Wildfires, Externalities, and Spatial Heterogeneity: An Economic Analysis of California

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Abstract

In California, wildfires are occurring with increased intensity and severity as climate change has lengthened wildfire seasons and made droughts more pronounced. Smoke from wildfires has serious health ramifications, even for Californians that are not directly in the line of fire. I propose a model and empirical estimation to address the following research question: How can the California state government allocate wildfire prevention funds to maximize the health benefit, subject to the government budget constraint? In this proposal, I will share background motivation for this question, as well as a proposed model, data, and empirical estimation.

Background

The two largest wildfires California has experienced in recent memory were the August Complex fire in August 2020 and the Dixie fire in July 2021, which each burned approximately 1,000,000 acres[1]. In fact, 9 out of the 20 largest fires since 1932 were in the last 2 years [1]. The increased frequency and severity of fires in California is largely attributed to climate change. Summer wildfire seasons are 40-80 days longer on average than they were 30 years ago, and droughts are more pronounced throughout California, making potential wildfire fuels (e.g. dead leaves and shrubs) more flammable [2]. As the frequency of wildfires has increased, the cost of wildfire prevention has increased dramatically as well. During the fire season, tens of thousands and firefighters and many millions of dollars' worth of equipment are dispatched throughout California [3].

In addition to the environmental and financial impacts of wildfires, exposure to wildfire smoke is associated with many respiratory health complications: decreased lung function, asthma, chronic obstructive pulmonary disease, and respiratory infections. Currently, an estimated 26% of organic aerosols in the western United States come from wildfires, and this fraction is expected to increase as wildfires become more prevalent. Fine particulate matter (PM2.5), a component of wildfire smoke, is especially damaging to health. In the US, the daily average National Ambient Air Quality Standard for PM2.5 is 35 μg/m3. However, ambient concentrations of PM2.5 in the vicinity of a wildfire can be extremely high. Hourly concentrations of 6,106 μg/m3 and daily concentrations of 394 μg/m3 have been documented. Finer particles, such as those produced from wildfires, have been shown to be more toxic for respiratory health than particulate matter produced from other sources [4].

Further, wildfire risk is not contained by private borders. Depending on wind patterns, smoke from wildfires can blow into neighboring areas, triggering respiratory complications outside of direct fire path. This negative externality to neighboring areas is not considered by private land owners when deciding how to optimally allocate prevention funds on their property. While in theory we could solve this externality in the private market, the private market for wildfire prevention fails

[1] This is equivalent to burning an area that is approximately 16 times the size of the city of Madison.

for 3 key reasons:

1. It is challenging to coordinate across private land owners

2. Individuals have different risk preferences

3. Private home owners insurance covers wildfire damage but not wildfire prevention

As a result, most wildfire prevention comes from federal, state, and local governments.

There is also considerable spatial heterogeneity of risk for both wildfires and respiratory complications. General respiratory health risk is concentrated in urban areas, where people have exposure to higher concentrations of pollution caused by automobile traffic or industrial emissions. Conversely, wildfires are primarily fueled by grasses, shrubs, and dead leaves, so fires are more common in forested areas. This mismatch in the spatial heterogeneity of wildfire risk and respiratory risk is illustrated in Figures 1-4 below.

In Figure 1, we can see the areas in California that were impacted by wildfires through 2019. Recall, 9 of the 20 largest wildfires documented are from the last 2 years, so they are not included in this map.

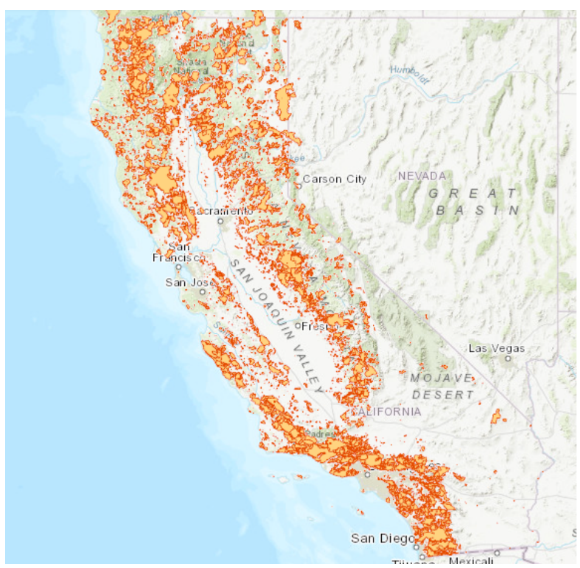

Figure 1. Wildfires Through 2019 [5]. The dark orange shows the perimeter of each fire, and the light orange shows the area impacted by each fire.

In Figure 2, we can see the fire hazard severity zones as determined by the California Department of Forestry and Fire Protection. This map is largely consistent with the location of the fires in Figure 1; much of the higher fire risk in Figure 2 is concentrated on the perimeter of the San Joaquin Valley, or near Los Angeles or San Diego..

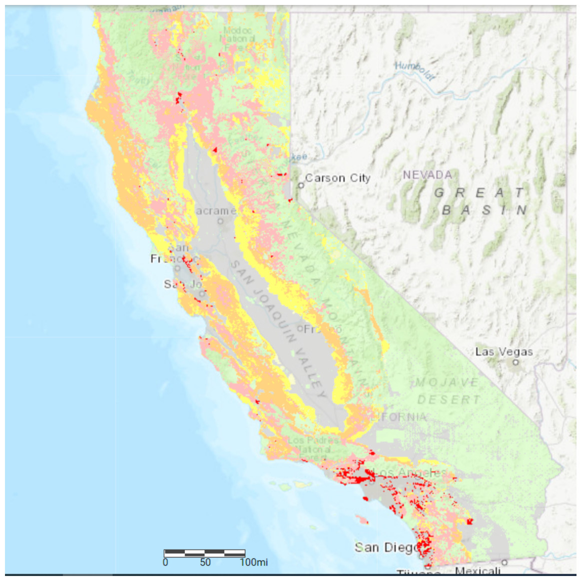

Figure 2. Wildfire Hazard Severity Zones [6]. The light green shows federally managed lands, and the grey shows Local Responsibility Areas (LRA). Of the state lands, yellow designates moderate fire risk, orange designates high fire risk, and light red designates very high fire risk. The dark red shows high fire risk within LRAs.

In Figure 3, we can see air quality in California as measured by PM2.5 levels. We can see higher concentrations of PM2.5 near urban areas, such as Fresno and Los Angeles, which is likely due to more vehicular traffic and industrial pollution. Note, there are very high levels of PM2.5 in the San Joaquin Valley, an area that is surrounded by high wildfire severity zones, despite not having many fires in the Valley itself.

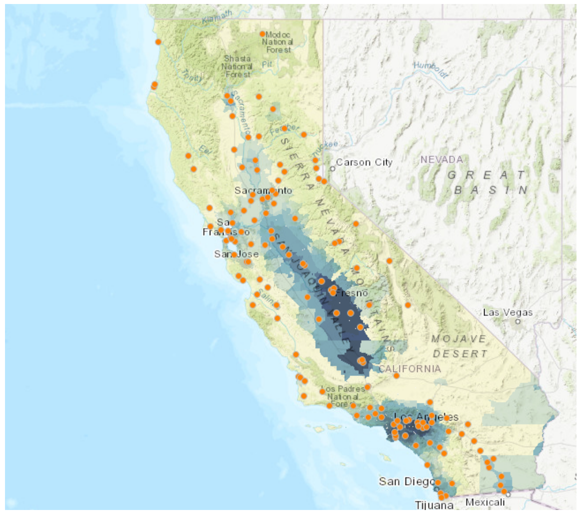

Figure 3. PM2.5 Concentrations [7]. The orange dots represent PM2.5 monitoring stations, and the darker blue indicates higher concentrations of PM2.5

In Figure 4, we can see which regions are disproportionately burdened by, and vulnerable to, multiple sources of pollution as determined by the California Office of Environmental Health Hazard Assessment. As expected, the regions with the most disadvantaged communities largely correspond to the areas with higher concentrations of PM2.5 that we observed in Figure 3.

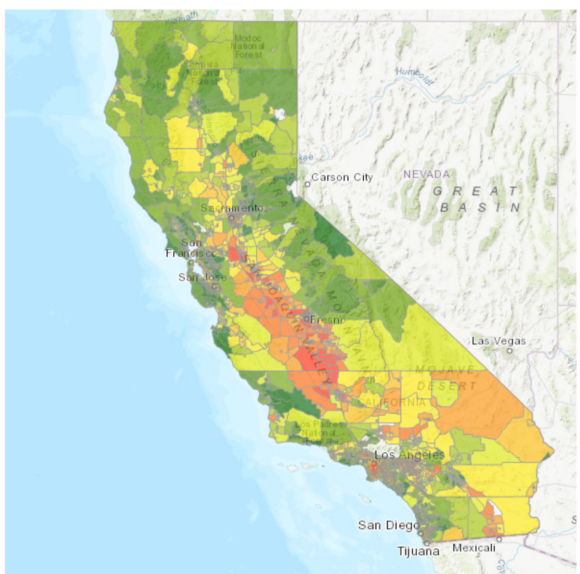

Figure 4. Communities at Risk for Respiratory Complications [8]. The more orange and red regions indicate census tracks that are disproportionately burdened by and vulnerable to multiple sources of pollution.

As we can see in Figures 1-4, there is a spatial mismatch between where the wildfires occur and where the most vulnerable populations for respiratory complications live, which causes ambiguity about where wildfire prevention funds should be focused. Using the structural model and estimation proposed in the following sections, we can solve this constrained optimization problem to determine the optimal policy.

Model

Using a static, structural model, I propose addressing how we should allocate wildfire prevention funds to maximize the health benefit, subject to the government budget constraint. The federal government provides funding to states and local governments, who decide how to allocate funding to federal lands in the state. Because county governments optimize within county borders, there is still an externality to neighboring counties which is absorbed by the state. As a result, I will focus on state-level optimization. My proposed model is:

$$\max \sum_i \lambda_i U(h_i)$$
$$\text{s.t.} \quad \sum_i (p_i + w_i + c_i) \leq \sum_i (\bar{p_i} + \bar{w_i} + \bar{c_i})$$

In this model, the state maximizes the sum of utility across i counties while holding the current level of spending on wildfire prevention p_i, wildfire cleanup w_i, and respiratory health expenditures borne by the government c_i constant. County pareto weights λ_i on utility can weight by population densities or by social determinants of health in each community. Utility is a function of respiratory healthcare utilization h_i, but the exact form of utility is yet to be determined.

The primary forms of wildfire prevention include vegetation management, brush clearance, and prescribed fire. Since these are ongoing maintenance activities, the proposed model is static, and the state government will re-optimize in each time period. In this model, the state chooses the spending on wildfire prevention in each county, which impacts the risk of a fire in each county. This in turn impacts the healthcare utilization, spending on healthcare, and spending on wildfire cleanup.

Data

To collect information on respiratory health utilization, I propose using data from the Healthcare Cost and Utilization Project (HCUP). The State Inpatient Database (SID) of HCUP contains inpatient care records by county within each state. This data is restricted access, so if obtaining the data becomes too costly or infeasible, and alternative data source for respiratory health utilitization would be the publicly available hospital annual utilization report from the California Health and Human Services (CHHS). The CHHS data contains hospital level health utilization data for acute respiratory care, but respiratory care is not broken into more fine diagnosis categories. As such, HCUP-SID is my preferred data source.

To collect information on where fires occur, I intend to use data from the California Department of Forestry and Fire Protection , which contains publicly available information on the number of fires, the location of fires, and the number of acres burned. To assess where the smoke from wildfires goes, I intend to use Air Data from the U.S. Environmental Protection Agency, which contains publicly accessible county-level historical data on outdoor air quality.

To collect information on healthcare costs, I plan to use data from the Medical Expenditure Panel Survey (MEPS). MEPS contains data on health expenditures for inpatient and outpatient health expenditures, and includes information specific to publicly provided insurance. Finally, to collect information on wildfire prevention and cleanup costs, I plan to use public records requests for the state and local governments, following the approach used in the 2021 working paper by Patrick Baylis and Judson Boomhower [3].

Empirical Estimation

In order to estimate this model, I will estimate the following 4 components:

1. The impact of government spending on wildfire prevention on fire risk
2. The impact of fire risk on fire clean up costs
3. The impact of fire risk on respiratory risk
4. The impact of respiratory risk on healthcare costs

1. The impact of government spending on wildfire prevention on fire risk

To estimate the impact of government wildfire prevention spending on fire risk, I propose estimating the following logit regression:

$$Pr(F_{it} = 1 | P_{it}, X_{it}, i, t) = \frac{\exp(\beta_0 + \beta_1 \log P_{it} + \beta_2' X_{it} + \gamma_i + \eta_t)}{1 + \exp(\beta_0 + \beta_1 \log P_{it} + \beta_2' X_{it} + \gamma_i + \eta_t)} \tag{1}$$

In this regression, the probability that the binary fire indicator is positive $F_{it} = 1$ is a function of spending on wildfire prevention P_{it} and other geospatial characteristics X_{it}. I have taken the log of fire prevention spending because I expect that spending will be non-linear with fire risk. The regression will also include county-location and time fixed effects γ_i and η_t to control for time and county varying risk.

For the remaining components of the model, we are interested in understanding the impact of wildfire prevention spending on healthcare utilization, spending on healthcare, and spending on wildfire cleanup. Because these outcomes are also affected by fire risk, I propose resolving endogeneity between wildfire prevention spending and fire risk by instrumenting for fire risk using equation (1). In order for the independence assumptions of this approach to be satisfied, I have assumed that the only impact of wildfire prevention spending on each outcome is through the the impact of prevention spending on fire risk.

2. The impact of fire risk on fire clean up costs

To estimate the impact of fire risk on fire clean up costs, I propose estimating the following regression:

$$\log W_{it} = \beta_0 + \beta_1 Pr(F_{it} = 1 | P_{it}, X_{it}, i, t) + \beta_2' X_{it} + \gamma_i + \eta_t + \varepsilon_{it} \tag{2}$$

In this regression, wildfire cleanup costs $\log W_{it}$ are a function of the fire risk estimated in equation (1) and other geospatial charactersitcs X_{it}. I have taken the log of fire cleanup spending because I expect that spending will be non-linear with fire risk. The regression will also include county-location and time fixed effects γ_i and η_t to control for time and county varying risk.

3. The impact of fire risk on respiratory risk

Recall that respiratory complications are the result of wildfire smoke, which may not necessarily coincide with the fire risk in a given county. I propose estimating the impact of fire risk on respiratory health using a 2 stage least squares regression:

1. Estimate the impact of fire risk on air quality
2. Estimate the impact of air quality on respiratory health

In order for the independence assumptions of this approach to be satisfied, I have assumed that the only impact of fire risk on respiratory health is through the impact of fire risk on air quality. The first stage regression is:

$$S_{it} = \beta_0 + \sum_{j \in V(i)} \beta_j Pr(F_{jt} = 1 | P_{jt}, X_{jt}, j, t) + \beta_2' X_{it} + \gamma_i + \eta_t + \varepsilon_{it} \tag{3}$$

In this regression, air quality S_{it} in county i is a function of the fire risk estimated in equation (1) in the j counties in the vicinity $V(i)$ of county i and other geospatial characteristics X_{it}. The regression will also include county-location and time fixed effects γ_i and η_t to control for time and county varying risk.

The second stage regression is:

$$Pr(R_{it} = 1|S_{it}, Y_{it}, i, t) = \frac{\exp(\alpha_0 + \alpha_1 S_{it} + \alpha_2' Y_{it} + \gamma_i + \eta_t)}{1 + \exp(\alpha_0 + \alpha_1 S_{it} + \alpha_2' Y_{it} + \gamma_i + \eta_t)} \tag{4}$$

In this regression, the probability of a respiratory complication for an individual living in county R_{it} is a function of air quality levels S_{it} and demographic characteristics Y_{it}. This regression will also include county-location and time effects γ_i and η_t to control for time and county varying risk.

4. The impact of respiratory risk on healthcare costs

To estimate the of respiratory risk on healthcare costs, I propose the following regression:

$$\log C_{it} = \beta_0 + \beta_1 Pr(R_{it} = 1|S_{it}, Y_{it}, i, t) + \beta_2' Y_{it} + \gamma_i + \eta_t + \varepsilon_{it} \tag{5}$$

In this regression, government healthcare expenditures on respiratory complications C_{it} are a function of respiratory risk estimated in equation (4) and demographic characteristics Y_{it}. I have taken the log of healthcare prevention spending because I expect that spending will be non-linear with respiratory risk. This regression will also include county-location and time effects γ_i and η_t to control for time and county varying risk. In order for the independence assumptions of this approach to be satisfied, I have assumed that the healthcare costs are only directly influenced by respiratory risk, and are independent of wildfire prevention spending, fire risk, and air quality.

Conclusion

By incorporating the spatial heterogeneity of wildfire and respiratory risk into a model of wildfire prevention spending, we can better allocate wild prevention funding to improve the health across the state of California. In addition to informing better policy, this project would contribute to the literature on environmental economics, environmental health, spatial economics, and optimal policy with constraints. Further, there are opportunities to build on this model for counterfactuals and additional analyses of California wildfire policy.

References

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