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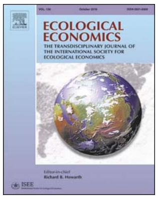

Analysis

Incorporating Ecosystem Health and Fire Resilience Within the Unified Economic Model of Fire Program Analysis☆

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ABSTRACT

We expand on a budget constrained, wildfire program optimization model to include a decision variable input for ecosystem health and fire resilience (*H*). With ecosystem health and fire resilience as a decision variable, two ecosystem states are delineated; the ecosystem can be within or outside its range of variability. The Southwest ponderosa pine ecosystem is used to illustrate the effects of fuels or restoration treatments on the decision variable input *H* within the probabilistic production function for wildfire losses. To estimate the health and fire resilience of the ecosystem, a short-term metric of ecosystem health (trees per acre for Southwest ponderosa pine) is used. Analysis of how the state of the ecosystem affects the optimization of the probabilistic production function for wildfire loss is carried out on the two ecosystem states. Results indicate that if the ecosystem is outside its range of variability, optimization of the objective function cannot be achieved. However, if the ecosystem is within its range of variability or if the ecosystem is transitioned within its range of variability through fuels or restoration treatments, the objective function can be optimized with respect to the decision input variables.

1. Introduction

The economics of wildfire has its beginnings in the United States with early works published at the start of the 20th century. Understanding of how fire affects natural capital stocks and social welfare has evolved since its early inception into the decision-making process. This paper focuses on how the health of the ecosystem affects the probability of losses associated with wildfire. Additionally, the dynamics of restoration and fuels treatment in altering the ecological state are introduced into predicting the probability of loss.

A recent USDA report shows wildfire suppression expenditure rising from 16% of the Forest Service budget in 1995 to 52% of the budget in 2015 (USDA, 2015). Current estimates for 2017's wildfire suppression expenditures are surpassing $2 billion, making 2017 the most expensive year ever in terms of wildfire suppression costs. With increased expenditure on wildfire suppression costs, expenditures on other non-fire related programs within the Forest Service's budget are being reduced. For example, the Vegetation and Watershed Management Program is responsible for restoration, enhancement, and post-fire restoration on National Forest System lands. Over the past 15 years the Vegetation and Watershed Management Program's budget has been reduced by 24%. Although classified as a non-fire program, the Vegetation and Watershed Management Program plays a significant role in shaping the landscape where potential wildfires may occur. Are current budgets for the wildfire suppression program not accounting for other programs that impact expenditures or losses resulting from wildfires? Showing that expenditures can be made to change ecosystem health and fire resilience within a fire program to alter expected wildfire loss is a focal point of analysis within this paper.

We begin with a history of wildfire economics in the United States and the management policies that coincided with the understanding of wildfire economics during that time to lay the foundations of where wildfire economics has progressed to today. Then, an outline of the Unified Economic Model of Fire Program Analysis (Rideout et al., 2008), which summarizes a current understanding of wildfire economics, is presented. We adapt Rideout et al.'s (2008) formulation of the objective function within the Unified Economic Model of Fire Program Analysis for further analysis by introducing a decision input variable that represents ecosystem health and fire resilience into. With this expansion, the framework can be used to analyze optimizing a fire program model when the ecosystem's health and fire resilience is both within and outside a range of variability. Discussion of the management implications stemming from the results concludes the analysis.

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1.1. History of Wildfire Economics

The effects of the 1910 fire season within the Northern Rocky Mountains have had lasting management and policy implications for the United States (Pyne, 1997). Prescribed burning and the use of fire as a management tool was one such issue. Naturalists of the time argued for fire's place in the ecosystem based on what they observed as the fire ecology of their location. A group of Californian loggers was particularly adamant in using low intensity fire as a management tool and brought it up for public debate in August of 1910. However, their timing coincided with one of the largest fire seasons in U.S. history and faced strong opposition from the Forest Service. The idea of using low intensity fire as a management tool failed to gain public support and was not considered by the Forest Service until the mid-1940.

The aftermath of the 1910 fire season fell on the recently created Forest Service and its chief, Gifford Pinchot. The U.S. Forest Service and the general public had little incentive to tolerate any fire on the landscape following these events. The notion of using prescribed fire as a management tool was squelched and fire suppression was the management objective. The first three chiefs of the U.S. Forest Service were all involved with the 1910 fire season and the policy of zero tolerance for fire or prescribed burns on the landscape did not change until Lyle Watts was appointed chief in 1943. With a strict regime of fire suppression being implemented, a natural social question to arise was, “How much fire suppression is optimal?”

In 1916 the first publications addressing the economics of fire suppression were put forth by Parish Lovejoy (1916) and Roy Headley (1916). Given a policy of fire suppression implemented by the Forest Service following the 1910 fire season, Lovejoy (1916) and Headley (1916) laid the first academic foundation for the least cost-plus damage method of determining expenditures for wildfire suppression (Pyne, 1997). In Lovejoy's (1916) and Headley's (1916) analysis, the damages associated with fire were assessed in terms of timber loss, watershed damage, and the loss of human infrastructure. Following this initial analysis of the economics of wildfire suppression, the least cost-plus damage method was expanded and graphically illustrated by Sparhawk (1925). Sparhawk's (1925) model included the independent variable protection costs (“presuppression”) that determined the suppression costs and damages (“total liability”). Total liability was assumed to be inversely related to presuppression expenditures with the objective function seeking to minimize the sum of total liability and presuppression costs. This framework guided the rationale for fire suppression policies across much of the United States. While the goal of early works sought to minimize the costs associated with fire suppression plus the damages incurred by the fire, management of wildfire gave little to no consideration of total liability damages. It was argued by forest managers that suppression costs were being kept to a minimum by quickly and efficiently containing wildfires once they were spotted. Little regard to the potential loss of assets (timber, watersheds or human infrastructure) was considered in determining which wildfires to suppress under the zero tolerance policies.

The inclusion of positive benefits associated with wildfire occurrence has more recently been incorporated into the least cost (LC) plus damage or loss (L) model to produce an objective function minimizing the cost of fire suppression (C) plus net value change (NVC) to the landscape (C + NVC). Rather than viewing wildfire as a destructive event producing only losses, NVC incorporates benefits wildfire provides society (e.g. fuel load reductions). Donovan and Rideout (2003) analyzed Sparhawk's least cost-plus loss model (LC + L) and argued the model contains two errors in its formulation. First, suppression expenditure is being incorrectly modeled as a model output rather than a decision variation or an input. Second, presuppression and suppression efforts are modeled as substitutes (i.e. increase in one implies decrease in the other). They argued that both suppression and presuppression expenditures should be modeled as independent inputs to optimize the net value change, which is the output. Their analysis expands on the earlier results of Rideout and Omi (1990) which demonstrated that suppression and presuppression efforts/expenditures are not necessarily negatively correlated (Donovan and Rideout, 2003).

Our analysis of the economics of a fire management program builds on the theory established in C + NVC framework. The unified economic model of fire program analysis presented by Rideout et al. (2008) is the base theoretical model that input variables are expanded on. The decision variable input of “fuels” (a proxy for fuels treatments or presuppression activities) used in the probabilistic production function in Rideout et al. (2008) is expanded on to incorporate the use of fuels treatments or restoration to change the state of the ecosystem and its fire resilience. It is then the state of the ecosystem after the fuels treatments or restoration which becomes a decision variable in the probabilistic production function rather than fuels treatments itself. Relating the state of the ecosystem to the Southwest ponderosa pine ecosystem and using the pre-European state of the ecosystem as a benchmark for ecosystem health and fire resilience, analysis of the probabilistic production function when the ecosystem is either within or outside of its historical range of variability is conducted. Incorporating the state of the ecosystem into the probabilistic production function allows for the analysis of the marginal productivity of fuels treatments or restoration. This distinction demonstrates why marginal analysis fails to produce an optimal solution when the ecosystem is outside its historical range of variability.

2. The Unified Economic Model of Fire Program Analysis

Rideout and Omi (1990) offered a more in-depth analysis of the C + NVC model by allowing decision inputs (suppression and presuppression) to interact as complements or substitutes with each other. Building on the analysis of the C + NVC model, Rideout et al. (2008) formulated a unified economic model of fire program analysis. Two key elements of a fire program are built in this model. First is the inseparability of the cost components that comprise the fire program. This point is highlighted in the cost function with the inclusion of a joint cost component. Many components of a fire program, both suppression and presuppression activities, share costs. Thus, analysis of the fire program cannot take place by analyzing the sum of the parts. Second is setting up the loss function with two key decision inputs, “suppression” and “presuppression”. The loss function allows for the marginal analysis of decision inputs and the corresponding effects marginal changes have on the other decision input when optimizing the objective function. The most general structure of this model is presented in Eq. (1) (Rideout et al., 2008).

$$Min\ Z = \Lambda[P(F,S)] + \lambda[B - C(F,S)] \tag{1}$$

where:

Λ denotes a general loss function of burn probability P across the program
$P(F,S)$ denotes the probabilistic production function for the program
$C(F,S)$ denotes the cost function of the fire program
F denotes the fuels decision variable
S denotes the suppression decision variable
B denotes the fire program budget
λ denotes the Lagrange multiplier for the program budget constraint.

To further analyze the benefits wildfire provides within the framework of Rideout et al.'s (2008) probabilistic production function, the use of an input variable to represent the ecosystem's health and fire resilience (H) is introduced. The use of this input in the probabilistic production function furthers the ability to assess the beneficial and negative impacts of fire on the landscape in terms of changes to the overall loss function. In addition, it allows us to analyze the most efficient allocations of restoration or fuels treatment investment given the