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Supplementary material for

Evaluating wildland fire liability standards – does regulation incentivise good management?

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Text S1. Landscape Data and Parameters

The underlying ecology is a crucial driver of agent behavior. To demonstrate this optimization framework, a representative landscape for SW Oregon was created using pre-existing ecological models and parameters to characterize the state variables, transition functions and reward functions. The action variables we model are fuel treatment and timber harvest. While there are many possible objectives for forest management, in this application we assumed that each landowner's goal is to maximize the expected net present value of harvested timber on the landscape. This objective is easy to define and characterizes the objectives of some state and private forest landowners. Our financial parameters include a real discount rate of 4% ($\delta = 0.96$; Row *et al*. 1981), log prices obtained from the Oregon Department of Forestry (2016), and harvest/haul costs were estimated based on a harvest cost model developed by Fight *et al*. (1984).

Landscape parameters

We modeled a representative forest landscape as an 8x8 grid consisting of 64 40-acre square stands that are flat (no elevation change) with the same soil conditions, climate, and weather. The defining feature of a forest stand is that its vegetation is relatively homogeneous and can be treated in a uniform manner (Tappeiner 2007). Smaller stand sizes increase the resolution and landscape heterogeneity, especially for determining the effect of fire on the landscape; larger stand sizes decrease modeling complexity. We selected 40 acres as a reasonable minimum size for a timber harvest unit. In order to account for edge effects, and because our model landscape is relatively small, we model the landscape as a torus that wraps on itself. This construction eliminates the need to model the costs associated with fire that spreads from outside the landscape, or fire that spreads off the edge of the landscape. It ensures that all effects of the fire are captured in the model, because a fire that spreads to the Eastern boundary (for example) wraps around and continues spreading inward from the Western boundary. It works as long as we assume that the surrounding landscape is similar to the model landscape in terms of vegetation, fire behavior, weather, and management options and objectives.

The initial landscape is created by randomly assigning an age class, with an associated vector of attributes, to each stand in the landscape. Each stand evolves over time independently of the other stands. We tracked the evolution of stand characteristics over time using a transition table—attributes we track are stand age, total cubic feet of biomass per acre, merchantable cubic feet per acre, merchantable board feet per acre, quadratic mean diameter, crown base height, tree height, and fuel model. These characteristics were used to drive simulations of fire events, and to compute the reward function resulting from landowner actions.

Stands transition into the next state as a result of vegetation growth, fire, harvest, and fuel treatment as follows:

- *Vegetation growth* was simulated using the Inland CA/Southern Cascades variant of Forest Vegetation Simulator (FVS) (Dixon 2002). In the vegetation simulations, bare ground is prepared for planting by piling and burning surface fuel and planting 500 Douglas-fir trees (*Pseudotsuga menziesii*) per acre. At age 15, the stands are thinned from below to a density of 300 trees per acre. After this time, trees are allowed to grow until they are harvested or destroyed in a fire, at which time the stand is re-planted. *Harvest* age for each stand is determined by the optimization algorithm. This approximates typical even-age stand management that would occur in this type of forest (Hobbs *et al*. 1992, Tappeiner *et al*. 2007). Surface fuel models classify a wide number of vegetative covers for the purpose of modeling fire spread (Anderson 1982). We used the Fire and Fuel Extension to the Forest Vegetation Simulator (FFE-FVS; Reinhardt and Crookston 2003) to assign fuel models to each stand in each time step as it grows, receives silvicultural treatments, is harvested, and has *fuel treatments* applied (simulated in FVS as piling and burning surface fuel).

- For *weather*, we used FireFamily Plus (Bradshaw and McCormick 2000), a software tool that analyzes weather observations and computes fire danger indices, to analyze Remote Automatic Weather Station (RAWS) data for several weather stations in SW Oregon in order to determine average wind speed and fuel moisture conditions for 4 different fire danger categories: low fire danger was the average conditions of the 0th-15th percentile of the fire danger index, moderate was the average conditions of the 16th-89th percentile, high was the average of the 90th-97th percentile, and extreme was the average of the 98th-100th percentile. Weather was drawn according to the following discrete distribution: lower fire danger, probability 0.15; moderate fire danger, 0.65; high fire danger; 0.07; extreme danger 0.03; this fire danger controls how quickly fire spreads through the landscape. Wind is not equally probable from all directions; it is more likely to come from some directions than others and the level of fire danger may be correlated with the wind direction. We assumed that each wind direction had the same distribution of fire danger. However, we modeled a prevailing wind direction by averaging each weather station's ranked wind direction probability and rounding to the nearest whole number. Since our representative landscape is symmetrical it doesn't matter which direction the prevailing wind comes from. On our landscape wind probabilities where specified as 30% from the West, 15% each from NW and SW, 10% each from North and South, 8% each from NE and SE and 4% from the East.

- *Fire* occurrence is characterized by ignition, spread rate, and duration. Because we assumed that fire arrival leads to stand destruction and complete value loss for the standing timber, we only modeled fire spread and not also fire intensity. *Ignition* probability was determined using statistics from the SW District of the Oregon Department of Forestry (Thorpe 2011). All stands on the representative landscape had equal probability of ignition. We used the BEHAVE fire modeling system (Andrews *et al*. 2005) to determine the fire *spread rates* associated with each fuel model/weather combination. The extent of fire spread for each ignition is controlled by the fire weather danger (described in the previous paragraph) and fire *duration*. Duration was a randomly drawn number between 24 and 96 hours, with longer durations more likely under more dangerous weather conditions. Fire duration is not based on empirical data; instead, repeated simulations on randoml generated landscapes using the parameters described above were performed to find a distribution of durations that led to a fire size distribution similar to that which has historically occurred in SW Oregon (Thorpe 2011). The primary shortcoming of this simple model of fire spread is that it does not account for variations in intensity due to changing weather conditions and changes in fuel conditions across the landscape as the fires spreads. This omission may be of interest in fire regimes where low intensity fire provides free fuel treatment. However this would be a valuable future extension of this work. Fuel treatment costs were determined based on a study by Calkin and Gebert (2006).

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