An Economic Approach to Measuring the Impacts of Higher Temperatures on Wildfire Size in the Western United States

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1. Introduction

- Over the past 30 years, the average size of wildfires in the United States has more than doubled, from 15 hectares per fire in the 1980s to 36 hectares per fire in the 2000s (National Interagency Fire Center, 2014).
- Previous studies by ecologists and other natural scientists suggest that increases in wildfire activity have been largely driven by changes in temperature and precipitation (McKenzie et al., 2004; Westerling et al., 2006; Little et al., 2009).
- However, these studies ignored the role humans play in determining the size of wildfires. Specifically, they do not account for suppression efforts by U.S. government agencies. As a consequence, their results may suffer from omitted variable bias (Johnston and Klick, 2011).

2. Objectives

- The purpose of this paper is to investigate the effect that higher temperatures will have on the size of wildfires in the western United States controlling for suppression effort, precipitation, and other factors.
- Using data for 1,840 wildfires that occurred on U.S. Forest Service (USFS) land between 1995 and 2012, I find that a 1% increase in temperature is associated with a 0.85% increase in wildfire size, even when holding suppression effort and other factors constant. The measured effect of temperature on wildfire size is approximately 49% smaller when not controlling for suppression effort. This suggests that previous studies that ignore the impact of suppression effort suffer from significant omitted variable bias.

3. Methods

Conceptual Model

- Wildfire size primarily depends on five factors: 1) the stock of available biomass to burn (i.e., fuel availability), 2) the combustibility of that biomass (i.e., fuel flammability), 3) the ecology of the surrounding area, 4) the topography of the surrounding area, and 5) how much effort is exerted to suppress the fire.
- Fuel flammability is primarily determined by temperature and precipitation in the month a fire occurred.
- Therefore, a general function determining the size of wildfire *i* can be expressed as
  - $Size_i = f\left(SuppExp_i, T_i, P_i, Fuel_i, Ecological\,Controls_i, Topographical\,Controls_i\right)$
- Where $SuppExp$ is the level of expenditures that were spent to suppress the fire, T_i is temperature in the month the fire was ignited, P_i is inches of precipitation in the month the fire was ignited, $Fuel_i$ is the stock of available fuel, $Ecological\ Controls_i$ are controls relating to the ecology of the area surrounding the fire, $Topographical\ Controls_i$ are controls relating to the topography of the area surrounding the fire (e.g., slope, aspect, elevation).

Data

- Data on the size and location of over 1,840 wildfires in the western United States were obtained from the National Interagency Fire Management Database.
- Data on temperature and precipitation of the area surrounding each fire were derived from PRISM according to Wang et al. (2012).
- Data on ecological and topographical characteristics of the area surrounding each wildfire were obtained from geographic information system layers provided by the USFS.
- Data on $Fuel_i$ were unavailable. However, the level of fuel present when the fire is started is a function of precipitation in previous periods. Therefore, we proxy for $Fuel_i$ by taking the average precipitation over the previous 6 months (P_6mo_i).

Estimated Models

- To see whether controlling for suppression expenditures significantly alters my estimate of the impact of higher temperatures on wildfire size, I estimated the following two models:
- Model #1:
  - $\ln\left(Size_i\right) = \alpha_0 + \alpha_1 \ln\left(T_i\right) + \alpha_2 \ln\left(P_i\right) + \alpha_3 \ln\left(P\_6mo_i\right) + \sum_j^k \alpha_j Controls_{ji} + u_i$
- Model #2:
  - $\ln\left(Size_i\right) = \beta_0 + \beta_1 \ln\left(SuppExp_i\right) + \beta_2 \ln\left(T_i\right) + \beta_3 \ln\left(P_i\right) + \beta_4 \ln\left(P\_6mo_i\right) + \sum_j^k \beta_j Controls_{ji} + e_i$
- I estimated the models above using data for 1,840 wildfires that occurred in the western United States. To see whether my results are robust to fuel-related unobservable variables, I also estimated these models for a subset of 563 wildfires that occur in the Northern and Middle Rockies ecosystems. Previous research has found that wildfires that occur in these ecosystems are typically not fuel-constrained; therefore, not having a good measure of fuel should have less of an impact on my results.

Estimator

Model #1 was estimated using Ordinary Least Squares (OLS). However, estimating Model #2 requires the use of an instrumental variables estimator, because including suppression effort as an independent variable likely introduces endogeneity bias. I used a two-stage least squares (TSLS) estimator with heteroskedasticity-robust standard errors. The instrumental variable that I used is the distance from a fire's point of origin to the nearest populated area.

Table 1. Descriptive Statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Size (Hectares)	1,840	2,945	10,436	40	217,755
T (°C)	1,840	17	5	−0.2	33
P (mm)	1,840	20	25	0	326
P_6mo (mm)	1,840	0.22	0.81	−3.26	3.59
SuppExp ($2010)	1,840	3,366,152	7,129,091	1,305.31	98,700,000
Distance (miles)	1,840	15	11	0.4	70

4. Results and Discussion

- Results for estimating Model #1 and Model #2 using data from the entire Western United States are provided in **Table 2**. As one can see, controlling for suppression expenditures results in significantly higher estimates for the impact of temperature on wildfire size. This suggests that studies that ignore suppression effort may suffer from significant omitted variable bias.
- Results for estimating the models using data from the Northern and Middle Rockies are provided in **Table 3**. As one can see, I still find that controlling for suppression expendiutes results in significantly higher estimates for the impact of temperature on wildfire size.

Table 2. Two-Stage Least Squares Estimates for Western United States

	Dependent Variable: ln(Size)			
	OLS Coefficients		TSLS Coefficients	
Variable	Model 1	Model 1	Model 2	Model 2
ln(SuppExp)	(-)	(-)	−0.79***(0.24)	−0.37** (0.15)
ln(T)	**0.51***(0.13)**	**0.57***(0.13)**	**1.07*** (0.05)**	**0.85 *** (0.20)**
ln(P)	−0.15*** (0.04)	−0.18*** (0.04)	−0.51*** (0.13)	−0.31*** (0.07)
ln(P_6mo)	0.11 (0.06)	0.05 (0.61)	0.37(0.12)	0.06 (0.08)
Topographical controls	Excluded	Included	Excluded	Included
Ecological controls	Excluded	Included	Excluded	Included
Year fixed effects	Excluded	Included	Excluded	Included

Robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Parameter of interest in bold.

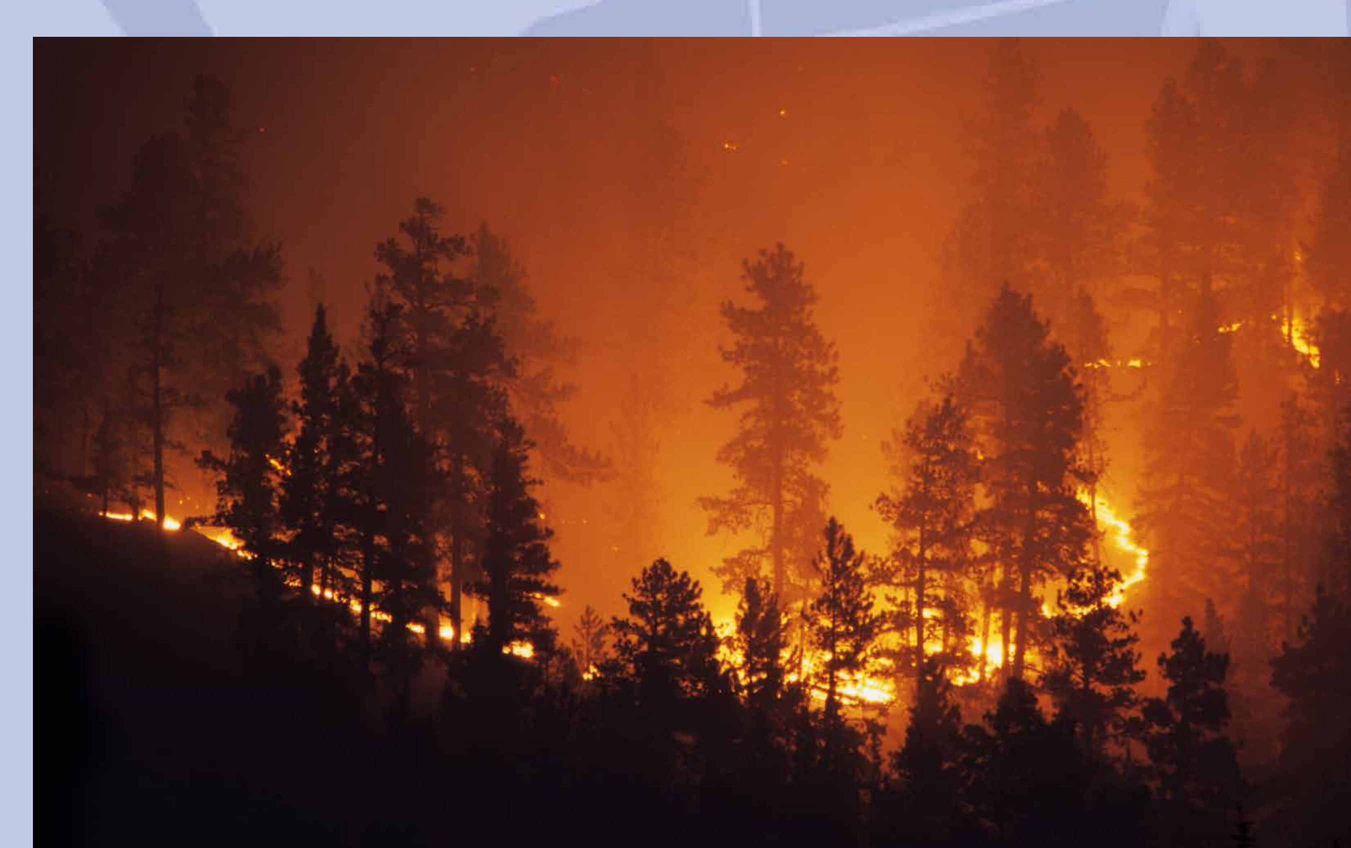
Table 3. Two-Stage Least Squares Estimates for Northern and Middle Rockies Ecosystem

	Dependent Variable: ln(Size)			
	OLS Coefficients		TSLS Coefficients	
Variable	Model 1	Model 1	Model 2	Model 2
ln(SuppExp)	(-)	(-)	−0.32** (0.15)	−0.26** (0.12)
ln(T)	**1.53*** (0.35)**	**0.99*** (0.37)**	**2.11*** (0.52)**	**1.39 *** (0.50)**
ln(P)	−0.19* (0.11)	−0.11*** (0.11)	−0.26** (0.13)	−0.20 (0.13)
ln(P_6mo)	−0.13 (0.18)	−0.17 (0.18)	−0.23 (0.22)	−0.24 (0.08)
Topographical controls	Excluded	Included	Excluded	Included
Ecological controls	Excluded	Included	Excluded	Included
Year fixed effects	Excluded	Included	Excluded	Included

Robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Parameter of interest in bold.



5. Conclusions

- These results can be of great use to USFS and other policy makers that want to anticipate how higher temperatures from climate change will influence wildfire size.
- Specifically, I find that wildfire size increases by 0.85% for every 1% increase in temperature, holding all other factors constant.
- To offset this increase in wildfire size, our preferred model shows that suppression expenditures would need to increase by 2.3%. For the average wildfire, this offset would translate into an increase in suppression expenditures of $77,421.

References

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