage, and s_d is productive for limiting damage per acre, with constant marginal costs r_a and r_d, respectively. Total suppression costs are $T = r_a s_a + r_d s_d$. Fire size $A(s_a, \boldsymbol{x}_a, \varepsilon_a)$, is a decreasing function of s_a, and is also affected by exogenous factors $\boldsymbol{x}_a$ and a random disturbance ε_a. Per acre suppression costs are therefore $C(s_a, s_d) = T/A(s_a, \boldsymbol{x}_a, \varepsilon_a)$. Damage per acre is $D(s_d, \boldsymbol{x}_d, \varepsilon_d)$, which is a decreasing function of s_d, and is also a function of exogenous factors $\mathbf{x}_d$ and a random disturbance ε_d. Total losses from the fire are then $L(\cdot) = D(s_d, \boldsymbol{x}_d, \varepsilon_d)A(s_a, \boldsymbol{x}_a, \varepsilon_a)$. The random disturbances are unobservable in the data, assumed uncorrelated with exogenous variables, and treated as i.i.d. random disturbances for *ex post* observation and estimation. This theoretical model formulation is designed to illustrate how endogenous suppression