Three Essays on Wildland Fire Economics

by

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Abstract

This dissertation consists of three manuscripts examining different aspects of wildland fire economics, with a specific focus on prescribed burning and expenditures made by the USDA Forest Service on wildland fire suppression. The first chapter uses data from the Forest Service to estimate the effects of prescribed burning treatments on fire suppression expenditures. This is accomplished using an instrumental variable model that first observes how prescribed burning impacts area burned and then how area burned impacts suppression expenditures. In the second chapter a demand system is estimated using Forest Service accounting records. The demand system provides a better understanding of the tradeoffs between different categories of fire suppression resources. The final chapter uses a dynamic programming technique to examine the impact of carbon pricing on the optimal level of prescribed burning.

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Introduction

This dissertation consists of 3 stand-alone papers connected by the common theme of wildland fire economics. Each paper is presented as a chapter, and attempts to develop a better understanding of how the Forest Service allocates resources to fight wildland fires. The first chapter focuses on the relationship between fuel-removal conducted by prescribed burning and subsequent fire suppression expenditures. This is accomplished utilizing an instrumental variable model that captures this relationship between pre-suppression efforts, specifically prescribed burning, and suppression expenditures. This relationship has been explored on a local spatial scale using state and country level data (Butry 2009, Mercer et al. 2007); however, it is examined here on a sub-national scale using the Forest Service region as the unit of observation. By developing an understanding of how different Forest Service region's budgets are impacted by the use of pre-suppression measures the first chapter attempts to aid the Forest Service in making informed decisions about the use of taxpayer resources.

The second chapter estimates the demand for fire suppression services using two approaches. The first approach estimates how the number of acres burned affects the overall amount spent on fire suppression. The second approach uses detailed accounting data to estimate the relationship between the largest spending categories for the Forest Service. These categories are general contracting, flight contracting, and transfers to state agencies. This dual approach develops a picture of how fire sizes affects the need for the Forest Service to spend resources fighting fire, and what resources are used as part of the fire suppression efforts.

While the first two chapters analyze Forest Service expenditures on wildland fire, the third chapters is concerned with the effects of a hypothetical carbon tax on fuel management decisions. The chapter starts from the premise the carbon dioxide levels are rising and that wildland fires are a contributing emitter (Raupach et al 2007, Flannigan et al. 2009). From this premise the chapter develops a model that attempts to account for the cost of carbon released from prescribed burning conducted as a pre-suppression activity, the wildland fire itself, and decay of vegetation following the fire. The model also includes the carbon sequestered through the eventual regeneration of vegetation. The inclusion of carbon pricing into the analysis of how much prescribed burning to conduct will allow policy makes to make informed decisions about the best fire management practices. Together these three chapters comprise this dissertation.

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Chapter 1 – Do Pre-suppression Efforts Reduce Wildland Fire Suppression Expenditures? A Case of Pay Now or Pay More Later

Abstract

Using data from the USDA Forest Service we estimate the effects of prescribed burning treatments on fire suppression expenditures. This is accomplished using an 11-year panel data set consisting of Forest Service regions, that is used to estimate an instrumental variable model that controls for the effects of weather and prescribed burning treatments on the current year's fire activity. This model enables us to generate an estimated elasticity between the area treated with prescribed burning and expenditures for suppressing wildland fires. The results indicate that the Forest Service could possibly see substantial savings from increasing prescribed burning programs especially in the western United States.

Introduction

In recent years the USDA Forest Service has adopted a holistic approach to wildland fire management, recognizing the role that fire plays in a healthy ecosystem. As part of this transition the Forest Service has increased the use of prescribed burning and wildland use fires for fuel management purposes (Cohesive Strategy 2010). During this period the Forest Service has also experienced escalating wildland fire suppression cost. Increasing fire activity has been one of the contributing causes to this trend. With an increasing number of acres burned the need for preventive measures is clear; however, it is unclear if these pre-suppression efforts are effective and economically efficient. The latter refers to whether the benefits of these efforts, in terms of the savings in current and future fire-fighting expenditure, exceed their costs.

In this paper we attempt to explore the relationship between fuel-removal, through the use of fire, and the cost associated with fire suppression. We construct an instrumental variable model that captures the relationship among pre-suppression efforts, weather, and fire-fighting expenditures and use the model to analyze data from 8 Forest Service regions. This allows us to estimate the point elasticities between fire-fighting expenditure and pre-suppression efforts, which are then used to determine how much each Forest Service region could save from a marginal increase in prescribed burning. Our results show that using prescribed burning can reduce suppression expenditures. This is important as it provides insight into the effectiveness of prescribed burning programs on a large spatial scale and may guide the Forest Service in allocating scarce resources to prescribed burning as a pre-suppression activity. The next section provides a brief review of U.S. policy on fighting wildland fires, followed by a description of our theoretical model. The final 2 sections present our empirical results and conclusions.

History and Literature Review

Since the early 1900s, the Forest Service has attempted to limit its expenditures on large fires. In 1926, then head of the Forest Service, William Greely observed:

> From a purely business standpoint it is obvious that we should do anything that can be done within reason to cut down these large emergency expenditures which are necessarily wasteful because they are made under emergency conditions that involve great haste and stress, and which, after all, simply represent the stopping of great destruction. They are not constructive expenditures (Pyne 1982).

Early efforts at controlling the cost of a wildland fire relied on the speed of attack as the primary means to reduce the severity and limit the need for large expenditures (Pyne 1982). This led to a policy environment that sought to limit wildland fire damage by extinguishing fires as quickly as possible. However, some feel this policy has resulted in higher fire risk through the accumulation of fuel loads over time (Arno and Brown 1991, USDA Forest Service 2000, Busenberg 2004). Fuel loads are generally defined as the amount of vegetative material present above the soil on a given landscape (Pyne et al. 1996).

Before the 1970s the Forest Service, keeping with its policy of quick suppression, focused on controlling fires by 10 A.M., under the fittingly named the 10 A.M. policy (Pyne 1982). Beginning in the early 1970s this policy started to evolve slowly into the current multifaceted approach that weighs net losses – recognizing the beneficial nature of fire in certain settings – against cost (Pyne 1982). In 1995, the Federal Government revised Federal Wildland Fire Policy to minimize the danger of catastrophic wildland fire. The new policy was driven by 3 major objectives: 1) protecting human life, property and natural/cultural resources, 2) reintroducing fire back into ecosystems, and 3) giving greater inter- and intra-agency support for fire managers (Hesseln 2000). The new policy recognized the possibility of using prescribed burning as a tool in overall fire management. However, prescribed burning has to be cost-effective as is required for all Forest Service programs (Hesseln 2000).

The need to develop a multifaceted approach has also been driven by rising real cost of fighting fires. In 2005 the Forest Service spent $760 million on fire suppression expenditures up from $160 million in 1977, with both figures being in 2003 dollars (Mercer et al. 2007). On the other hand, estimates of the cost of prescribed burning treatments vary greatly between regions. For example Wood (1988) estimated a range of $2.78/ac to $33.65/ac in 1988 dollars for prescribed burning of Southwestern Ponderosa Pine, while Cleaves et al. (2000) had a range of $7.67/ac to $344.46/ac in 1994 dollars for prescribed burns on all National Forests. A consistent finding in previous research is that prescribed burning exhibit economies of scale on the size of the treatment area (Jackson et al. 1982, Gonzalez-Caban and McKetta 1986, Wood 1988, Rideout and Omi 1995).

Whether prescribed burning reduces overall fire suppression cost is still an open question, some analysis has been done at the state level (Prestemon et al. 2002, Mercer et al. 2007, Butry 2009, Butry et al 2010). These early works focused on Florida and generally supported the notion that various pre-suppression programs did reduce fire suppression cost. Prestemon et al. (2002) found that vegetation management through prescribed burning does affect wildland fire risk; however, some of their results were counterintuitive in that they showed an increase in vegetation management leads to increased wildfire risk. The authors hypothesized that this was due to an omitted risk factor and expressed a need for analysis at a finer spatial scale to confirm their findings (Prestemon et al. 2002).

Looking at Volusia County in Florida, Mercer et al. (2007), extending on Prestemon et al. (2002), explored the role that prescribed burning plays in cost-effective wildland fire management regimes. They found that wildfire intensity as opposed to simply the number of acres burned provided a better basis for analyzing the success of prescribed burning programs. While Mercer et al. (2007) found that prescribed burning could help minimize economic damage caused by wildland fire; they expressed concern over the inelasticity of prescribed burning services and possibility of crowding out of prescribed burning on private land. Butry (2009) found that prescribed burning might be a useful tool to limit the extent and intensity of wildland fires and that prescribed burning has a persistent effect, lasting up to 3 years, following its application.

Theoretical and Empirical Framework

Wildland fire management decisions are often framed using the cost (C) plus net value change (NVC) model. This framework addresses the challenges of optimizing pre-suppression and suppression efforts. The C+NVC is a minimization problem that has two distinct parts: the cost of the fire that includes suppression and pre-suppression expenditures and the net value change that is the sum of the damages caused by the fire minus the benefits received from the fire, the C+NVC function is (Rideout and Omi 1990):

$$MIN: C + NVC = W^p P + W^s S + NVC(P, S) \tag{1}$$

Where P and S denote pre-suppression and suppression activities, and W^p and W^s are the unit cost of those activities, respectively.

Net value change (NVC) not only captures the damage that a fire causes, but also incorporates the positive benefits that a fire (e.g.: restoring a fire dependent ecosystem or reducing fuel loads through wildland use fires) can provide to a landscape. As long as NVC is not greater than 0, the C+NVC minimization problem becomes a trade-off between spending resources on pre-suppression activities such as fuel-removal or spending resources fighting fires. Although we do not have evidence that NVC is not greater than zero in all cases, the fact that we spend money and resources to fight wildfires indicate that at least the public will not accept a "do nothing and let it burn" policy toward wildfires. This assumption allows us to ignore the NVC part and focus on the possible relationship and linkage between pre-suppression and suppression expenditure.

The question we attempt to answer here is whether or not pre-suppression efforts, specifically prescribed burning, reduces the suppression cost in a manner that results in a net savings for the Forest Service. Following Butry (2009) and Mercer et al. (2007), we hypothesize that area burned by wildfires in a region is negatively related to the acreages treated with prescribed burning and acreages treated with wildland use fires and positively related to fuel load (amount of biomass), drought (weather conditions), and possible unspecified regional factors. We also hypothesize that regions will see varying use of prescribed burning. Thus, we have

$$\begin{aligned} (2)\quad & ln\left(USFS\ Acres\ \frac{Burned}{Forestland}\ Area\right) \\ & = \beta_1 + \beta_2 ln\left(Acres\ Treated\ with\ Prescribed\ \frac{Fires}{Forestland}\ Area\right) \\ & + \beta_3 ln\left(Acres\ Treated\ with\ Wildland\ Use\ \frac{Fires}{Forestland}\ Area\right) \\ & + \beta_4 ln\left(\frac{biomass}{Forestland}\ Area\right) + \sum_j \gamma_j\ Region_j + \varepsilon \end{aligned}$$

where $ln(USFS\ Acres\ Burned/Forestland\ Area)$ is the natural log for the ratio of USFS acres burned to forestland area in the region; $ln(Acres\ Treated\ with\ Prescribed\ Fires/ Forestland\ Area)$ is the natural log for the ratio of acres treated with prescribed fires by the Forest Service to forestland area in the region; $ln(Acres\ Treated\ with\ Wildland\ Use\ Fires/ Forestland\ Area)$ is the natural log for the ratio of acres treated with wildland use by the Forest Service to forestland area in the region; $Drought$ is a dummy variable for drought conditions throughout the year, and $Region_j$ is a dummy variable for the Forest Service region j (j=1, 2, 3, 4, 6, 8, and 9, with region 5 being dropped and treated as a control), all β and $\gamma$are coefficients, and ε is a residual.

Since fire is a spatial phenomenon, we believe using regional level data offers an opportunity to estimate the effects of fuel reduction programs on overall fire suppression expenditures and determine if the optimal level of fuel treatments are being applied. Further, we hypothesize that fire suppression expenditure is positively related to the area burned in a region:

$$(3)\qquad ln(Real\ Suppression\ Exp) \\ = \beta_1 + \beta_2 ln(USFS\ Acres\ \widehat{Burned}/Forestland\ Area) + \sum_j \varphi_j\ Region_j + \omega$$

Where:

where $ln(Real\ Suppression\ Exp)$ is the natural log of USFS real fire suppression expenditures, $ln(USFS\ \widehat{Acres}\ Burned/Forestland\ Area)$ is the forecasted acreages burned based equation 2 all α and $\varphi$are coefficients, and ω is a residual.

Equations (2) and (3) consist of a system of equations that can be best estimated with an instrumental variable model using a limited information maximum likelihood (LIML) estimator as opposed to a 2SLS estimator. This is done since LIML has better finite sample properties compared to 2SLS estimator (Cameron and Trivedi 2009, Angrist and Piscke 2009). The model is also estimated using robust standard errors to account for any heteroskedasticity in the errors (Cameron and Trivedi 2009) and using the natural log form with all variables except dummy variables to ensure the errors are normally distributed (Greene 2008). This allows the coefficients from the regression to be read as elasticities and provides an estimated relationship for fire suppression expenditures for a given change in acres burned as a percent of forested area.

A different specification of the model included the one-year lags for both prescribed and wildland use fires; however, the variables were found to be statistically insignificant. This differs from previous work that looked at prescribed burning at the county level in Florida (e.g., Butry et al. 2010). A possible reason for this difference might be the large spatial scale (a Forest Service region) being examined in this paper in contrast with small scale (county) in previous studies. The results presented here do not included the area of wildland use fire or prescribed burning accumulated in previous years, but focuses only on the effects of prescribed burning within a single period.

Data

A panel data set is created by pooling observations for the Forest Service regions, with region 10, consisting solely of Alaska being excluded, with 11-years (1998-2008) of data creating an 88-observation data set. Table 1-1 lists the summary statistics for the continuous variables and the number of positive responses for the binary dummy variables, and Figure 1-1 shows the geographic location of referenced Forest Service regions. Figures 1-2 and 1-3 provide the time series plots for selected Forest Service regions. The data for fire suppression expenditures was provided by the Forest Service and is based on its accounting records. The fire suppression expenditures represent money spent on large fires by the Forest Service and the GDP deflator is used to adjust for inflation, with a base year of 2004. The data for acres burned, wildland use fires, and prescribed burning is obtained from the National Interagency Coordination Center (NICC).[i] The total acres of timberland and reserve forests in each region are from Smith et al. (2001, 2004, and 2009).

To control for biomass per acre of forestland a variable, termed *biomass,* is derived from net timber volume on timberland (and then divided by the total timberland and reserved forest area) in each region. Each state's net volume on timberland for 1997, 2002, and 2007 were obtained from Smith et al. (2001, 2007, and 2009). We then aggregate the state level data to the Forest Service region level.[ii] Taking the difference between the surveyed years and dividing by the number of years in between provides estimates for the average annual change in net volume. This average annual change was then added to each year in order to create an estimated value for that year. The biomass ratio is then calculated in cubic feet per acre.

The *drought* variable is a binary variable based on the Palmer Drought Severity H Index, which has been used to forecast suppression cost in previous studies (Abt et al. 2009). The Palmer Index is weighted based on the amount of national forestland in each region and is also provided by the Forest Service. The Palmer Index uses precipitation and temperatures to create a long-term index for measuring droughts. A 0 reading for the Palmer Index indicates a normal measure with drought conditions receiving a negative value and periods of above average rainfall a positive value (NOAA 2010). Each year has four Palmer Index readings: March, June, September, and December. A region receives a 1 for *drought* if, for a given year, at least 3 of the 4 reading are negative; otherwise the region receives a 0 for that year. The regional dummy variables are included in order to see if fire activity and costs vary be Forest Service region. Region 5 (California) is excluded for basis of compression

Empirical Results

The results for the instrumental variable model are presented in Tables 1-2 and 1-3. The estimation is performed using Stata 11's *ivregress* command with robust standard errors. The results for the first-stage show that our model fits well: the R^2 is 0.71 and three variables (the ratio of prescribed burning, and the biomass ratio, and drought) are statistically significant. The first-stage results are presented in Table 1-2. For the region dummy variables Regions 1, 2, 6, 8, and 9 have a negative and statistically different relationship compared to Region 5. Region 3 (Arizona and New Mexico) has a positive relationship, and with a p-value of 10.9% just outside the traditional cutoff for a statistically significant relationship. Region 4 is not statistically significant. The results match the expected outcome that the regional dummies differ and the first-stage results support the intuitive idea that different Forest Service Regions experience different levels of fire activity.

The instrumented variables in the first-stage all show the expected signs, with only wildland use fires not being statistically significant. The finding that wildland use fires do not have a statistically significant impact on *ln(USFS Acres Burned/Forestland Area)* is understandable since wildland use fires are often conducted for reasons other the fuel reduction and fire risk management. For example wildland use fires might be allowed to burn as part of an effort to restore fire to a fire dependent ecosystem (Cohesive Strategy 2010). The dummy variable for drought is statistically significant at the 1% level with a positive coefficient of 0.94. This is the expected result since drought conditions are an often-cited contributing cause of wildland fires (Flannigan et al. 2009, Meyn et al. 2010).

The two most important policy measures being examined in this study are *ln(Acres Treated with Prescribed Fires/Forestland Area)* and *ln(Biomass/Forestland Area)* and both are statistically significant at the 5% level or better with the expected signs. Of the two *ln(Acres Treated with Prescribed Fires/Forestland Area)* is perhaps the one most closely controlled by the Forest Service, as it has substantial control over the amount of prescribed burning it conducts. The results from the first-stage indicate that a 1% increase in the proportion of forestland treated with prescribed burning would reduce the amount of acres burned on the forestland by 0.83%. For Region 5 this means that over the 11-year period examined an increase in 536 acres in prescribed burns conducted would have led to an average reduction in 5,823 acres in burned.

To observe the effects of increasing forest density on the amount of wildland fires, *ln(Biomass/Forestland Area*) is included in the first-stage regression. This variable shows that increasing forest density by 1% leads to a 1.93% increase in the proportion of acres burned. This finding has important implications since increasing forest density to sequester carbon has been one option proposed to deal with rising levels of atmospheric carbon dioxide. This result should not be viewed as an indictment of carbon sequestration, but it is an indication that as forest density increases more resources may need to be allocated to deal with the rising risk of wildland fire.

The second-stage regression includes the Forest Service regions and the *ln(USFS Acres Burned/Forestland Area)*. Since the Forest Service region is the basis of observation the inclusion of the regions control for variation in the cost of suppression. The results show that Regions 1, 2, 3 and 4 have lower real fire suppression expenditures compared to Region 5. Regions 6, 8, and 9 are not statistically significant for the second-stage regression. That Region 5 represents the most expensive region for wildfire suppression is not surprising as the region has an extensive wildland-urban interface that requires responding to wildland fires in order to protect life and property.

Conclusions and Discussion

Using the Forest Service region as the unit of observation, we create a model to observe how the level of prescribed burning, acting through area burned, affects the cost of wildland fire suppression. Using an instrumental variable approach to control for weather, prescribed burns, biomass, and region we are able to obtain elasticity estimates for the Forest Service as a whole. These elasticities are used to estimate how suppression cost are affect by a hypothetical 1% increase in area treated with prescribed fires. The results of our analysis shows the Forest Service is failing to fully maximize the benefits of a prescribed fire regime, specifically in the western United States. By increasing the use of prescribed burning the Forest Service has the potential to lower suppression expenditures, while reintroducing fire to western landscapes.

Using the elasticities between prescribed burning and acres burned from Table 1-2, we estimate the amount of prescribed burning necessary to attain a 1% reduction in the number of area burned for Forest Service. This is accomplished by determining how many acres need to be treated with prescribed burning to achieve this 1% reduction in area burned for each year and region. The 11-year average for each region is presented in Table 1-4, column A. Forest Service region 8 requires the largest increase in prescribed burning to achieve the 1% reduction. Column B shows the reduction in acres burned resulting from the decrease in fire activity.

Using the results from the second-stage it is possible to see how much a 1% reduction in area burned will reduce spending on fire suppression. Taking the total savings from this reduction in area burned, and dividing by the amount of additional area needed to be treated with prescribed burns, provides an estimate of the per acre saving from prescribed burning. These results are presented in column C. Since the specific policy question this paper attempts to explore is whether the Forest Service could lower expenses by extending prescribed burning programs the cost and benefits must be compared. To answer this question the cost of the prescribed burning treatments is also needed. Updating the results from Cleaves et al. (2000) to 2004 dollars provides a cost estimate for each region and these results are presented in column D.

Comparing column C and D it is possible to see how regions are effect by a change in prescribed burning. The only region that would not see a benefit from increasing prescribed burning is region 8. Region 5 saw the largest estimated savings at $3,982.87 an acre. Regions 1, 4, and 6 all have savings of over $1,000 an acre. Region 5 also has the highest average cost at $423.39. Regions 5, 4, and 1 have the largest savings over the cost of prescribed burning treatments. Of course this analysis is looking at average cost when marginal cost is the true variable that should be examined. The Forest Service might have to acquire capacity to conduct prescribed burning in clumps, if so the large positive savings may be reduced.

By extending prescribed burning to land that is currently considered marginal for treatment, due to other areas taking precedent as a result of limited funds, the Forest Service can bring the estimated savings closer in-line with costs. One concern is that as the Forest Service increases prescribed burning programs the marginal benefits of such programs will fall as marginal costs increase. While this is a valid concern, the magnitude of the estimated savings is very high for the western regions. Also, maintenance treatments are needed to prevent the reaccumulation of fuels after a prescribed burn is conducted. Together these factors lend support to idea that the Forest Service should increase funding for fuel-removal programs that utilize prescribed burning.

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Figures

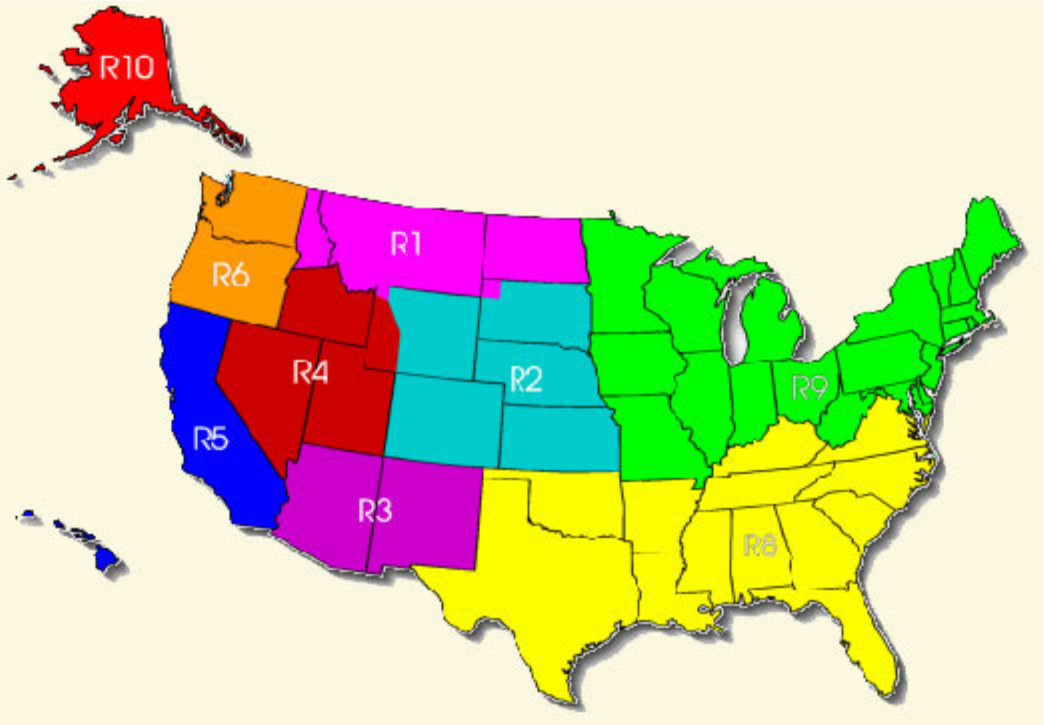

Figure 1-1: Forest Service Regions (USDA Forest Service 2011).

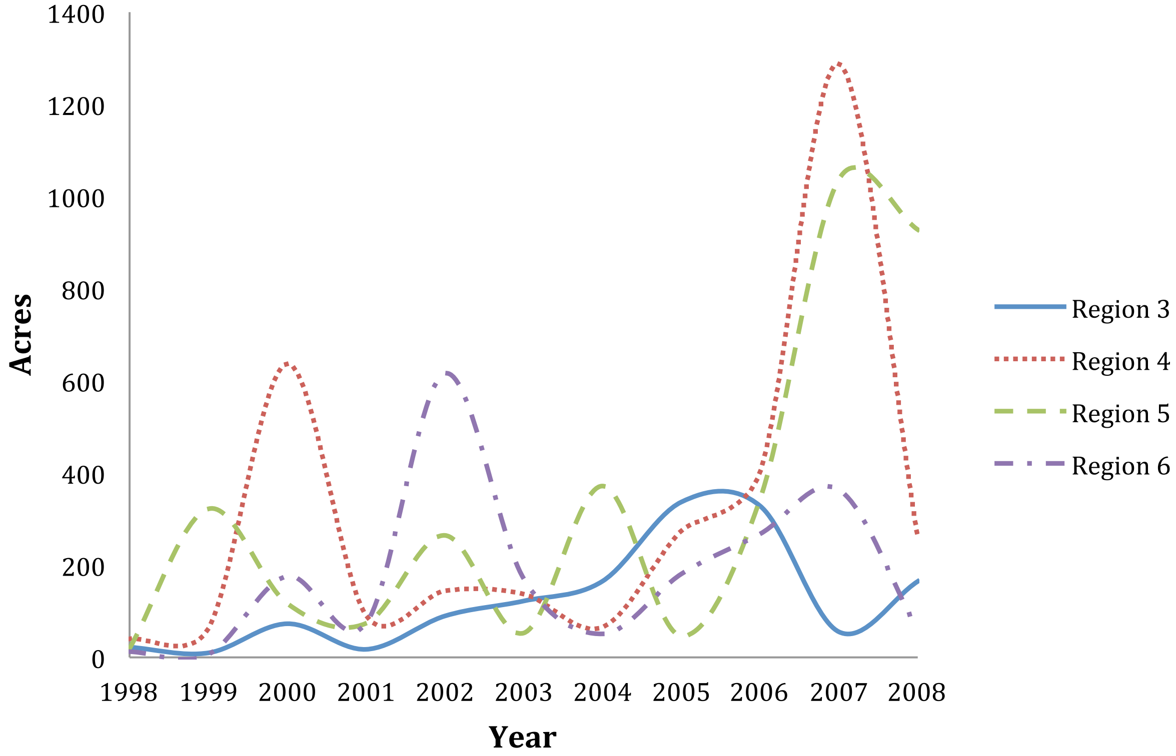

Figure 1-2: Average USDA Forest Service Wildland Fire Size for Selected Regions.

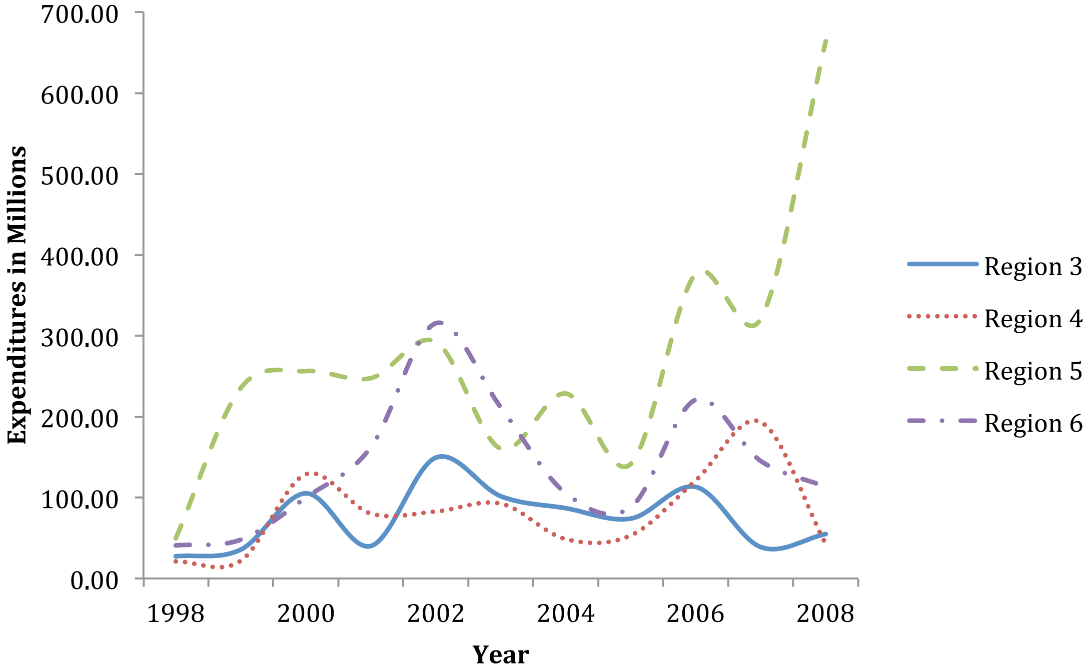

Figure 1-3: USDA Forest Service Wildland Fire of Suppression Expenditures for Selected Regions.

Tables

Table 1-1: Summary Statistics.

Variable	Mean	Standard Deviation	Minimum	Maximum
Real Suppression Cost (in $'000's)	$95,344	$107,894	$2,698	$663,972
USFS Acres Burned/Forestland Area	0.0057	0.0093	0.0001	0.0491
Acres Treated with Prescribed Fires/Forestland Area	0.0015	0.0011	0.0001	0.0049
Acres Treated with Wildland Use Fires/Forestland Area	0.0002	0.0005	0.0000	0.0008
Biomass/Forestland Area	0.0014	0.0006	0.0004	0.0030

Binary Variable		Responses	1	0
Drought			70	18
Region 1 (or 2, 3, 4,5,6,8,9)			11	77

Table 1-2: First-Stage Regression.

Dependent Variable	ln(USFS Acres Burned/Forestland Area)
	Coefficient (Standard Error)
ln(Acres Treated with Prescribed Fires/Forestland Area)	-0.83***
	(0.28)
ln(Acres Treated with Wildland Use Fires/Forestland Area)	-0.03
	(0.03)
ln(Biomass/Forestland Area)	1.93*
	(1.10)
Drought	0.94***
	(0.31)
Region 1	-1.03*
	(0.57)
Region 2	-1.02**
	(0.50)
Region 3	2.48^{t}
	(1.53)
Region 4	0.76
	(0.82)
Region 6	-2.42***
	(0.56)
Region 8	-2.02***
	(0.54)
Region 9	-6.39***
	(0.71)
Constant	0.99
	(7.49)
N	88
R^2	0.71
F(4, 76)	5.65***
F(11, 76)	22.26***

Note: *** is 1%, ** is 5%, * is 10%, and ^{t} is 10.9% levels of statistical significance.

Table 1-3: Second -Stage Regression.

Dependent Variable	ln(Real Suppression Expenditures)
	Coefficient (Standard Error)
ln(USFS Acres Burned/Forestland Area)	0.79***
	(0.13)
Region 1	-0.52**
	(0.24)
Region 2	-0.89***
	(0.28)
Region 3	-0.65**
	(0.26)
Region 4	-0.80***
	(0.23)
Region 6	0.45
	(0.30)
Region 8	0.70
	(0.46)
Region 9	0.67
	(0.68)
Constant	23.08***
	(0.67)
N	88
R^2	0.80

Note: *** is 1%, ** is 5%, * is 10%, and ^{t} is 11.5% levels of statistical significance.
The first-stage estimates the effects of prescribed burns, wildland use fires, drought, and the Forest Service region on the area burned. Using this estimation a second-stage is estimated with real suppression cost as the dependent variable with the instrumented area burned and Forest Service Regions used as the dependent variables.

Table 1-4: Estimated Savings in 2004 dollars of a 1% Reduction in Acres Burned.

Region	Additional Treated Area with Prescribed Burning in Acres (A)	Estimated Reduction in Acres Burned (B)	Estimated Saving From Increased Prescribed Burning per Acre (C)	Average Prescribed Burning Cost[1] (D)
1	529.41	-2,748.24	$1,567.81	$197.81
2	474.04	-992.75	$630.08	$64.46
3	1,055.13	-2,312.50	$562.83	$67.29
4	534.72	-3,381.04	$1,190.12	$112.74
5	536.23	-5,823.21	$3,982.87	$423.39
6	811.11	-2,509.83	$1,372.87	$231.44
8	8,941.22	-762.28	$36.56	$44.00
9	310.65	-193.38	$291.82	$67.19
Average	1649.06	-2340.40	$1204.37	$151.04

1. The average cost for all types of prescribed burning from Cleaves et al. 2000 updated to 2004 dollars.

Chapter 2 – An Demand System for Fire Suppression Services

Abstract

In this paper, we use region level data to estimate the demand for fire suppression services by the USDA Forest Service. This is accomplished using a pair of methods. The first method uses regression analysis to examine how the number of acres burned effects the per acre average suppression expenditure. The second method uses select budget categories from Forest Service accounting records to estimate a demand system, with the categories treated as commodity classes. Our results show that fire size does reduce the average per acre fire suppression expenditure in all but the most extreme cases, and that selected budget categories respond differently as spending changes. These results offer insight into where future efforts to control the fire suppression budget for the Forest Service should focus.

Introduction

In this paper, we explore the demand for wildland fire suppression services by the USDA Forest Service using a duel approach to analyze quarterly data. First a semi-log regression model is estimated to examine how fire size influences the average per acre expenditure on wildland fire suppression. For the second method accounting data from the Forest Service is used to develop an indirect transcendental logarithmic (indirect trans-log) demand system. The demand system is estimated in order to better understand how Forest Service spending evolves as additional resources are employed to fight wildland fires. This research aims at developing a better understanding of how different portions of the Forest Service budget responds to changing spending levels.

As Figure 2-1 indicates the Forest Service is experiencing an upward trend in real expenditures for wildland fire suppression. From 1995 to 2009 total real expenditures has increased at an average rate of 8.58% per year[iii]. This increase in expenditures can partly be attributed to an increase in the amount of fire activity. Figure 2-2 shows that yearly acres burned have increased from 1998 to 2008. The average expenditure per acre has fallen during this period as shown in Figure 2-3. This is can likely be attributed to the high fixed costs of fire suppression being spread across more acres, but a detailed statistical analysis is needed to verify this hypothesis.

For both the regression analysis and the demand system Forest Service region level expenditure data is used. The regression model examines how the number of acres burned affects average expenditure per acre. The trans-log demand system is based on the 3 largest spending categories, representing more than 97 percent of the total spending on fire suppression activities, and allows for the estimation of own, cross, and income (expenditure) elasticities. The estimation of these elasticities will further the understanding of how fire suppression resources are utilized to fight wildland fires. Specifically the demand system explores the substitution between budget categories and how budget categories respond to variation in expenditures made to fight wildland fires.

Literature Review

Schuster et al. (1997) examined Forest Service fire-related expenditures from the 1970 to the 1995 and found that, when 1994 is excluded, real expenditures had not seen a significant increase. Since the mid 1990's it is increasingly looking as if 1994 was less of an outlier and more the beginning of a new trend. While Schuster et al. (1997) found that most of the increases in expenditures from 1970 to 1995 could be attributed to inflation, since the late 1990's the Forest Service has had to grapple with escalating real expenditures. Figure 2-1 shows real expenditures since 1995, with a linear trend line fitted. This increase in total real expenditures has put pressure on the Forest Service to maximize the value of the resources spent suppressing wildland fires.

One major source for the increase in suppression expenditures is the success of previous wildland fire suppression efforts. By reducing the role of fire in the forest ecosystem fuel loads steadily increase, eventually leading to more catastrophic wildland fires (Steelman and Burke 2006, Busenberg 2004, Arno and Brown 1991). A second major source has been growth in the wildland-urban interface (WUI) (Liang et al. 2008, Snyder 1999), with the federal government internalizing the cost of protecting private landholders Snyder (1999) notes:

> As long as Federal wildland firefighting agencies continue to absorb protection and suppression costs for indirect structure protection in the name of wildland fire protection, we can only expect a corresponding escalation in wildland protection

cost. That increased cost will be borne by the federal taxpayer. However, one could hope that long-term goals would prevail to give all taxpayers a fair chance.

Finally, global climate change has been linked as a contributing factor to increasing fire activity (Meyn et al. 2010, Flannigan, et al. 2009, Westerling et al. 2006, Running 2006). Studying wildland fires in the western United States, Westerling (2006) found that earlier and drier springs are major cause of the increase in wildland fires. This has resulted in large fires occurring more frequently, and the average duration of the fire increasing. Since the mid-1980's the average burn time for a fire has increased from 1 week to 5 weeks (Westerling 2006). Combined these factors have contributed to the Forest Service experiencing rising real expenditures for wildland fires.

Wildland fires are considered heavy tail events, with a small percentage of fires accounting for a large percentage of damage and costs. Strauss et al. (1989) found that 1 percent of forest fires account for 80 to 96 percent of the damages in Southern California. This heavy tail nature has resulted in the use of Pareto distributions in the analysis of wildland fires as an approach to address the non-normal distribution (Strauss et al. 1989, Holmes et al. 2008). Another approach used to control for non-normal distribution is truncating the data by placing an upper or lower bound based on fire size. Holmes et al (2008) determined 500 acres was an appropriate lower bound for wildland fires in the Sequoia National Forest. Studying wildland fires in Alberta, Canada Cumming (2001) found wildland fires above 1,000 ha (2471 acres) had the greatest impact on total area burned.

Analytical Framework

As mentioned in the introduction this paper explores the demand for wildland fire suppression services in two ways first a regression is estimated to analyze the relationship between expenditures, acres burned, regions and drought. The second method estimates a demand system for different types of fire suppression services using Forest Service accounting data. The purpose of both techniques is to better understand the specific factors influencing the rising cost of wildland fire suppression.

The regression model is estimated using ordinary least squares with white standard errors to control for possible heteroskedasticity (Wooldridge 2006). The model is in semi-log form, which gives the rate of increase for the average expenditure per acre given the increase in the independent variables (Greene 2008). The functional form is:

$$\begin{aligned} Log(Average\ Expenditures) &= \beta_1 + \beta_2 Acres\ Burned + \beta_3 Acres\ Burned^2 + \beta_4 Drought + \sum_j \gamma_j\ Region_j \\ &+ \sum_j \tau_j\ Quarter_i + \varepsilon \qquad (1) \end{aligned}$$

Where:

$Average\ Expenditures$ is average per acre expenditure for the quarter and Forest Service region.

$Acres\ Burned$ is the number of acres burned for the quarter and Forest Service region.

$Acres\ Burned^2$ is the square of the number of acres burned for the quarter and Forest Service region.

$Drought$ is the Palmer Drought H Index based on a weighted average for the quarter and Forest Service region.

$Region_j$ is a dummy variable for the Forest Service region j (j=1, 2, 3, 4, 6, 8, and 9, with region 5 being dropped and treated as a control)

$Quarter_i$ is a dummy variable based on the calendar quarter i (i=1,2, and 4 with the 3rd quarter being dropped for control).

$\beta, \gamma, and\ \tau_j$ are coefficients, and ε is a residual.

The model is also estimated using the quadratic form for acres burned in order to examine the marginal effect of fire size on the average expenditures per acre. The model also includes a measure for drought conditions that is weighted based on the amount of national forest land in each region. The Forest Service regions and calendar quarters are included in the model as a series of dummy variables.

The second portion of the analysis is an indirect trans-log model estimated using a system of equations. In fighting wildland fires the Forest Service is faced with maximizing the utility of resources available for fires suppression, this is analogous to consumers maximizing their utility given their budget constraint. The indirect trans-log model uses 3 budget object code (BOC) categories as commodity classes with expenditure share of each commodity class as a dependent variable. The system is developed from the following direct utility function (Christensen et al 1975):

$$-ln\, u = ln\, \alpha_0 + \sum_{i=1}^{n} \alpha_i ln\, q_i + \tfrac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} ln\, q_i\, ln\, q_j \tag{2}$$

The direct utility function in (2) uses quantity of the commodities, q_i, and with i and j representing commodities classes consumed. The left hand side variable u is the direct utility from the consumption of the commodities. On the right hand side α_0 is the constant term, α_i is the slope coefficient associated with commodity *i,* and b_{ij} is the slope coefficient for the interaction between commodities i and j. The direct utility function is then transformed into the following indirect utility function:

$$ln\,v = \alpha_o + \sum_{i=1}^{n} \alpha_i ln\left(\frac{p_i}{texp}\right) +$$

$$\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij} ln\left(\frac{p_i}{texp}\right) ln\left(\frac{p_j}{texp}\right) \qquad (i \neq j; i, j = 1, \ldots, n) \tag{3}$$

Where, p_i equals the price, i and j represent commodities classes, and $texp$ is the value of total expenditures. Where, v is the indirect utility from the consumption of the commodities. On the right hand side α_0 is the constant term, α_i is the slope coefficient associated with expenditure share of commodity *i,* and b_{ij} is the slope coefficient for the interaction between the expenditure share for commodities *i* and *j*. The derivation of the expenditure shares leads to the following equation:

$$Share_i = \frac{\alpha_i + \sum_j b_{ij} ln\left(\frac{p_j}{texp}\right)}{\sum_k \alpha_k + \sum_j b_{ij} ln\left(\frac{p_j}{texp}\right) + \sum_i b_{ji} ln\left(\frac{p_i}{texp}\right)} \tag{4}$$

The estimated model uses equation (3) as part of a system of equations. Resulting in a 3 equation system where the expenditure share for each commodity is used once as the dependent variable:

$$Share_{2540} = \frac{(a_1+b_{11}*log(p_{2540})+b_{12}*log(p_{2541})+b_{13}*log(p_{2551})-log(texp)*(b_{11}+b_{12}+b_{13})}{1+2*(b_{11}*log(p_{2540})+b_{12}*log(p_{2541})+b_{13}*log(p_{2551})+b_{12}*(log(p_{2540})+log(p_{2541}))+b_{13}(log(p_{2540})+log(p_{2551})))} \tag{5}$$

$$Share_{2541} = \frac{(a_1+b_{12}*log(p_{2540})+b_{22}*log(p_{2541})+b_{23}*log(p_{2551})-log(texp)*(b_{21}+b_{22}+b_{23})}{1+2*(b_{11}*log(p_{2540})+b_{12}*log(p_{2541})+b_{13}*log(p_{2551})+b_{12}*(log(p_{2540})+log(p_{2541}))+b_{13}(log(p_{2540})+log(p_{2551})))} \tag{6}$$

$$Share_{2551} = \frac{(a_1+b_{31}*log(p_{2540})+b_{32}*log(p_{2541})+b_{33}*log(p_{2551})-log(texp)*(b_{13}+b_{32}+b_{33})}{1+2*(b_{11}*log(p_{2540})+b_{12}*log(p_{2541})+b_{13}*log(p_{2551})+b_{12}*(log(p_{2540})+log(p_{2541}))+b_{13}(log(p_{2540})+log(p_{2551})))} \tag{7}$$

The variables p_{2540}, p_{2541}, and p_{2551} represent the average expenditure per acre burned as a proxy for unit price. With Share_{2540} representing the budget share for BOC 2540, Share_{2541} the budget share for BOC 2541, and Share_{2551} the budget share for BOC 2551. Quantity is represented by *USFS_Acres* and total expenditure is represented by *texp*. This 3 equation system is estimated by iterated seemly unrelated regressions using the *Proc Model* function of SAS 9.2. SAS uses a Gaussian method for its minimization process, and all three equations converged to 0.001, within 8 iterations.

The parameters from equations 5, 6, and 7 are used to calculate the elasticities for the three budget classifications. It should be noted that some of the parameters that are used later to calculate the elasticities are not estimated but are imposed by restrictions placed on the model. These parameters are a_1, b_{11}, b_{22} and b_{33}. Adding up is imposed on a_1 by the following restriction $a_1 = 1 - a_2 - a_3$. Symmetry and homogeneity is imposed by the following restrictions $b_{11} = -(b_{12} + b_{13})$, $b_{22} = -(b_{12} + b_{23})$ and $b_{33} = -(b_{13} + b_{23})$. To test the restrictions a Chi-Square test is used to compare the results between the unrestricted and restricted models. The results indicate that the hypothesis of symmetry cannot be rejected, and that the restrictions are valid.

Data

The expenditure data used in this paper is provided by the Forest Service and consists of 6 years' worth of quarterly data covering 2004 through 2009. Data for 8 Forest Service regions is used, with Forest Service Region 10 being excluded from the data set, giving an initial 182 observations. The expenditure data was inflation adjusted to 2006 constant dollars using the GDP deflator. The Forest Service provided data on 116 Budget Object Codes (BOC); however, most of these represented a small portion of total expenditures. The regression model uses the total expenditures, while the demand system utilizes specific BOCs.

Wildland firefighting consists of many heterogeneous goods with the manner in which resources are employed differing greatly between fires. The Forest Service classifies these expenditures into a few broad categories that mask much of the heterogeneity. Table 2-1 presents the top 15 BOCs in terms of total real expenditures for the 6 years of data. These 15 BOCs represent 99.96% of the total Forest Service expenditures on wildland fire suppressions. Of these 15 only 4 were greater than 1 percent of the total and the top 3 BOCs accounting for 97.93% of total expenditures. The categories representing the largest share of expenditures are BOC 2540: (Contractual Services-Other), BOC 2541: (Flying Contracts), and BOC 2551: (Cooperating State Agencies). These 3 BOCs are the focus of the demand system portion of the paper, and are treated as commodities classes. By treating the budget categories as commodity classes it's possible to examine how consumption of fire suppression resources respond to changes in the average expenditure per acre.

The expenditure data obtained from the Forest Service consisted of monthly figures, but to estimate the demand system the quarterly average expenditure per acre for each of the BOC is need. To create this average the monthly figures are first summed to create a quarterly value and then divided by the number of acres burned each quarter. This provides the quarterly average expenditure per acre, which is used as a proxy for average expenditure per unit of good. This quarterly figure is then used as a price variable. Monthly acres burned are calculated using data from the Incident Management Situation Reports (IMSR) obtained from the National Interagency Coordination Center (NICC) web portal and then summed to obtain the number of acres for the quarter.[iv] The IMSR's provide a rolling year-to-date total that is decomposed to create a monthly variable.[v]

The *drought* variable is the Palmer Drought Severity H Index. Previous studies (Abt et al. 2009) have shown that Drought conditions, and specifically the Palmer Index, can help forecast wildland fire suppression cost. The Palmer Index is weighted based on the amount of national forest land in each region and is also provided by the Forest Service. The Palmer Index uses precipitation and temperatures to create a long-term index for measuring droughts. A 0 reading for the Palmer Index indicates a normal measure with drought conditions receiving a negative value and periods of above average rainfall a positive value (NOAA 2010). For example a reading of negative -4 would be a severe drought. The index has ranges from just below -4 to just above 4. Each year has four Palmer Index readings: the March readings is quarter 1, June readings is quarter 2, September readings is quarter 3, and December readings is quarter 4.

To control for the heavy tail distribution of wildland fires this paper uses 3 different lower bounds to examine the impact of different cut off points on the demand system. The 3 lower bounds used are 1,000, 2,000, and 3,000 acres, and represents the number of acres burned in a quarter instead of a measure for a specific fire. One hindrance common to work on wildland fire expenditures is poor data quality, and this paper is no exception. As already noted this paper relies on data categorized under the Forest Service's Budget Object Code (BOC) system. Gebert et al. (2008) identify several flaws with this class of data: including overly broad categories, periodic changes in how data is collected, and a mismatch between fire activities and the Forest Service region the expenditure is attributed to. In 2007 the Forest Service began tying expenditures to the region where the fire began; replacing a previous system where expenditures were tied to the region providing the resources (Gebert et al. 2008). The limitation of the available data has often been cited as a factor constraining research on wildland fire expenditures (Gebert et al. 2008, Donovan et al. 2004, Schuster et al. 1997).

Analysis

Table 2-2 and 2-3 presents the summary statistics and regression results respectively for equation 1. The results show that the number of acres burned has a quadratic relationship with average expenditures per acre that different Forest Service regions have different expenditures, and that seasonality affects average expenditures per acre. The results also show that drought conditions do not directly affect suppression expenditures. The inclusion of the quadratic functional form for area burned allows for the exploration of the marginal effect of the number of acres burned. The negative sign for acres burned indicate that initially as the number of acres burned increases the average expenditure per acre falls. However at some point this relationship changes and additional area burned leads to high average suppression expenditures as indicated by the square value of acres burned having a positive sign. This inflection point occurs approximately at 485 thousand acres burned in a quarter[vi]. The initial reduction in average expenditure reflects the economies of scale achieved fighting wildland fires; however, in the case of very large wildland fires the need for additional resources leads to a rising average expenditures. It should be noted that such a large volume of fire is an outlier in this dataset with only 4 observations meeting or exceeding the 485 thousand acre threshold.

Region 5, consisting mostly of California, is excluded from the model in order to provide a basis of comparison for the Forest Service regions. Three regions, 1, 2, and 9, have statistically different results compared to Region 5. All regions have a negative coefficient indicating that Region 5 has the highest average expenditure. Dummy variables are used to control for seasonality with the 3rd quarter (July, August and September) being excluded from the model. The results are statistically significant for all 3 quarters included in the model, with all having a negative coefficient. The results show that the 1st quarter (January, February, and March) has the lowest average expenditures, followed by the 4th quarter (October, November, and December). These results reflect the fact that late summer is the height of the fire season and when the Forest Service is faced with the most intense demand for wildland fire suppression services.

The demand system is estimated thrice using an increasingly larger lower bound. Table 2-4 presents the summary statistics for the 1,000 acre lower bound while, Tables 2-5 and 2-6 use 2,000 and 3,000 acres respectively. Using equations 5, 6, and 7 a demand system is estimated using iterated seemingly unrelated regression with the results for the parameter estimates listed in Table 2-7. The parameters for the 3 lower bounds are statistically significant at the 1 percent level and are used calculate the own, cross, and income elasticities are for each lower bound. This results in 27 elasticities being estimated. Table 2-8 presents the notation used for each type of elasticities for each budget category. Table 2-9 groups the mean and standard deviation of the elasticities by lower bound.

The results for own price elasticities are all positive; however, all are within one standard deviation of being negative. Typically own price elasticity has a negative sign reflecting a reduction in demand as prices rise (Nicholson 2005). However, wildland fire expenditures are often made under emergency conditions where containing a fire is of the upmost importance. This creates a situation where resources must be expended to fight the fire. Given this dynamic the results of positive own price elasticity makes intuitive since. For ε_{11}, with the 1,000-acre lower bound, a 1% increase in the average expenditure per acre will result in the Forest Service seeing a 0.25% increase in the consumption of contractual services or BOC 2540. For the 3,000-acre lower bound a 1% increase in average expenditure leads to ε_{11} seeing a 0.15% increase. Flying contracts or BOC 2541 experiences increases of 0.59%, 0.71%, and 0.99%, respectively for the 1,000, 2,000, and 3,000 lower bounds, for a 1% increase in average expenditures. The

Forest Service payments to cooperating state agencies or BOC 2551 see the largest increases for a 1% increase in average expenditure and ε_{33} increases steadily as the lower bound is raised. This could reflect a situation that if state cooperation occurs it tends to occur at a high level, with the Forest Service making substantial transfers.

The cross elasticities of the budget categories allows an examination in how different categories are used to fight wildland fires and provides an indication of whether budget categories are complements or substitutes. Contractual services, or BOC 2540, are complementary with both flight contracts and cooperating state agencies, regardless of the lower bound. The relationship for ε_{23} is negative for the all 3 lower bounds, but the absolute value is very small. This small absolute value and could imply that BOC 2541 and BOC 2551 are independent of each other or the relationship is passing through BOC 2540.

The final type of elasticity estimated is expenditure (income) elasticity, which looks at how consumption changes as total expenditures increase. The expenditure elasticity of BOC 2540 is greater than 1, and positive for all 3 lower bounds. The formal interpretation of this result is that the BOC 2540 is a luxury good and the Forest Service consumes more of as its expenditures increase. A more practical interpretation might be that BOC 2540 plays central role in the Forest Service efforts to suppress wildland fires. BOC 2541 is an inferior good, since its expenditures elasticity is negative for all 3 lower bounds, that is the Forest Service consumes less of it as expenditures increase. BOC 2551 is also an inferior good since ε_{13} is negative for all lower bounds. This means the Forest Service reduces consumption of flight contracts and cooperating state agencies as expenditures increase. This could mean the Forest Service relies less on both budget categories as the wildland fire expenditure increases, or it could mean that BOC 2540 is more responsive to changes in the demand for fire suppression. For aircraft supply might reflect a longer budgeting and forecasting process that is not impacted by quarterly fluctuations in expenditures. A possible interpretation for BOC 2551 is that if the Forest Service is making large expenditures on wildland fire suppression then the Forest Service is fighting fire on its own land and is not cooperating with an outside state agency, which requires fewer transfers.

Conclusions and Discussion

In this paper we found that the number acres burned in a quarter impacts the average expenditures for fire suppression. The semi-log model shows that initially as the area burned increases the average expenditures fall, but for very large fires the average expenditure increase. These large fires were exceedingly rare in the data set. Of the 175 observations only 4 exceeds the 485 thousand acres burned in a quarter that leads to rising average expenditure for wildland fire suppression. Only during the most active periods of wildland fire are the Forest Service resources so strained that the economies of scale associated with firefighting outweighed by the need to rapidly bring more resources to bear.

Following the regression model a demand system is estimated to calculate the elasticities between various BOCs. This is accomplished by treating different budget categories as commodities classes. The results for this system show that general contracting services are central to the Forest Service wildland firefighting efforts and that BOC 2540 category is complementary to both flight contracting and payments to cooperating state agencies. It appears that as more resources are spent on wildfire suppression the more important general contracting becomes.

The results from this study provide a foundation for future work on the elasticities for different budget categories. As better data becomes available from data collection changes already adopted by the Forest Service the results should become more robust. Specifically this applies to the 2007 change tying the expenditures to the region where the fire occurs. Some other areas where data collection could be improved is having Region level data that ties expenditures directly to specific to fires, and less broad categories for the 3 most important BOCs. Understanding the interaction between different budget classes is an important area of wildland fire research, as it will aid the Forest Service and other government agencies in maximizing taxpayer resources. The results also provided guidance on where the Forest Service can focus within its budget, specifically general contracting, to achieve greater savings to taxpayers.

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Figures

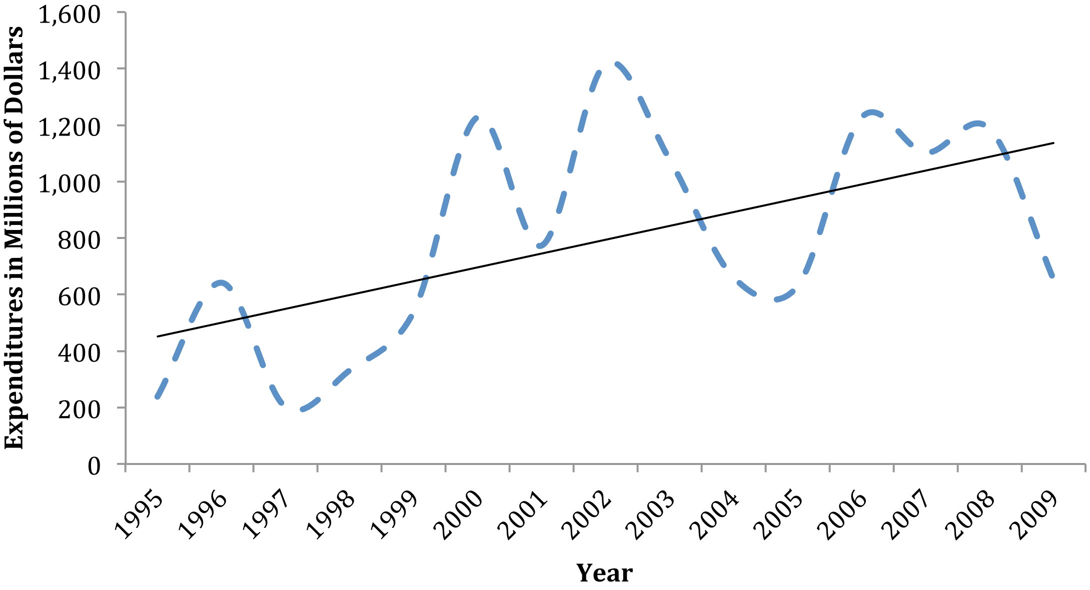

Figure 2-1: Yearly Real Expenditures on Wildland Fire Suppression in 2006 Dollars.

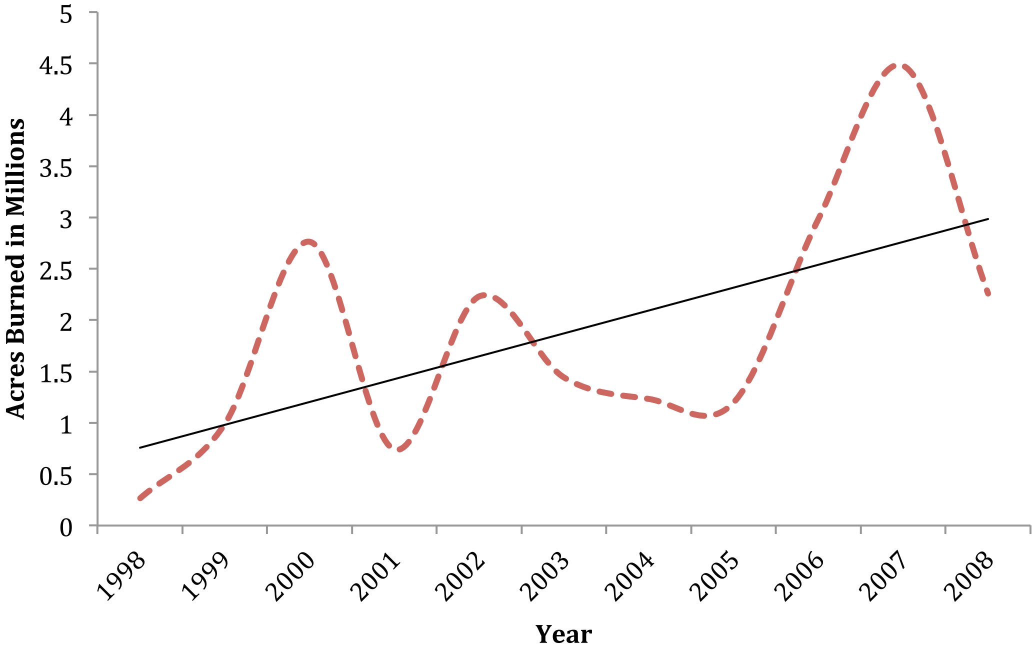

Figure 2-2: Yearly Acres Burned.

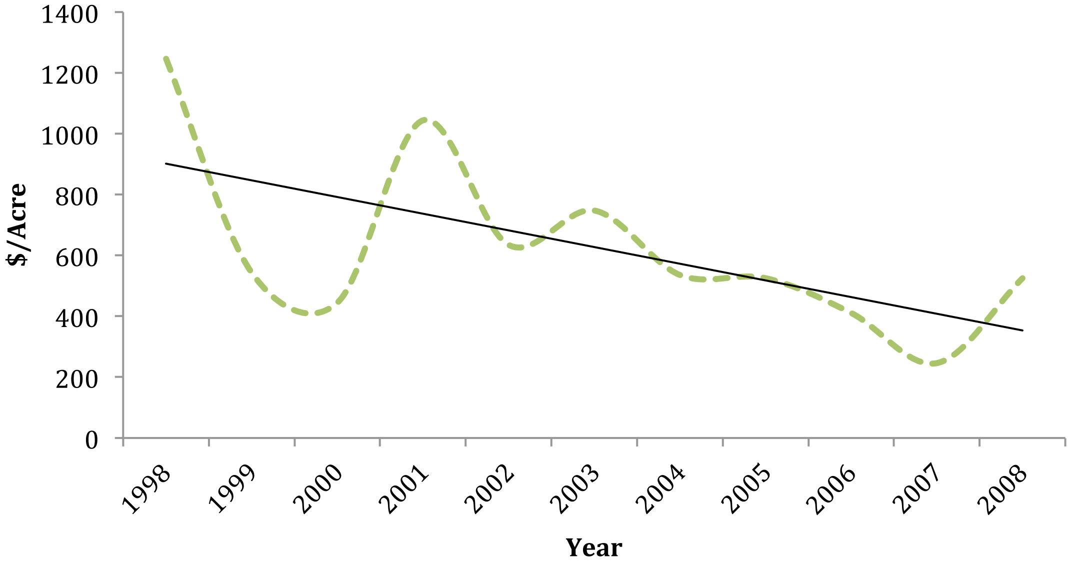

Figure 2-3: Yearly Real Expenditures Per Acre on Wildland Fire Suppression in 2006 Dollars.

Tables

Table 2-1: Top 15 Budget Object Codes.

Budget Object Code	Description	Percent of Total
2111	Common Carrier-Domestic	1.327%
2222	Freight, Express, Drayage, and Other Local Transportation	0.089%
2342	Building Rental-non-GAS	0.004%
2510	Contractual Services Performed by Other Federal Agencies	0.020%
2540	Contractual Services-Other	42.045%
2541	Flying Contracts	33.331%
2550	Cooperative Agreements	0.025%
2551	Cooperating State Agencies	22.549%
2559	Agreements Other	0.305%
2570	Miscellaneous Services	0.025%
2616	Aviation Fuel	0.005%
2670	Supplies and Materials-General	0.012%
4220	Indemnities	0.210%
4221	Regular Indemnity	0.005%
4230	Litigation Fees and Awards	0.007%

Table 2-2: Regression Model Summary Statistics.

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Average Expenditure Per Acre	182	140,062.60	859,173.50	0	8,764,138.00
USFS Acres ‘000	184	51.22	127.45	0	955.67
(USFS Acres ‘000)^2	184	18777.73	91,844.08	0	913,301.40
Drought	184	-0.69	1.78	-4.47	3.88

Table 2-3: Regression Results for Natural Log of the Average Expenditure.

Variable	Coefficient	Standard Error
USFS Acres '000	-0.03***	$4.92\text{x}10^{-3}$
(USFS Acres '000)^2	$3.09\text{x}10^{-5}$***	$6.68\text{x}10^{-9}$
Drought	-0.07	0.14
Region 1	-1.04***	0.32
Region 2	-1.08***	0.32
Region 3	-0.45	0.29
Region 4	-0.29	0.28
Region 6	-0.43	0.34
Region 8	-0.53	0.39
Region 9	-1.19***	0.39
Q1	-4.21***	0.79
Q2	-2.13***	0.60
Q4	-2.98***	0.61
Constant	-0.35	0.81
R-Squared		0.467
N		175

Table 2-4: Summary Statistics USFS Acres Burned >1,000.

Variable	Description	Mean	Standard Deviation
p_{2540}	Average Expenditures on BOC2540 per USFS acre burned	687.23	2,062.39
p_{2541}	Average Expenditures on BOC2541 per USFS acre burned	778.78	2,300.44
p_{2551}	Average Expenditures on BOC2551 per USFS acre burned	336.98	832.69
Share_{2540}	Budget Share of BOC 2540	0.28	0.17
Share_{2541}	Budget Share of BOC 2541	0.47	0.23
Share_{2551}	Budget Share of BOC 2551	0.25	0.21
TEXP	Total Expenditures	$15,746,286.46	$35,125,812.42
USFS_Acres	Acres Burned each quarter on USFS land	74,130.75	161,046.17
		N	91

Table 2-5: Summary Statistics USFS Acres Burned >2,000.

Variable	Description	Mean	Standard Deviation
p_{2540}	Average Expenditures on BOC2540 per USFS acre burned	608.34	1881.50
p_{2541}	Average Expenditures on BOC2541 per USFS acre burned	603.19	1575.27
p_{2551}	Average Expenditures on BOC2551 per USFS acre burned	264.10	651.11
Share_{2540}	Budget Share of BOC 2540	0.28	0.18
Share_{2541}	Budget Share of BOC 2541	0.47	0.23
Share_{2551}	Budget Share of BOC 2551	0.25	0.20
TEXP	Total Expenditures	16,517,179.38	36,335,225.88
USFS_Acres	Acres Burned each quarter on USFS land	80,198.96	166,249.08
		N	84

Table 2-6: Summary Statistics USFS Acres Burned >3,000.

Variable	Description	Mean	Standard Deviation
p_{2540}	Average Expenditures on BOC2540 per USFS acre burned	540.19	1900.36
p_{2541}	Average Expenditures on BOC2541 per USFS acre burned	456.32	1302.40
p_{2551}	Average Expenditures on BOC2551 per USFS acre burned	200.97	588.26
Share_{2540}	Budget Share of BOC 2540	0.28	0.18
Share_{2541}	Budget Share of BOC 2541	0.48	0.23
Share_{2551}	Budget Share of BOC 2551	0.24	0.20
TEXP	Total Expenditures	17,251,070.10	37,997,641.60
USFS_Acres	Acres Burned each quarter on USFS land	88,378.28	172,844.02
		N	76

Table 2-7: Iterated similarly unrelated regression results.

USFS Acres Burned Parameter	>1,000 Coefficient (Standard Error)	>2,000 Coefficient (Standard Error)	>3,000 Coefficient (Standard Error)
a2	0.44***	0.44***	0.45***
	(0.02)	(0.02)	(0.02)
a3	0.27***	0.27***	0.27***
	(0.02)	(0.02)	(0.02)
b12	-0.07***	-0.07***	-0.08***
	$(1.52\text{x}10^{-3})$	$(1.73\text{x}10^{-3})$	$(1.79\text{x}10^{-3})$
b13	-0.05***	-0.07***	-0.06***
	$(1.38\text{x}10^{-3})$	$(1.16\text{x}10^{-3})$	$(1.72\text{x}10^{-3})$
b23	$-3.54\text{x}10^{-6}$***	$-4.53\text{x}10^{-6***}$	$-5.32\text{x}10^{-6***}$
	$(5.86\text{x}10^{-7})$	$(7.61\text{x}10^{-7})$	$(9.17\text{x}10^{-7})$
R-Squared for Each Equation			
Share_{2540}	0.72	0.72	0.75
Share_{2541}	0.51	0.54	0.59
Share_{2551}	0.48	0.48	0.50

Table 2-8: Description of elasticities.

Elasticity	Description
ε_{11}	Own price elasticity for BOC 2540
ε_{22}	Own price elasticity for BOC 2541
ε_{33}	Own price elasticity for BOC 2551
ε_{12}	Cross price elasticity between BOC 2540 and BOC 2541
ε_{13}	Cross price elasticity between BOC 2540 and BOC 2551
ε_{23}	Cross price elasticity between BOC 2541 and BOC 2551
ε_{1E}	Expenditure elasticity for BOC 2540
ε_{2E}	Expenditure elasticity for BOC 2540
ε_{3E}	Expenditure elasticity for BOC 2540

Table 2-9: Estimated Elasticities.

Elasticity	Mean of the Elasticity	Standard Deviation
Indirect Translog System with greater than 1,000 acres burned in a quarter		
ε_{11}	0.25	3.20
ε_{22}	0.59	11.57
ε_{33}	0.66	9.87
ε_{12}	-0.58	1.83
ε_{13}	-0.41	1.37
ε_{23}	-7.69×10^{-5}	5.61×10^{-4}
ε_{1E}	1.13	4.84×10^{-6}
ε_{2E}	-0.53	11.57
ε_{3E}	-0.58	9.87
Indirect Translog System with greater than 2,000 acres burned in a quarter		
ε_{11}	0.29	3.35
ε_{22}	0.71	12.07
ε_{33}	0.73	10.38
ε_{12}	-0.61	1.90
ε_{13}	-0.43	1.44
ε_{23}	-1.06×10^{-4}	7.47×10^{-4}
ε_{1E}	1.13	6.14×10^{-6}
ε_{2E}	-0.64	12.06
ε_{3E}	-0.66	10.38
Indirect Translog System with greater than 3,000 acres burned in a quarter		
ε_{11}	0.15	2.38
ε_{22}	0.99	13.50
ε_{33}	1.14	12.35
ε_{12}	-0.49	1.32
ε_{13}	-0.37	1.06
ε_{23}	-1.36×10^{-4}	-9.23×10^{-4}
ε_{1E}	1.14	7.66×10^{-6}
ε_{2E}	-0.93	13.50
ε_{3E}	-1.06	12.35

Chapter 3 – Optimal Prescribed Burning Polices Under Carbon Pricing Regimes

Abstract

In this paper we use a dynamic optimization model to examine how incorporating a monetary value for carbon emitted from prescribed burning, and wildland fire alter the optimal level of prescribed burning done in advance of fire season. Both prescribed burning and wildland fires result in a release of a significant amount of carbon dioxide both at the time the fire takes place, and following the fire as biomass decays. Eventually the forest starts to sequestrator carbon as the biomass is regenerated. Our results show the desirability of prescribed burning as a fire management tool is reduced when the value of the carbon released is incorporated into the cost benefit analysis of prescribed burning management regimes.

Introduction

In this paper we attempt to incorporate a monetary value for carbon that is released due to both prescribed burning and wildland fires into the decision on the optimal level of prescribed burning to conduct. Recently there have been calls to include the value of non-market goods in wildland fire management decisions (Venn and Calkin 2011) and wildland fires are an important emitter of greenhouse gases with wildland fires releasing between 25% and 31% as much carbon dioxide (CO_2) as industrial processes and fossil fuels (Raupach et al. 2007). Besides CO_2 wildland fires release methane (CH_4) and carbon monoxide (CO), and represent a disturbance to the carbon cycle (Flannigan et al. 2009). In Canada the amount of carbon released during a year of high fire activity can equal the amount released from the use of fossil fuels (Amiro et al. 2001). In the United States Clinton et al. (2006) found that in October 2003 wildland fires in Southern California released over 6 million tons of carbon from more than 235,267 ha burned.

The CO_2 released during a fire is only one phase of the carbon cycle. Following a fire the decay of organic matter continues to release carbon. The rate of decay depends on many local variables, such as microorganism and organic matter present, as well as environmental factors, such as climate (Flannigan et al. 2009). Also following a fire, conditions are often favorable for vegetation to grow leading to increasing carbon sequestration (Amiro 2001, Flannigan et al. 2009). This creates a situation where a forest is a source of carbon during and immediately following a fire, but the forest will switch to carbon sequestration as more carbon is sequestered than is being released from decay.

The Economics of Fire Management

As early as 1976 Simard (1976) discussed how the externalities of wildland fires affected individuals who were not owners or users of a forest and supported a view that market processes often captured the cost of the externalities. The externalities Simard (1976) discussed were local occurrences: flood control, smoke, and the destruction of improvements. With rising levels of atmospheric CO_2 being a central contributor to global warming the release of carbon due to wildland fires is becoming a global problem. By incorporating a price for both released and sequestered carbon into the analysis it is possible to better estimate the appropriate level of prescribed burning that best reflects the true cost of alternative fire management regimes.

Simard (1976) argued that all fires have a positive initial Net Value Change (NVC) that becomes negative as fire intensity increases; this creates a minimization problem that has two distinct parts. The cost of the fire (C), which includes suppression and pre-suppression expenditures and the net value change, which is the sum of the damages caused by the fire minus the benefits received from the fire. The C+NVC function is (Rideout and Omi 1990):

$$MIN: C + NVC = W^p P + W^s S + NVC(P, S) \tag{1}$$

Where P and S denote pre-suppression and suppression activities and W denotes the cost of those activities.

The NVC function incorporates the positive benefit fire can provided to a landscape in the earlier phases of a fire. At some inflection point the damage from the fire equals the benefits from the fire or when the fire's marginal net value change equals zero. This point is the optimal point at which the fire should be extinguished. Identifying a fire's NVC is difficult since many of the benefits and cost are not clearly identified and do not have market determined prices.

Proposed Prescribed Burning Policy Model

The dynamic optimization model used in this paper estimates the impact of various levels of carbon pricing on prescribed burning policies. For the model we assume that there are several state variables and that the level of prescribed burning is the decision variable. The model also requires some assumptions on the timing of events. It is assumed that the prescribed burning occurs at the start of a given period, and that the wildfire, termed fire event, occurs at the end each period. The length of each period is one year, and the decision regarding the level of prescribed burning to be conducted must be decided before the drought conditions are known. The observable factors are the pervious period's level of prescribed burning and drought conditions.

The dynamic optimization model is solved for each region and using carbon prices that range from zero to $10 per ton and the results are presented in Tables 3-5 through 3-10. The high end of the tax range comes from proposed legislation in congress, specifically the Save our Climate Act of 2011, which purposes to implement a $10 per ton tax in the United States (Stark 2011). The lower intermediate values represent possible compromise values for the carbon tax. The legislation does not propose taxing forest fires, but does include a provision for taxing biomass used for power generation.

Decision Variable

Prescribed burning is an effective fire management tool that can reduce the risk of large wildland fires (Butry 2009, Mercer et al 2007). This is accomplished by reducing the risk of crown fires, and breaking up landscapes to improve the abilities of firefighters to quickly contain wildland fire. The current year's level of prescribed burning is a treated as the decision in this model. With an index of the previous year's level of prescribed burning becoming a discrete state variable. The index consists of nx decision alternatives with the model being solved for nx equals 20.

To construct the index the average amount of prescribed burning in each Forest Service region is doubled to create a maximum value. The maximum value is then divided by nx - 1 to calculate the incremental value of prescribed burning. Then starting with the maximum value the incremental value is subtracted from the proceeding decision alternative until the index is populated with nx observations. One aspect of this approach is that the minimum value is not zero, but is actually equal to the incremental value of prescribed burning. This has 2 implications. The first is that some minimum level of prescribed burning must be conducted. The second is that mathematical complications arising from attempting to take the natural log of zero are avoided.

State Variables

The state variables describe the conditions at a particular moment in time and represent the minimum information needed to compute the decision and transition functions (Powell 2011). The state variable provides the historic information that can be used to model the system being examined. State variable can take on discrete, continuous, or relative values (Lemebersky and Johnson 1975). Powell (2011) describes three types of states: physical, information, and belief/knowledge with the three building on each other.

This paper uses two information state variables. The first state variable is the drought conditions for each Forest Service region and is determined by a stochastic process. The second is the level of prescribed burning from the previous year and is deterministic. Drought conditions have been shown to be useful in forecasting the severity of future fire seasons (Abt et al 2009). This paper uses data from the 6 Forest Service regions in the western United States covering the 11-year period from 1998 to 2008. The Palmer Drought Severity Index uses precipitation and temperatures to create a long-term index for measuring droughts. The Palmer Drought Index is weighted based on the amount of national forest land in each region and is provided by the Forest Service.

A zero reading for the Palmer Drought Index indicates a normal measure with drought conditions receiving a negative value and periods of above average rainfall receiving a positive value (NOAA 2010). To create a value that falls between zero and 1, the Palmer Drought Index in increased by 5, than divided by 10. This creates a variable with a range of 0.04 to 0.78 where a value closer to zero represents drought conditions and a value closer to 1 represents above average rainfall. The summary statistics are reported in Table 3-1.

State Transition Probabilities

This paper assumes that drought conditions follow a first-order autoregressive pattern that can be estimated according to the following equation:

$$DI_t = \sum_j \gamma_j \, Region_j + \beta_1 DI_{t-1} + \varepsilon_t \tag{2}$$

Where:

$Region_j$ is a dummy variable for the Forest Service region j (j=1, 2, 3, 4, 5, and 6)

DI_t is the drought measure for period t

All γ and β are coefficients, and ε_t is a residual.

The constant term is suppressed to allow all 6 regions to be included. The results of the regression are presented in Table 3-2 and are used to calculate the probabilities of transitioning from a drought condition in year t-1 to year t. The transition probabilities are then used in the recursive equation.

Prescribed Burning Decisions and Suppression Cost

To determine the effects of various prescribed burning regimes an instrumental variable model is estimated. The first regression estimates the elasticities between prescribed burning regimes and acres burned. The first regression results are then used to estimate the elasticities between the fire size and the fire suppression cost. A limited information maximum likelihood

(LIML) estimator is used since it has better finite sample properties compared to the 2SLS estimator (Cameron and Trivedi 2009).

The instrumental variable model is estimated using data from the western Forest Service regions for a total of 66 observations. The level of prescribed burning for both the current and the previous year are included in the model. This is done since prescribed burning has been found to have a persistent effect on landscapes following application (Butry 2009). Previous work examining prescribed burning in Florida has found that the beneficial effects of prescribed burning can persist for up to 3 years. The model presented here found that following the benefit of prescribed burning in year 1, year 2 saw increased the risk of wildland fire. This difference in results is most likely due to use of different spatial scales and geographic regions.

In addition to prescribed burning the drought conditions for the current year are included in the first-stage. The constant term is also suppressed so all 6 regions can be included in the model as dummy terms. The functional form of the instrumental variable model is listed in equation 3 and 4 and the results are presented in Tables 3-2 and 3-3.

First-Stage Regression:

$$\begin{aligned} (3) \quad & ln(USFS\ Acres\ Burned/Forestland\ Area)_t \\ & = \beta_1 ln(Acres\ Treated\ with\ Prescribed\ Fires/Forestland\ Area)_t \\ & + \beta_2 ln(Acres\ Treated\ with\ Prescribed\ Fires/Forestland\ Area)_{t-1} \\ & + \beta_3 DI_t + \sum_j \gamma_j\ Region_j + \varepsilon_t \end{aligned}$$

Second-Stage Regression:

$$\begin{aligned} (4) \quad & ln(Real\ Suppression\ Exp)_t \\ & = \beta_1 ln(USFS\ Acres\ \widehat{Burned}/Forestland\ Area)_t + \sum_j \gamma_j\ Region_j \\ & + \omega_t \end{aligned}$$

Where:

$ln(Real\ Suppression\ Exp)$ is the natural log of USFS real fire suppression expenditures.

$ln(USFS\ Acres\ Burned/Forestland\ Area)$ is the natural log for the ratio of USFS acres burned to forestland area in the region.

$ln(Acres\ Treated\ with\ Prescribed\ Fires/Forestland\ Area)$ is the natural log for the ratio of acres treated with prescribed fires by the Forest Service to forestland area in the region.

DI is a dummy variable for drought conditions throughout the year.

$Region_j$ is a dummy variable for the Forest Service region j (j=1, 2, 3, 4, 5, and 6)

All β and γ are coefficients

ε_t and ω_t are residuals .

In the first-stage regression both the total acres burned and the amount of land treated with prescribed burning is normalized by amount of the total acres of timberland and reserve forest in each region, which we term forestland[vii]. The natural log is then used in the regression model. Using the instrumented variables from first-stage the second-stage is estimated in order to observe the impact of area burned on the cost of fire suppression. By taking the natural log of total suppression cost it is possible to read the results as elasticities where $B_i = \left(\frac{\partial y}{\partial x_i}\right)\left(\frac{x_i}{y}\right)$ allowing for the estimation of the suppression cost associated with different levels of fire activity.

Rewards

The reward is the net value that accompanies a given prescribed burning regime and is the value produced by a given combination of state and decision variables. The reward is the sum of the cost for both pre-suppression and suppression activities and the net value change attributed to both activities. The forest economic profession has written a great deal about how cap and trade schemes would affect optimal timber rotation lengths and the supply and demand for carbon sequestration services (Murray 2003; Sohngen and Mendelsohn 2003). To adapt this work to prescribed burning several assumptions are imposed on the dynamic optimization problem. These assumptions are that the forest is in a steady state at the time of the fire event, and that the fire event results in a large release of carbon, followed by smaller releases due to decay of vegetation, and then an eventual carbon sequestration.

The estimate for the amount of carbon released due to prescribed burning and fire come from North and Hurteau (2011), which examined at carbon released from both plots treated with prescribed burning and untreated plots for mixed-conifer forest in California. North and Hurteau (2011) found that prescribed burning treatments released 50.3 Mg C ha^{-1} at time of treatment, and 29.7 Mg C ha^{-1} at the fire event and untreated plots released 67.8 Mg C ha^{-1} at time of the fire events. Plots treated with prescribed burning see a higher carbon release when the treatment and fire events are combined; 80 Mg C ha^{-1} for treated areas verses 67.8 Mg C ha^{-1} for untreated. However, areas treated with prescribed burning have lower carbon releases following the fire due to a lower rate of biomass decay. North and Hurteau (2011) state that decay could lead to a doubling of the carbon released from the untreated sites, and places an upper bound of 128.5 Mg C ha^{-1} on this release, while also citing earlier work (Harmon et al., 1987) that places a 14 year half-life on this decay.

To model the carbon cycle it is assumed that in the first year following the fire event a forest would release carbon at a rate of 14 Mg C ha^{-1} for untreated area and 5 Mg C ha^{-1} for treated area, the second year would see 12 Mg C ha^{-1} for untreated area and 4 Mg C ha^{-1} for treated area, and the third year would see 10 Mg C ha^{-1} for untreated area and 3 Mg C ha^{-1} for treated area. Following the 3 years of decay it is assumed that both treated and untreated areas will see increased carbon sequestration for 5 years while the forest returns to a steady state. While North and Hurteau (2011) use tons per hectares we convert their measurements to tons per acre to make the comparison with prescribed burning regimes consistent. The value of the carbon releases can be thought of as a stream of cash flows that need to be discounted to a net present value at the time of the fire event. The net present value calculation for cycle is:

$$\begin{aligned}(5)\quad NPV\ C = \; & C_{RX,1}(1.04)^{1} + C_{RX,1} + C_{F,1} + C_{RX,2}(1.04)^{-1} + C_{F,2}(1.04)^{-1} \\ & + C_{RX,3}(1.04)^{-2} + C_{F,3}(1.04)^{-2} + C_{RX,4}(1.04)^{-3} + C_{F,4}(1.04)^{-3} \\ & - \left[C_{RX,5-10}\left(\frac{(1.04)^{5}-1}{.04(1.04)^{5}}\right)\right](1.04)^{-4} - \left[C_{F,5-10}\left(\frac{(1.04)^{5}-1}{.04(1.04)^{5}}\right)\right](1.04)^{-4}\end{aligned}$$

Where:

$C_{RX,i}$ equals the pre-discounted value of the carbon released due to prescribed burning decisions during year i.

$C_{F,i}$ equals the pre-discounted value of the carbon released due to the fire event during year i.

For discounting purposes it is assumed that the prescribed burning is conducted at the start of the year and the fire events occur at the end of the year. For the fire event and for the 3 years following the carbon value are positive. With a positive value representing the need to increase the cost associated with prescribed burning decisions and the fire event due to the social cost of carbon being incorporated into management decisions. Starting in year 5 the value is negative as the forest begins to sequester more carbon than is released through decay. The values of all carbon releases are discounted to the fire event. The Office of Management and Budget calendar year 2012 7-year discount rate of 2.5% is used (Lew 2012).

As mentioned above fire management decisions are often made with the intention of minimizing the C +NVC associated with various decision outcomes. This is important in the construction of the recursive equation, which will select the lowest cost reward as opposed to the highest profit as in a profit maximizing dynamic program. In both cases the reward depends on the state variables and the transition probabilities. This paper assumes the reward is affected by 3 factors: the cost of the fire suppression, the cost of conducting prescribed burning treatments, and the hypothetical cost of the carbon released.

The cost of fire suppression is estimated according to equation 3 and 4. For each level of the state and decision index a cost of fire suppression is calculated. The cost of the prescribed burning comes from the average cost of prescribed burning treatment as estimated by Cleaves et al. (2000) and updated to 2004 dollars. To reflect the elasticity of supply for prescribed burning services the cost of prescribed burning treatments is increased in 20 incremental steps, corresponding to the incremental steps in the state and decision variables. This creates a range from 75% of the average cost of prescribed burning treatment, as estimated by Cleaves et al. (2000), at the low end to a 125% of the average cost at the high end.

Optimal Prescribed Burning Policies

The dynamic program determines the lowest cost level of prescribed burning based on a combination of the previous year's drought conditions and level prescribed burning conducted.

$$V_t(Rx_t) = \min_{Rx_t} \mathbb{E}[Cost(Rx_t, Rx_{t-1}, DI_{t-1}] \tag{6}$$

Where:

Rx_t is the level of prescribed burning during period t

Rx_{t-1} is the level of prescribed burning during period t-1

DI_{t-1} is the drought conditions during period t-1.

$V_t(Rx_t)$ is the optimal level of prescribed burning.

A solution is characterized beginning in the last period, and solving the recursive equation backwards in a stepwise fashion. The model uses the index of prescribed burning as the decision variable in determining the level with the lowest total cost. The total cost consists of the cost of suppression, the cost of prescribed burning treatments, and net present value of the carbon released. The cost of suppression is determined by completing equations 3 and 4 for the different levels of prescribed burning. The cost of prescribed burning treatment is determined by multiply the cost prescribed burning treatments by the number of acres treated. The NPV of carbon released is determined by completing equation 5 for level of prescribed burning and the expected level of acres burned from equation 3 for a given level of prescribed burning. Since equation 3 is calculated using the current period drought index, and only the previous period drought index is known the cost are calculated in equation 5 as expected value based off of transition probabilities calculated from equation 2. The process of determining the optimal level of prescribed burning is repeated for each Forest Service region and for different levels of carbon prices.

Tables 3-5 through 3-10 presents the optimal level of prescribed burning given different carbon values and drought conditions. For comparison with current policy the each regions average amount of prescribed burning for 1998 to 2008 is included in each table. Carbon value set to zero to match current policy and then the value increases in \$2 increments from zero to \$10 a ton. The results from the dynamic optimization problem indicate that 2 regions, Region 1 and

6, should conduct less prescribed burning than their current average. For the other regions, Regions 2, 3, 4, and 5, the results indicate that the level of prescribed burning should be increased from the current averages. A possible explanation for this result is that the model does not fully capture regional differences concerning the acceptability of the use of prescribed burning as part of a fuel management regime.

The results indicate that as the price of carbon increases the level of prescribed burning conducted should be scaled back. Comparing the estimated results for zero and \$10 per ton price using the most severe drought conditions for each region shows that all regions included in the model experience a reduction in the optimal amount of prescribed burning compared to the zero carbon price scenario. Region 2 and 4 see the largest reduction in the optimal level going from 48,256 acres with a zero carbon price verses 35,095 acres for a \$10 per ton price or a reduction of 27%. Region 1 and 3 see reductions of 13%, and 9%. When the most severe drought are used conditions Regions 5 and 6 do not see a reduction; however, both see a reduction in the optimal level of prescribed burning when drought conditions are less severe.

Conclusion

In this paper dynamic programming is used to pull together several different lines of research to model how different levels of carbon pricing affect the optimal level of prescribed burning. By increasing the price of carbon the model indicates that all Forest Service regions should modestly decrease the level of prescribed burning. These results largely reflect the timing of the carbon releases in the model. Both prescribed burning and wildland fires release carbon into the atmosphere that is later recaptured through biomass regeneration with the carbon stock in the forest assumed to return to a steady state. With a constant price for carbon and a return to a steady state the timing of the carbon streams greatly influence the value of reward.

Sohngen and Mendelsohn (2003) point out the raising levels of atmospheric CO_2 could lead to a raising carbon price. Under such a scenario the carbon that is later sequestrated would be more valuable than carbon released earlier due to the fire and prescribed burning. Another consideration is that the data used in this paper is estimated using several Forest Service regions and the beneficial effects of prescribed burning is limited to a single year. This is in contrast to Butry (2009) where prescribed burning in Florida has a positive benefit that can endure for up to 3 years. Both a rising price of carbon and a longer lasting benefit to prescribed burning could justify greater levels of prescribed burning than the results estimated here.

At higher carbon prices the desirability of prescribed burning treatments fall due to the front-loading of the carbon releases and hence costs. While the specific assumptions of the model will alter the results; the fact that prescribed burning regimes release carbon early and quickly in the carbon cycle creates a significant negative hurdle for prescribed burning regimes to overcome. At higher prices this large initial release of carbon dampens the desirability of prescribed burning, and will favor fuel management regimes that have smaller initial releases of carbon.

Currently the United States has not implemented carbon pricing, nor does Congress appear likely to adopt a regime soon. The Save Our Climate Act of 2011 only has 10 co-sponsors, which can be taken as a proxy for the low level of political support for the implementation of a nationwide carbon tax. However, incorporating the social cost of carbon into optimal decision making is a small step that can be accomplished by government agencies that could lead to lower carbon emissions. Our results indicate that if Forest Service incorporates the price of carbon into management decisions the optimal amount of prescribed burning is reduced.

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Tables

Table 3-1: Summary Statistics.

	Average Drought Conditions	Prescribed Burning (Average Acres)	Average Per Acre Prescribed Burning Cost
Region 1	0.29	43,941	$197.81
Region 2	0.39	41,675	$64.46
Region 3	0.37	87,576	$67.29
Region 4	0.37	44,382	$112.74
Region 5	0.40	44,507	$423.39
Region 6	0.32	67,322	$231.44

Table 3-2: Regression Results for Equation 2.

Variable	Coefficient	Standard Error
Lagged PDSI	0.31***	0.10
Region 1	0.19***	0.06
Region 2	0.26***	0.07
Region 3	0.25***	0.07
Region 4	0.24***	0.07
Region 5	0.26***	0.07
Region 6	0.21***	0.07
	N	60
	R-Squared	0.85

Table 3-3: First-Stage Regression For The Instrumental variable Model.

Dependent Variable	Log(USFS Acres Burned/Forestland Area)
	Coefficient (Standard Error)
Log(Acres Treated with Prescribed Fires/Forestland Area)	-0.84**
	(0.39)
Lagged log(Acres Treated with Prescribed Fires/Forestland	0.83**
	0.39
DI	-0.48***
	(0.22)
Region 1	-6.22
	(4.25)
Region 2	-6.47
	(4.27)
Region 3	-5.75
	(3.78)
Region 4	-5.65
	(4.37)
Region 5	-4.86
	(4.31)
Region 6	-6.60
	(4.35)
N	60
R^2	0.97
Partial R^2	0.96
F(9, 57)	255.21***

Note: *** is 1%, ** is 5%, * is 10%, and levels of statistical significance.

Table 3-4: Second-Stage Regression For The Instrumental variable Model.

Dependent Variable	Log(Real Suppression Expenditures)
	Coefficient (Standard Error)
Log(USFS Acres Burned/Forestland Area)	0.71***
	(0.14)
Region 1	22.12***
	(0.80)
Region 2	21.60***
	(0.86)
Region 3	21.95***
	(0.78)
Region 4	21.83***
	(0.78)
Region 5	22.67***
	(0.67)
Region 6	23.02***
	(0.89)
N	60

Note: *** is 1%, ** is 5%, and * is 10%, and levels of statistical significance.

Table 3-5: Results of the Dynamic Program for Forest Service Region 1.

		Carbon Rent				
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	37,003	37,003	37,003	37,003	37,003	32,378
0.08	37,003	37,003	37,003	37,003	32,378	32,378
0.12	37,003	37,003	37,003	37,003	32,378	32,378
0.16	37,003	37,003	37,003	37,003	32,378	32,378
0.20	37,003	37,003	37,003	32,378	32,378	32,378
0.24	37,003	37,003	37,003	32,378	32,378	32,378
0.27	37,003	37,003	32,378	32,378	32,378	32,378
0.31	37,003	37,003	32,378	32,378	32,378	32,378
0.35	37,003	37,003	32,378	32,378	32,378	32,378
0.39	37,003	32,378	32,378	32,378	32,378	32,378
0.43	37,003	32,378	32,378	32,378	32,378	32,378
0.47	37,003	32,378	32,378	32,378	32,378	32,378
0.51	37,003	32,378	32,378	32,378	32,378	32,378
0.55	32,378	32,378	32,378	32,378	32,378	32,378
0.58	32,378	32,378	32,378	32,378	32,378	32,378
0.62	32,378	32,378	32,378	32,378	32,378	32,378
0.66	32,378	32,378	32,378	32,378	32,378	32,378
0.70	32,378	32,378	32,378	32,378	32,378	32,378
0.74	32,378	32,378	32,378	32,378	32,378	32,378
0.78	32,378	32,378	32,378	32,378	32,378	27,752
Current Prescribed Burning Average						43,941

Table 3-6: Results of the Dynamic Program for Forest Service Region 2.

		Carbon Rent				
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	48,256	43,869	39,482	39,482	39,482	35,095
0.08	48,256	43,869	39,482	39,482	35,095	35,095
0.12	48,256	43,869	39,482	39,482	35,095	35,095
0.16	48,256	43,869	39,482	39,482	35,095	35,095
0.20	43,869	43,869	39,482	39,482	35,095	35,095
0.24	43,869	43,869	39,482	39,482	35,095	35,095
0.27	43,869	43,869	39,482	39,482	35,095	35,095
0.31	43,869	43,869	39,482	39,482	35,095	35,095
0.35	43,869	39,482	39,482	35,095	35,095	35,095
0.39	43,869	39,482	39,482	35,095	35,095	35,095
0.43	43,869	39,482	39,482	35,095	35,095	35,095
0.47	43,869	39,482	39,482	35,095	35,095	35,095
0.51	43,869	39,482	39,482	35,095	35,095	30,708
0.55	43,869	39,482	39,482	35,095	35,095	30,708
0.58	43,869	39,482	39,482	35,095	35,095	30,708
0.62	43,869	39,482	39,482	35,095	35,095	30,708
0.66	43,869	39,482	35,095	35,095	35,095	30,708
0.70	43,869	39,482	35,095	35,095	35,095	30,708
0.74	43,869	39,482	35,095	35,095	30,708	30,708
0.78	39,482	39,482	35,095	35,095	30,708	30,708
Current Prescribed Burning Average						41,675

Table 3-7: Results of the Dynamic Program for Forest Service Region 3.

		Carbon Rent				
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	101,403	92,185	92,185	82,966	82,966	73,748
0.08	101,403	92,185	82,966	82,966	82,966	73,748
0.12	101,403	92,185	82,966	82,966	82,966	73,748
0.16	101,403	92,185	82,966	82,966	73,748	73,748
0.20	92,185	92,185	82,966	82,966	73,748	73,748
0.24	92,185	92,185	82,966	82,966	73,748	73,748
0.27	92,185	92,185	82,966	82,966	73,748	73,748
0.31	92,185	92,185	82,966	82,966	73,748	73,748
0.35	92,185	92,185	82,966	82,966	73,748	73,748
0.39	92,185	82,966	82,966	73,748	73,748	73,748
0.43	92,185	82,966	82,966	73,748	73,748	73,748
0.47	92,185	82,966	82,966	73,748	73,748	73,748
0.51	92,185	82,966	82,966	73,748	73,748	73,748
0.55	92,185	82,966	82,966	73,748	73,748	73,748
0.58	92,185	82,966	82,966	73,748	73,748	64,529
0.62	92,185	82,966	82,966	73,748	73,748	64,529
0.66	92,185	82,966	82,966	73,748	73,748	64,529
0.70	92,185	82,966	73,748	73,748	73,748	64,529
0.74	92,185	82,966	73,748	73,748	73,748	64,529
0.78	82,966	82,966	73,748	73,748	73,748	64,529
Current Prescribed Burning Average						87,576

Table 3-8: Results of the Dynamic Program for Forest Service Region 4.

	Carbon Rent					
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	51,389	51,389	51,389	51,389	46,718	46,718
0.08	51,389	51,389	51,389	46,718	46,718	46,718
0.12	51,389	51,389	51,389	46,718	46,718	46,718
0.16	51,389	51,389	51,389	46,718	46,718	46,718
0.20	51,389	51,389	51,389	46,718	46,718	46,718
0.24	51,389	51,389	46,718	46,718	46,718	46,718
0.27	51,389	51,389	46,718	46,718	46,718	46,718
0.31	51,389	51,389	46,718	46,718	46,718	46,718
0.35	51,389	51,389	46,718	46,718	46,718	46,718
0.39	51,389	46,718	46,718	46,718	46,718	42,046
0.43	51,389	46,718	46,718	46,718	46,718	42,046
0.47	51,389	46,718	46,718	46,718	46,718	42,046
0.51	51,389	46,718	46,718	46,718	42,046	42,046
0.55	46,718	46,718	46,718	46,718	42,046	42,046
0.58	46,718	46,718	46,718	46,718	42,046	42,046
0.62	46,718	46,718	46,718	42,046	42,046	42,046
0.66	46,718	46,718	46,718	42,046	42,046	42,046
0.70	46,718	46,718	46,718	42,046	42,046	42,046
0.74	46,718	46,718	46,718	42,046	42,046	42,046
0.78	46,718	46,718	42,046	42,046	42,046	42,046
Current Prescribed Burning Average						44,382

Table 3-9: Results of the Dynamic Program for Forest Service Region 5.

		Carbon Rent				
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	56,219	56,219	56,219	56,219	56,219	56,219
0.08	56,219	56,219	56,219	56,219	56,219	51,534
0.12	56,219	56,219	56,219	51,534	51,534	51,534
0.16	56,219	56,219	51,534	51,534	51,534	51,534
0.20	51,534	51,534	51,534	51,534	51,534	51,534
0.24	51,534	51,534	51,534	51,534	51,534	51,534
0.27	51,534	51,534	51,534	51,534	51,534	51,534
0.31	51,534	51,534	51,534	51,534	51,534	51,534
0.35	51,534	51,534	51,534	51,534	51,534	51,534
0.39	51,534	51,534	51,534	51,534	51,534	51,534
0.43	51,534	51,534	51,534	51,534	51,534	51,534
0.47	51,534	51,534	51,534	51,534	51,534	51,534
0.51	51,534	51,534	51,534	51,534	51,534	51,534
0.55	51,534	51,534	51,534	51,534	51,534	51,534
0.58	51,534	51,534	51,534	51,534	51,534	46,849
0.62	51,534	51,534	51,534	51,534	46,849	46,849
0.66	51,534	51,534	51,534	46,849	46,849	46,849
0.70	51,534	46,849	46,849	46,849	46,849	46,849
0.74	46,849	46,849	46,849	46,849	46,849	46,849
0.78	46,849	46,849	46,849	46,849	46,849	46,849
Current Prescribed Burning Average						44,507

Table 3-10: Results of the Dynamic Program for Forest Service Region 6.

	Carbon Rent					
Drought	Zero Rents	$2 a ton	$4 a ton	$6 a ton	$8 a ton	$10 a ton
0.04	56,692	56,692	56,692	56,692	56,692	56,692
0.08	56,692	56,692	56,692	56,692	56,692	56,692
0.12	56,692	56,692	56,692	56,692	56,692	56,692
0.16	56,692	56,692	56,692	56,692	56,692	49,606
0.20	56,692	56,692	56,692	56,692	56,692	49,606
0.24	56,692	56,692	56,692	56,692	56,692	49,606
0.27	56,692	56,692	56,692	56,692	49,606	49,606
0.31	56,692	56,692	56,692	56,692	49,606	49,606
0.35	56,692	56,692	56,692	49,606	49,606	49,606
0.39	56,692	56,692	56,692	49,606	49,606	49,606
0.43	56,692	56,692	56,692	49,606	49,606	49,606
0.47	56,692	56,692	49,606	49,606	49,606	49,606
0.51	56,692	56,692	49,606	49,606	49,606	49,606
0.55	56,692	56,692	49,606	49,606	49,606	49,606
0.58	56,692	56,692	49,606	49,606	49,606	49,606
0.62	56,692	56,692	49,606	49,606	49,606	49,606
0.66	49,606	49,606	49,606	49,606	49,606	49,606
0.70	49,606	49,606	49,606	49,606	49,606	49,606
0.74	49,606	49,606	49,606	49,606	49,606	49,606
0.78	49,606	49,606	49,606	49,606	49,606	49,606
Current Prescribed Burning Average						67,322

Conclusion

This dissertation explores some of the challenges facing the USDA Forest Service as it makes wildland fire management decisions. The results from the first chapter show that the Forest Service could decrease the need for fire suppression by increasing the number of acres treated with prescribed burning. This result is determined by estimating an instrumental variable model that controls for drought, biomass and region. The results indicate that on average the Forest Service could see a savings of $1,204.37 per acre of additional prescribed burning verses an estimated cost of $151.04 per acre.

The second chapter examines the demand for fire suppression services utilizing a pair of models. First the chapter uses an ordinary least squares regression to determine whether the number of acres burned has a quadratic relationship with respect to the average cost of suppression per acre. The results show that the average cost of fire suppression decreases as fire size increases; however, for quarters with an extremely large number of acres burned the average cost increased. The infliction point is estimated at 485 thousand acres in a quarter, and is only observed in 4 out of 175 observations. Following the regression analysis a demand system is estimated by treating the 3 largest budget categories as commodity classes. The results show that general contracting or BOC 2540 plays a central role in fire suppression efforts. This central role can be observed in that BOC 2540 is a complementary good with the other two categories.

The final chapter develops a dynamic programming model in order to determine how the optimal level of prescribed burning is impacted by including a monetary value for the carbon released from pre-suppression and suppression efforts. The results indicate that when the value of the carbon released is included in management decisions most regions see a decrease in the amount of prescribed burning that should be conducted. This is mostly due to the timing of the releases, with prescribed burning having a substantial release of carbon that is not recouped until much later in the carbon cycle by the regeneration of biomass. With the carbon cycle being modeled as a steady state system this initial release imposes a substantial penalty on prescribed burning as a fire management tool. While not explored in the third chapter, management tools that don’t have this early carbon penalty would fare better.

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[i]. The NICC geographic area coordination centers were paired with the Forest Service (FS) regions in the following way. FS Region 1 consisted of the NICC Northern Rockies region, FS Region 2 consisted of the NICC Rocky Mountain region, FS Region 3 consisted of the NICC Southwest region, FS Region 4 consisted of the NICC Great Basin West and Great Basin East, FS Region 5 consisted of the NICC Southern and Northern California Operation regions, FS Region 6 consisted of the NICC Northwest region, FS Region 8 consisted of the NICC Southern region, and FS Region 9 consisted of the NICC Eastern region.

[ii]. Forest Service Regions 1, 2 and 4 required some states to be appropriated between them. Region 1 was determined by summing Montana, North Dakota, 50 percent of Idaho, and 5 percent of South Dakota. Region 2 included 66 percent of Wyoming, 95 percent of South Dakota, Nebraska, Kansas, and Colorado. Region 4 was made up of Nevada, Utah, 33 percent of Wyoming, and 50 percent of Idaho. The remaining states fell in whole under a Forest Service region. This method is admittedly ad hoc, but a more structured method could not be found.

[iii] The average annual real increase is calculated by transforming the level of real expenditures presented in Figure 1-1 into natural logs and then regressing the natural logs of real expenditures against a time variable for the years.

[iv] http://www.predictiveservices.nifc.gov/intelligence/archive.htm

[v] The NICC provides a year-to-date figure through Incident Management Situation Report at various intervals. During peak fire seasons the year-to-date number is updated daily, during other periods the figures are updated weekly. The last reported Incident Management Situation Report for each month is used to obtain an estimated monthly figure for burned acres. This is done by subtracting the previous months total from the desired months year-to-date total rendering an estimation of how many acres where burned in the intervening month.

[vi] Calculated by: $Area\ Burned^* = |\hat{\beta}_1/2(\hat{\beta}_2)|$ (Wooldridge 2006)

[vii] Forest Service Regions 1, 2 and 4 required some states to be appropriated between them. Region 1 was determined by summing Montana, North Dakota, 50 percent of Idaho, and 5 percent of South Dakota. Region 2 included 66 percent of Wyoming, 95 percent of South Dakota, Nebraska, Kansas, and Colorado. Region 4 was made up of Nevada, Utah, 33 percent of Wyoming, and 50 percent of Idaho. The remaining states fell in whole under a Forest Service region. This method is admittedly ad hoc, but a more structured method could not be found.