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COMPETITION FOR PERSONNEL: A BARRIER TO PRESCRIBED BURNING IN THE SAN JUAN NATIONAL FOREST

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COMPETITION FOR PERSONNEL: A BARRIER TO PRESCRIBED BURNING IN THE SAN JUAN NATIONAL FOREST

By

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Abstract

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Using personnel data from the Resource Ordering and Status System (ROSS) this paper analyzes the relationship between personnel and prescribed burn frequency for the San Juan National Forest. Prescribed burning is used as a tool for mitigating wildfire risk by removing hazardous fuels but faces many barriers from policy to systemic disincentives. Personnel unavailability is one of these barriers that consistently challenges managers on National Forests when attempting to conduct prescribed burns. An instrumental variables approach is used to estimate the impact of personnel unavailability on managers decisions to conduct prescribed burns between 2014 and 2022. Estimates do not support the hypothesized negative relationship between resource unavailability on the likelihood of prescribed burns, potentially due to limitations in the data including a small sample of prescribed burns and relying on personnel unavailability as a proxy for personnel availability. However, the framework of this study provides a contribution to enhance and guide future research on this topic by empirically testing this hypothesis, providing a causal estimate, and creating a unique dataset.

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1. Introduction

As a result of the escalating frequency and severity of wildfires, the United States is grappling with a forest management crisis that is causing economic costs to surge, estimated to range between $71.1 billion to $347.8 billion annually in 2016 US Dollars (Thomas et al., 2017). Expanding development in wildfire prone areas where wilderness and urban regions meet (wildland-urban interface) and aggressive efforts to suppress wildfires have also contributed to these rising costs (Ingalsbee & Raja, 2015). Rising temperatures and decreased precipitation due to climate change are anticipated to increase the size of areas burned by wildfire by as much as 74% by 2085 in states like California (Westerling et al. 2011), potentially escalating these costs. Research has found that the exclusion of fire on the landscape has increased fuels such that these forests are capable of fostering larger and more severe fires (Stephens et al., 2012). This challenge has been examined by fire managers and policy makers who consistently recommend conducting fuels management using prescribed fire to reduce the amount of fuel in overgrown, dense forests to mitigate wildfire risk (Prichard et al., 2021). Prescribed burning not only helps decrease fuel accumulation for up to a decade (Tolhurst & McCarthy, 2016) but it also provides communities with job creation (Hjerpe & Kim, 2008), regeneration of forests (Kilgor & Curtis, 1997), and improvements in air quality by mitigating air pollution from wildfires (Altshuler et al., 2020). Thus far, however, the scale of fuel treatments have been too limited to adequately remove fuels from the landscape (North et al., 2012).

Qualitative research suggests that a lack of personnel has remained a barrier to increasing prescribed burns on forests (C. A. Schultz et al., 2019; Miller et al., 2020; Yung et al., 2022). Increased suppression of wildfires is likely to increase the demand and competition for these personnel such that prescribed burning is less likely given that managers are expected to balance personnel assignments to both wildfire suppression and mitigation. This balance is challenged if personnel are siphoned away from local forests to fulfill demand for wildfire suppression assignments during prescribed-burn windows. For example, administrative directives requiring the diversion of qualified personnel to suppression efforts during times of increased wildfire activity could disrupt prescribed burning (Christiansen, 2021). Adding to the difficulty, the U.S. Forest Service (USFS) plans to increase fuels management rates in National Forests (See definition in Appendix, *Confronting the Wildfire Crisis*, 2022) yet workforce limitations are increasing (U.S. Government Accountability Office, 2022). These challenges coupled with an increase in wildfires and prioritization of suppression is theorized to strain personnel resources and inhibit prescribed burns in the absence of policy interventions like dedicating personnel solely to prescribed burning. In addition to fire suppression policies, financial incentives may also systematically encourage managers to assign personnel to wildfire suppression instead of wildfire mitigation assignments such as conducting prescribed burns.

Determining the effect of personnel availability on the likelihood of prescribed burns is potentially important for developing policies to effectively improve resource-related barriers to wildfire mitigation and forest management. This paper aims to empirically test the hypothesis of personnel availability as a barrier to prescribed burning by quantitatively identifying whether increased personnel unavailability reduces the likelihood of prescribed burns on the San Juan National Forest. The effect of personnel constraints on the likelihood of prescribed burning specifically from competition with wildfire suppression have yet to be empirically analyzed. The San Juan National Forest (SJNF) was selected as a case study for examining the tradeoffs between conducting prescribed burns and wildfire suppression in the face of competition for the same pool of personnel resources. The primary objective is to estimate the impact of personnel assignment away from the San Juan Forest on the likelihood of prescribed burns to determine the extent that personnel limit burns during prescribed burn windows which are weather-dependent opportunities when the conditions are optimal for burning. In order to accomplish this, an instrumental variables approach was implemented. Understanding this problem could provide policymakers and forest managers with an understanding of the consequences for prescribed burning from assigning personnel to suppress wildfires.

This research aims to help researchers and National Forests explore how to model the prescribed burning decision-making process given personnel-resource constraints and inform future data collection on the necessary variables. Multiple datasets of resource and environmental data were merged to explore this question of how personnel unavailability impacts prescribed burn decision-making during the fire season. A major contribution of this research is the use of an instrumental variables approach to address this question as well as the dataset used.

Section 2 outlines the literature from previous work and Section 3 describes the key data sources and variables and Section 4 presents the two methods of analysis, first the linear regression and then the instrumental variables (IV) regression. Section 5 presents these results followed by the discussion of them in Section 6 and Section 7 concludes.

2. Background

2.1 Rising Costs of Wildfires

Costs for wildfire suppression were rising 15 years ago (Mercer et al., 2008) and are still increasing today (Foard, 2022). The annualized economic burden for the US Forest Service from wildfire is estimated to be between $71.1 billion to $347.8 billion (2016 US dollars) and is composed of costs for intervention and prevention, wildfire mitigation and suppression, and wildfire related losses (Thomas et al., 2017). The annual costs for restoration of natural resources and repair of infrastructure are estimated to range from $63.5 billion to $285.0 billion and costs for conducting suppression and fuels management account for an estimated $7.6 billion to $62.8 billion (Thomas et al., 2017). Losses include both direct losses such as deaths, health impacts, timber loss, and structure damages as well as indirect losses like evacuation costs, housing market and supply chain disruptions, and economic decline in affected communities (Thompson et al., 2017).

Previous work has shown that these damages, particularly from structure loss, are accelerating as wildfires have become larger and more frequent (Buechi et al., 2021). A recent study by Baylis & Boomhower (2023) found that a large portion of these wildfire costs were from attempts to prevent property damage, a cost that was passed onto the state and federal government to the degree of billions of dollars per year. The study found that costs were increasing due to homeowners increasingly building in the Wildland-Urban Interface (WUI) and generating large externalities when wildfires occur. The authors conclude that the U.S. government was implicitly providing subsidies for homeowners throughout the Western states in the form of large transfer of state and federal revenues to homeowners in areas that are more costly to protect from wildfires compared to urban housing developments. Climate change is expected to increase the total number of acres burned by up to 41 percent by 2050 (Westerling et al., 2011) which could result in increased fire danger to homes in the WUI and thus higher protection costs and larger implicit subsidies to residents (Spracklen et al., 2009).

2.2 Benefits of Prescribed Burning

To address the risks and damages caused by wildfires to homes in the WUI, Fernandes and Botelho (2003) found prescribed burns to be a viable solution. One study found that prescribed burning can decrease fuel accumulation for up to 10 years (Tolhurst & McCarthy, 2016), reducing fire risk for up to a decade and allowing for large areas to be effectively treated to protect forests and communities. With over 11 million acres in the WUI requiring treatment to mitigate hazardous fuels (Graham et al., 2004), investing in prescribed burning programs offers a potentially cost-effective approach. This is significant considering the substantial expenditure involved in nationwide fire management, primarily driven by wildland fire suppression costs (Kilgor & Curtis, 1997). Although prescribed burning treatments are costly to the federal government, one study found that it is more efficient than continued fire suppression (Snider et al., 2006). Mercer et al. (2007) demonstrated that prescribed fires are much more cost effective and welfare maximizing compared to fire suppression by minimizing damages to structures and reducing overall fire management costs.

Beyond damage reduction, Hjerpe and Kim (2008) found that prescribed burns are also able to provide economic benefits by generating hundreds of local jobs and stimulating rural economies. Furthermore, there are benefits of fuels management using prescribed fire for forest regeneration and biodiversity protection (Kilgor & Curtis, 1997; Wade, 1989). Prescribed burning protects biodiversity and forests by reducing fire sizes and severity, thus protecting the habitats of fire-sensitive species (Pastro et al., 2011). Prescribed burning helps protect forests and remove fuels by decreasing crown fires (fires that spread from treetop to treetop) and by decreasing the density of small trees that act as fuel and intensify wildfires (Pollet & Omi, 2002). Stoddard et al. (2021) found that areas treated with prescribed fire had lower tree mortality and higher growth rates as well as reduced fuel loads in the forest canopy and an overall reduced crown fire potential over a 20-year period compared to the control group. Prescribed fire can also promote resilience among ecosystems in the long run and protect them even under climate changed induced drought and warming scenarios (Stoddard et al., 2021). This is especially important given that ecosystems historically have adapted to burn frequently across an estimated 100 million acres in the Western U.S. and may benefit from restoring fire (Graham et al., 2004). In Southwestern forests like the San Juan, the ecosystem was radically altered by land uses including logging, livestock grazing, and suppression of wildfires (Allen et al., 2002). Allen et al. finds that this has led to a decline in both old-growth forests and biodiversity, leaving humans and ecosystems vulnerable to destructive severe fires due to the increased density and volume of fuel from young trees and fuel accumulation.

Public health benefits of prescribed burning from improvements in air quality can come from preventing severe wildfires and the hazardous smoke they produce (Altshuler et al., 2020). According to Williamson et al. (2016), prescribed burning can decrease the occurrence of wildfires, resulting in a trade-off between more frequent short-term smoke pollution events at a local scale and reduced exposures to a broader population over a longer time period. There is a growing concern that extreme wildfire smoke exposure has largely been excluded from estimates of wildfire damages. Diminished air quality from wildfire smoke can impact human health up to thousands of miles from the fire, increasing the scope of its effects (O'Dell et al., 2021). Richardson et al. (2012) found that the economic cost of health effects from wildfires is $9.50 per exposed person per day. The study also estimated that the willingness to pay for a reduction in days with wildfire smoke induced symptoms was between $85 and $95 per person per day. At the community level, economic studies on the health costs associated with exposure to wildfire smoke have found that hospital admissions increase by 0.3% costing up to $2.2 million per unit of PM2.5 from smoke (Moeltner K, et al., 2013). A similar study (Kochi et al., 2016) found that in 2007 wildfire smoke led to additional hospital admissions costing $3.4 million in healthcare costs and a more recent study, Johnston et al., 2021a, valued the health care costs of fires in Australia from 2019 to 2020 to be nearly $2 billion Australian Dollars. Another study found that living within 30 miles of a single wildfire increased the likelihood of lung cancer by 5% and brain tumors by 10% (Korsiak et al., 2022). Although prescribed burning also generates smoke, evidence has shown that it does so at lower concentrations than uncontrolled wildfire and is subject to the regulations of the Clean Air Act (Selimovic et al., 2020; Jaffe et al., 2020). Further research could help to further understand the differences in health effects between smoke from wildfire and prescribed fire.

2.3 Challenges And Barriers To Prescribed Burning

Prescribed burning for forest management has faced many challenges. These challenges have historically limited prescribed burning and include public resistance to air pollution from smoke, regulatory hurdles, budgetary restraints, a lack of incentives, and the risk of prescribed burns becoming wildfires and burning private property. (Stephens & Ruth, 2005). Recently, public land managers looking to conduct prescribed burns have been impeded by budget limitations as well as resource capacity issues (Kobziar et al., 2015). Another challenge for implementing prescribed burns is the lack of clearly defined measurable objectives (Penman et al., 2011).

One of these challenges is financial incentives which could result in suppression assignments being preferred over prescribed burns given that overtime wages can provide a 50% increase in pay for additional hours beyond the first eight worked per day on wildfire suppression assignments when compared to assignments on the local forest for prescribed burns. Overtime may be less than 50% on prescribed burns due to Fair Labor Standard Act practices (Swenka, 2019). Fire suppression assignments may also receive a 25% hazard pay boost which would significantly increase pay when coupled with the overtime wages relative to other planned assignments like prescribed burns. Combined, there is a strong financial incentive for personnel and managers to prefer suppression assignments due to higher pay and more hours that could significantly increase total earnings. The pressure to meet workers' financial needs or expectations might compel managers to predominantly assign personnel to suppression duties. Furthermore, the prospects for career advancement linked with suppression assignments elevate the opportunity cost of undertaking local prescribed burn tasks, intensifying the preference for suppression assignments. Thus, this incentive structure applied to a workforce responsible for both wildfire response and prescribed burning may result in reduced local workforce capacity and lower rates of prescribed burn treatments.

Previous GAO reports highlight the challenge of personnel as far back as 2003 (U.S. Government Accountability Office, 2003). This report, based on qualitative research from discussions with officials from seventeen Forest Service land units, found that the diversion of funding from fuels reduction to fire suppression programs accounted for about thirty percent of the total fuels reduction project delays recorded in 2002 at the local units they visited, interfering with fuels reduction program implementation. Project delays were counted from each of the local land units using planned fuel treatment data from fiscal year 2002 including the dates of treatment, whether they were completed as scheduled, and if not, the reason why. The report also highlighted how policies requiring personnel be immediately available for suppression efforts elsewhere can create competition for and reassignment of personnel that inhibit local fuels reduction projects like prescribed burning. Thus, resource competition could make managers reluctant to use personnel for controlled burns to ensure suppression readiness, highlighting the tradeoff between fuels management and readiness to deploy. More recent qualitative research (Miller et al., 2020) noted the diversion of funding and personnel from wildfire prevention to suppression as a potential barrier to prescribed burning. Inadequate personnel availability was identified as a barrier to prescribed burning by forty-seven percent of interviewees, with some attributing the lack of personnel crews to constant demand from suppressing wildfires.

Recent research such as Schultz et al. (2018) identified many challenges to conducting prescribed burns such as issues with financial resource sharing and monetary exchange when trying to conduct prescribed burns. National Forests are unable to share funds with other federal agencies to pay personnel for prescribed burns like they can for wildfire suppression, resulting in delays. Specifically, some National Forests partner with agencies like the National Park Service and the Bureau of Indian Affairs to conduct burns for an area that crosses land ownership or jurisdictional boundaries but are unable to easily transfer money between agencies to do this. (C. Schultz, Mclntyre, et al., 2018). Furthermore, inconsistencies in interpretations of funding agreements present legal issues for collaborative prescribed burns that employ personnel from more than one National Forest. Differing opinions among lawyers and funding specialists on how funds can be used (depending on the grant or region) can lead to cumbersome regulatory barriers that prevent prescribed burns from being implemented when multiple agencies are involved. Collectively, a lack of collaboration among organizations means available personnel resources struggle to cooperate when capacity is strained, making it all the more challenging to conduct burns. (Schultz et al., 2018)

Beyond the regulatory and bureaucratic hurdles, respondents surveyed by Schultz et al. (2018) noted obstacles from a lack of available qualified personnel as they are assigned away from their local forest to work on wildfires during the available burn windows. Forests also end up lacking available personnel for prescribed burns when they are required to be readily available for reassignment to suppression assignments at any given moment. This dynamic affects managers decisions and planning based on expectations of whether personnel will be available. Competition with wildfire suppression assignments is exacerbated by lengthening wildfire seasons by reducing the number of days when personnel are available on the local unit. Additional misalignment of personnel availability and burn windows occurs due to seasonal workers leaving at the end of the fire season and less commonly, overlap with employee leave and training (Schultz et al., 2018). Additionally, Schultz et al. (2018) found that the budgetary limitations of National Forests result in tradeoffs between conducting prescribed burning or mechanical thinning, with some managers noting that after conducting mechanical treatments there can be insufficient funding to complete burning treatments (Schultz et al. 2018). Current incentives require a set number of acres to be treated with fuel reduction methods and can be satisfied by multiple means, resulting in potential mechanical thinning bias given it is a more predictable, versatile option that poses less risk to the organization and public. Mechanical thinning can be conducted for most months of the year meaning there are many more windows of opportunity for them to take place, making it an easier choice for managers to meet agency performance measures.

Forest managers may choose not to burn for reasons unrelated to resource availability or the necessary environmental and regulatory conditions such as risk aversion, lack of incentives, and public perception. Interviewees from Schultz et al. (2018) found that managers' and employees' willingness to burn was impacted by concerns about personal liability in case of an escaped fire as well as whether legal protection would be provided even if they acted within the parameters of the burn plan. The negative consequences for employees' career and reputation from the risk of being liable for an escaped burn is noted as a deterrent for proactive wildfire mitigation using prescribed burning. Lastly, if burn windows overlap with times of high fire activity, forest managers can be subjected to pressure not to burn when a high visibility fire is occurring nearby. Thus, with minimal incentives to burn and barriers abundant, if a manger is risk averse, interviewees felt that prescribed fire would be minimal on that unit.

Schultz et al. (2019) identified the primary policy barriers for prescribed burning across the Western U.S. as insufficient personnel resources and funding, deficient incentives, and high-risk aversion at multiple agency levels using qualitative interviews of forest managers. The study observes that prescribed fire programs that were successful at increasing application of prescribed fire depended upon both the leadership and dedication of fire managers. The majority of these managers reported that limited capacity led to difficulties implementing a burn on days when the environmental conditions allowed prescribed burns to occur. This study further stressed the challenges of narrow burn windows and the overlap of these windows with the wildfire season wherein personnel are unavailable due to assignments in wildland fire suppression. Availability of necessary personnel was also observed to have been reduced by factors such as loss of seasonal workers, training activities, or annual leave.

Additional challenges for prescribed burning have been demonstrated by Quinn-Davidson et al. (2011) finding that in Northern California, prescribed burns were only able to be conducted on 38% of the land needed to fulfill their management objectives, with 66% of managers reporting dissatisfaction with the amount of prescribed fire activity achieved. These managers indicated that narrow burn windows were one of the top impediments along with legal and social barriers but that they varied based on context and land ownership. Baijnath-Rodino et al. (2022) confirmed the issue of narrow prescribed burn windows in the California context, finding that winter and spring burn windows are decreasing by 1 day per year due to declines in relative humidity. A recent study (Striplin et al., 2020) on the Lake Tahoe Basin in California found that burn windows lasting multiple days (two to three consecutive days) were very infrequent, occurring only twice per month. Given the limitations of burn windows, increasing staffing of personnel during these windows to optimize the size of burns and thus amount of land treated was deemed important. According to Striplin et al. (2020), there is significant interannual variability in the frequency of burn windows posing challenges for managers who aim to capitalize on periods when burn windows are frequent while also minimizing costs associated with keeping crews employed during times when burning opportunities are limited.

The need for research into the tradeoffs between wildfire suppression and prescribed burning given the short period of time in which prescribed burns can be accomplished is evident with the challenges facing land managers to prevent large, severe wildfires. If burn windows are becoming less frequent and shorter in duration, then efficient planning and budgeting is required to maximize the number of days spent treating the landscape and the amount of hazardous fuels removed. Reduced opportunities to conduct prescribed burns would thus require improvements in planning and resource allocation in order to achieve prescribed burning in the future in affected locations. Striplin et al. (2020) demonstrated the importance of understanding burn windows to align them with workforce schedules in order to provide sufficient personnel resources for prescribed burn implementation. This is important as the Forest Service uses these same qualified personnel for fire suppression as it does for prescribed fires, resulting in resource competition. It was also noted that there are typically fewer seasonal fire personnel available to conduct burns during the optimal prescribed burning seasons of fall, winter, and spring. Striplin et al. (2020) observed that in order to create more innovative staffing solutions, it necessary to understand how both limited wildfire personnel and regional fire activity can inhibit capacity to do prescribed burns.

3. Data

The data begins in 2014 and concludes at the end of 2021 (excluding 2020) and includes only days where conditions would allow prescribed burning, generating 828 days of observations. Due to the COVID-19 pandemic, resource assignments since 2020 changed drastically from historical trends (Belval et al., 2022; Wells et al., 2023). Additionally, prescribed burns in 2020 were expected to be much lower than usual due to COVID-19 related challenges and historic fire seasons that increased demand for personnel. A 90-day ban on prescribed burning was established in May of 2022, hence, both 2020 and 2022 were not included in the analysis. In order to understand what information was used by managers at the time, archiving the data used in decisionmakers' prescribed burning planning including local data on smoke and drought is vital. Additionally, rather than relying on personnel unavailability as a proxy for the total availability of personnel, National Forests can be cognizant of the importance of keeping accurate and consistent counts of daily personnel to account for any changes in the baseline workforce capacity for future analysis. Currently, this paper utilizes assignment data which provides an understanding of the unavailability or absence of personnel but the number of available personnel a National Forest could change due to time spent on official leave or training.

3.1 Response Variable

The response variable of interest is *Prescribed Burns*. A prescribed burn is defined as applying fire to an area for the purpose of reducing fuel hazards, as a forest resource management treatment, or both. *Prescribed Burns* are represented by a single daily binary variable (Yes/No) and indicate whether or not broadcast burning occurred on a given day in the San Juan National Forest. The specific type of prescribed burn that is used here is a broadcast burn where fire is applied to the majority or all of an area with well-defined boundaries (U.S. Forest Service, 2023). Spatial and temporal data on prescribed burns was obtained from a national dataset managed by the U.S. Forest Service called the Forest Activity Tracking System (FACTS). FACTS was spatially merged with VIIRS (Visible Infrared Imaging Radiometer Suite) to detect fires via satellite. This was necessary as the dates for prescribed burns in the FACTS database can be inexact, displaying a lag of one to two days from the actual day of the fire. Spatially merging FACTS with VIIRS using GIS to get the exact dates of fires resolved this issue. The VIIRS satellite data refreshes every 12 hours, thus short duration burns and fires that occur under severe cloud cover, would be difficult to detect, resulting in reliance on the FACTS dates for these observations. The data contains all activities related to the reduction of hazardous fuels for which prescribed burns were used.

3.2 Explanatory Variable

San Juan Personnel Unavailability is the variable of interest given the hypothesized effect that increased unavailability due to assignment of personnel to other areas reduces the likelihood of prescribed burns. It represents the number of personnel from the San Juan that are on assignment on a given day, deployed somewhere other than the San Juan National Forest and therefore unavailable to assist with prescribed burns. Personnel are the primary resource type of interest and is the aggregated count of Crew, Air, Equipment, and Overhead crew positions into a single variable. These different position types are the key personnel for conducting a prescribed burn. Data on personnel assignments came from the Resource Ordering and Status System (ROSS; 2014-2019) and the Interagency Resource Ordering Capacity (IROC; 2020-present). The ROSS/IROC software houses the main database that tracks the supply and demand for wildland fire resources in the US and is used by resource dispatchers to manage personnel requests from wildfire incidents (Belval et al., 2020).

3.3 Control Variables

There are several control variables needed to isolate the effect of personnel unavailability on the likelihood of a prescribed burn occurring. This is due to the influence that smoke ventilation rates, local fire activity, drought, and Preparedness Levels (PLs, which reflect fuel conditions and weather) can have on the ability and decision to conduct a burn.

The smoke transportation or ventilation rate is needed to account for adequate dispersion of smoke on a given day to maintain healthy air quality levels. Smoke data is important as prescribed burns are authorized under a burn permit and must meet a set of environmental regulations to maintain air quality and safety standards including NEPA (National Environmental Policy Act). This data is sourced from the Grand Junction National Weather Service and is measured using radiosonde balloons that are filled with hydrogen or helium, rise to high elevations, and measure pressure, temperature, and relative humidity. Adequate or "Fair" ventilation rates to meet standards are defined as an index of 40,000 or above, "Good" at a level of 60,000 or above. However, 60,000 is the defined minimum in this model to account for the 100-mile distance between the San Juan National Forest and the Grand Junction Weather Station. The smoke transportation rate is measured by multiplying the mixing altitude of the atmosphere (feet) by the wind speed (average transport speed of winds in knots) and represents the ability of the atmosphere to disperse of pollutants like smoke (*Fire Weather Operating Plan: Fire Weather Services for Most of Missouri and Adjacent Counties of Eastern Kansas, Southern Illinois,* *Southwest Indiana, and Western Kentucky*, 2016). The higher the rate, the greater the removal of smoke away from a fire. This data was used to create the Smoke variable (*Smoke5D)* used in this analysis, which is a five-day moving average of smoke transport rates with a 1 indicating that rates are 60,000 or above, adequate for a prescribed burn.

Local Fire Activity is a count of the daily number of local fires in the San Juan NF from 2014-2022. Fire activity is controlled for at the local level to account for the infeasibility of conducting prescribed burns while active wildfires are occurring on the SJNF, primarily due to the weather and fuel conditions. Local fire occurrence data was sourced from a FireFamily Plus Fires dataset (2014-2020) and the 2020-2022 years was provided by the Colorado Durango Interagency Dispatch Center. The greater the number of local fires, the greater the potential for pressure in terms of resource requests to respond to these fires, but also the reduced likelihood that managers would feel conditions where right for a prescribed burn.

Drought is measured as an index and comes from the U.S. Drought monitor map to create a single value for a specific area. These values are called DSCI or Drought Severity and Coverage Index and were pulled for the San Juan area to account for drought in the prescribed burning decision-making process. DSCI values range from 0 to 500, ranging from drought-free without any abnormally dry conditions, to all of an area experiencing exceptional drought, respectively.

The next important control variable is *Preparedness Level* (PL). Preparedness level variables exist at the regional and the national level. For this research, the focus will be on the

National PL level which is defined as “Increments of planning and organizational readiness” and are based on resource availability, fire activity, and forecasted burning conditions for a region or the nation. (*Preparedness Level | NWCG*, 2023) Preparedness levels range from 1 to 5 (lowest to highest) and escalate or deescalate based on changes in conditions conducive for large fire growth and the current temperatures, weather, fuel moistures, and resource commitment and mobilization levels. For this research, we find that prescribed burning does not occur at PL 4 or 5 (see Table 1). The National PL level is determined by the National Multi-Agency Coordination Group (NMAC) with the goal of ensuring suppression resource availability as wildfire incidents emerge across the country.

Table 1: The distribution of Prescribed Burns across National Preparedness Levels

	Prescribed Burn (Yes/No)		
National PL	0 (No)	1 (Yes)	Total
1	298	13	311
2	347	18	365
3	74	1	75
4	37	0	37
5	40	0	40
Total	**796**	**32**	**828**

The Early Season dummy variable was introduced to test for managers preferences to conduct burns earlier or later in the year, coded as 1 and 0, respectively. The data was filtered for specific months when prescribed burns are possible with the "Early season" comprised of April, May, and June, and "Late season" including only September and October. Additionally, an off-season control variable *October* was implemented to account for potential changes in baseline personnel availability that may result from seasonal employee turnover. Turnover occurs from October to March but burns have only been significantly observed during October. During the off-season of October, personnel capacity was estimated to be reduced by approximately 50% (C. Newman, personal communication, February 24, 2023).

3.4 Uncontained Large Fires

A second measure of fire activity is Uncontained Large Fires which provides a count of fires in the U.S. Wildfires are only included in the Uncontained Large Fire metric if they are significantly sized and managed under a full suppression strategy per the Incident Management Situation Report (ISMR) (Predictive Services, 2019). The criterion for a significantly sized fire is 300 acres for grass and brush fuels and 100 acres in timber fuels.

3.5 Data Statistics and Filters

Table 2 contains the summary statistics for each variable in the empirical analyses. The average number of San Juan personnel unavailable for a given day is approximately 26 with a standard deviation of approximately 21 and potential values up to 97, demonstrating the wide variability of how many personnel are unavailable during prescribed burn windows. Prescribed Burns occur on only a small proportion of about only 4% of all days in the dataset. PL 4/5 and PL 3 each represent 9% of days while nearly 82% of days are at PL 1/2. Additionally, an average 13 large fires per day with a max of 65 indicates how much wildfire activity and the implied demand for personnel for suppressing these wildfires can change throughout the season.

Table 2: Summary Statistics for the study period (2014-2022)

Variable	Count	Mean	Median	Std. Dev.	Min.	Max.
Response Variable						
Prescribed Burns	828	0.04		.1928695	0	1
Explanatory Variable						
Personnel Unavailable	828	26.51	22	20.74824	1	97
Control Variables						
Smoke Dispersal	828	0.79		.4110539	0	1
Local Fire Count	828	0.64		1.575051	0	21
Drought Index	828	213.15	191.75	173.3401	0	499.38
Natl PL 1 & 2	828	.816425		.3873711	0	1
Natl PL 3	828	0.09		.287184	0	1
Natl PL 4 & 5	828	0.09		.2906012	0	1
Early Dummy	828	0.57		.4955376	0	1
Off Season	*828*	*0.20*		*.404175*	*0*	*1*
Instrumental Variable						
Uncontained Large Fires	828	13.43	10	12.86181	0	65

The 828 observations are the product of dropping data using two "filters" to create a reduced sample size specific to studying the times when prescribed burning is feasible based on historical occurrences. The first applied filter is Burn Forecast which captures the environmental suitability of being able to conduct a burn on a given day based on minimum and maximum temperatures, relative humidity, daily wind speed and direction, as well as fuel moisture levels. Burn forecast is represented as a percentage of whether a day was conducive to prescribed burning, ranging from very unlikely (0%) to very likely (100%) anywhere in the San Juan National Forest with the cutoff at 50% likelihood being used in the model to capture the majority of conducted prescribed burns. Utilizing 50% for the cutoff accounts for the variability in burn opportunities on the SJNF, with some areas being very suitable for burning when the forest as a whole is not given fuel conditions. For example, the burn forecast can be lower if it is likely a prescribed fire would not burn enough due to colder, wetter conditions, or conversely, if it is likely the fire could escape when conditions are hot and dry. Burn Forecast was developed as a decision support tool for managers to identify opportunities for prescribed burn treatments based on models that used RAWS (Remote Automated Weather Station) weather data. The burn forecast was key to choosing the San Juan National Forest as a case study to understand the effects of resource competition on prescribed burning during burn windows since it was the one of the first to be developed that is easily accessible. The development of burn forecast is an example of the importance of investing in decision support tools for both research and management applications as otherwise, empirical analysis would not be possible.

The data is then filtered a second time to isolate months that prescribed burns could feasibly take place. Selecting only specific months in which most prescribed burns occurred (89%) yields a sample size of 828 observations. While this sample size is smaller, it is more appropriate for understanding the true effect of resource competition on the decision to conduct a prescribed burn given the necessary environmental conditions to do so. The filter for month includes April, May, June, September, and October. Furthermore, for each day within these months, not all burns occurred when the burn forecast was a 1 (100%), rather 53% of fires occurred below this threshold. Thus, the second filter includes all days with a burn forecast of 50% (0.50) or greater. Combined, these two filters yield 32 prescribed burns, removing 5 from the unfiltered sample of 37.

4. Methods

4.1 Empirical Strategy: Ordinary Least Squares (OLS)

The OLS linear probability model is represented in Equation (1) where prescribed burns depend on the key variable of San Juan Personnel Unavailability for *t* day and *y* year. All control variables relevant to prescribed burn decisions are included.

$$(1)\ \textit{Prescribed Burn}_{ty} = \beta_0 + \beta_1\, \textit{Personnel Unavailability}_{ty} + \beta_2\, \textit{PL4/5}_{ty} + \beta_3\, \textit{PL3}_{ty} + \beta_4\, \textit{Drought}_{ty} + \beta_5\, \textit{Local Fires}_{ty} + \beta_6\, \textit{Smoke Ventilation} + \beta_7\, \textit{Early}_{ty} + e_{ty}$$

All control variables in equation (1) are dummy variables except for *Drought* and *Local Fires*. Each dummy variables takes on a value of one if true and zero if false. For Preparedness Level, *PL 1/2* is the base case, and *PL 4* is grouped with *PL 5* given that prescribed burning is equally unlikely at either level. The expected relationship between the San Juan *Personnel Unavailability* and *Prescribed Burns* is negative with a burn being less likely as workers become assigned elsewhere and thus unavailable to conduct burns. A negative relationship is also expected for the variables of *Drought, Local Fires, and PL4/5* as drier conditions can prevent prescribed burns as well as increased need for resources to suppress local fires. The coefficient on *Smoke Ventilation* is expected to be positive as a 1 indicates adequate smoke transport rates to facilitate a prescribed burn. As for *Early Season*, a negative coefficient is expected with managers anecdotally having a preference to burn in the fall given that the coming winter season provides security in terms of preventing burns from getting out of control and developing into wildfires.

4.2 Empirical Strategy: Instrumental Variables

In order to empirically obtain a causal estimate of the unavailability of personnel on prescribed burns, an instrumental variable (IV) approach is utilized to control for endogeneity between San Juan Personnel and the error term. IV helps to control for estimation bias due to endogenous variability, for example, personnel assignments being correlated with variables that are omitted from the model. Omitted variable bias would result in a regression with biased coefficients, providing a non-causal relationship that does not reflect the true effect of personnel unavailability on prescribed burns. Utilizing IV to overcome concerns where personnel is endogenously related to the error term requires the instrument to strongly correlate with personnel yet be unrelated to unobservable endogenous factors (Wooldridge, 2012). The coefficient on prescribed burns can be estimated consistently from omitted variables by using only the part of the variability in personnel that is uncorrelated with omitted variables. Compared to the initial linear regression, IV isolates the average direct effect of the treatment (personnel unavailability count) on the outcome (prescribed burns) independent of the observed sources of variability (*Instrumental Variables - an Overview | ScienceDirect Topics*, 2023).

The variable of *uncontained large fires* is the selected instrument given the expected significant relationship with the count of San Juan Personnel unavailable. This instrument is not expected to have any direct effect on our outcome variable of Prescribed Burns except through the unavailability of personnel conditional on the inclusion of the control variables like Preparedness Level. Controlling for Preparedness Level accounts for the political environment regarding strained personnel resource capacity and wildfire activity that influences forest managers decision to conduct a burn. Large fires cause surges in demand for personnel to suppress them, drawing upon the qualified resources of National Forests like the San Juan. When controlling for the primary factors that affect the prescribed burns, we can expect *uncontained large fires* to exert influence on them only through the instrumented personnel unavailability. The less this instrument correlates with the unobserved influences in the error term, the more consistent the estimate will be and the more likely the true effect will be estimated between personnel and prescribed burns. The validity of this instrument holds conditional on the inclusion of controls for preparedness level and factors that drive prescribed burns.

To estimate the impact of personnel on the likelihood of broadcast burning using an instrumental variable, *uncontained large fires* provide a source of exogeneity to identify the variation in personnel that is not correlated with the error term which accounts for measurement error and omitted variable bias. The *Uncontained large fires* variable is used to instrument for personnel as it is correlated with personnel unavailability but not a determinant of broadcast burns nor is it correlated with unmeasured confounding variables in the error. The exogeneity of uncontained large wildfires is aided by the benefit of being random in terms of when they ignite and thus the variable is unlikely to be correlated with the error term. Large wildfires are relatively random due to the nature of the events that ignite them such as lightning and human activities from power transmission line failures and railroad transportation to grilling and exploding target shooting (National Wildfire Coordinating Group, 2020). *Uncontained large fires* is a count of wildfires nationwide, located outside of the San Juan National Forest, that are managed under a full suppression strategy and are at least 100 acres in timber fuels or 300 acres in grass fuels (Predictive Services, 2019). The decision to manage a fire under a full suppression strategy has historically been the default and is made by agency administrators who are the managers of the land on which the fire is burning. Conditional on the controls in the model like Preparedness levels (PL), large fires outside the SJNF are expected to only affect outcome the of prescribed burns through personnel unavailability. Since forest managers don't have any control over these uncontained large fires across the nation, it is reasonable to treat this variable as exogenous as it does not enter the decision-making process to conduct prescribed burns directly (except through the unavailability of personnel).

An instrument must also be correlated with the explanatory variable of personnel to satisfy the relevance condition. The *uncontained large fires* instrument demonstrates this with a significant F statistic of 73.640 for the Cragg-Donald Wald F test was found for the IV-YD model, significantly higher than the Stock-Yogo critical value of 16.38. Additionally, there is a moderately strong, positive relationship (0.60) between *uncontained large fires and* personnel unavailability. This allows us to isolate the part of personnel unavailability that is explained by *uncontained large fires*. A positive relationship is expected as increased wildfire occurrences creates demand for personnel to suppress them, re-assigning them away from their local forest. A relevant instrument helps identify the causal effect of personnel on prescribed burns by exploiting the exogenous variation in large wildfires. Although Preparedness level is correlated with the instrument of *uncontained large fires,* the effect of this is *c*ontrolled for by including PL in the model.

The demand for both wildfire suppression and prescribed burning creates competition for personnel. To investigate this tension, personnel unavailable is regressed on broadcast burns, instrumenting the latter with large fires. The count of personnel unavailable is used as a proxy for resource competition. The exclusion restriction implied by the instrumental variable regression is that, conditional on the controls included in the model, uncontained large fires has no effect of on the likelihood of a prescribed burn, other than their effect through personnel unavailability. A concern with this exclusion restriction is that the estimates of large fires could be correlated with other factors that also influence broadcast burns. Controls are included for a number of variables that could be potentially correlated with broadcast burns such as weather, drought, and National Preparedness level (PL). Surprisingly, contrary to the results of qualitative studies, the instrumental variables estimate of the effect of personnel on broadcast burns is relatively small, positive, and statistically insignificant. The estimates change remarkably little when controls are included for seasonal employment and day of the year, but they do yield a negative coefficient on *Personnel* which aligns with the theorized decrease in burns as unavailability increases.

In the below equations, a forest managers decision to conduct a prescribed burn is modeled by estimating the relationship between personnel and prescribed burns, accounting for the primary factors that inform the decision. Each stage has its own respective error term.

(2) $\textit{Prescribed Burn}_{ty} = \delta_0 + \delta_1 \textit{ Personnel Instrument}_{ty} + \delta_2 \textit{ PL4/5}_{ty} + \delta_3 \textit{ PL3}_{ty} + \delta_4 \textit{ Drought}_{ty} + \delta_5 \textit{ Local Fires}_{ty} + \delta_6 \textit{ Smoke Ventilation} + \delta_7 \textit{ Early}_{ty} + \delta_8 \textit{ Year Dummies}_y + u_{ty}$

where *Prescribed Burn* is whether a burn occurred on a given date *t* in year *y*. The variable *Year Dummies* represents all the different coefficients for the years 2014-2021 (excluding 2020). The base case for the Year Dummies is 2015.

(3) $\textit{Personnel Instrument}_{ty} = \beta_0 + \beta_1 \textit{ Uncontained Large Fires}_{ty} + \beta_2 \textit{ PL4/5}_{ty} + \beta_3 \textit{ PL3}_{ty} + \beta_4 \textit{ Drought}_{ty} + \beta_5 \textit{ Local Fires}_{ty} + \beta_6 \textit{ Smoke Ventillation}_{ty} + \beta_7 \textit{Early}_{ty} + \beta_8 \textit{ Year Dummies}_y + e_{ty}$

The second stage of the IV model is presented in Equation (2) and estimates the effect of personnel unavailability on prescribed burns using the Large Fires-Personnel instrument, controlling for factors that could affect decisions. This equation is intended to isolate the causal effect of resource competition as measured by resource unavailability on the likelihood of prescribed burns.

5. Results

Column (1) of Table 3 presents the results of the OLS model, full results are in the appendix. The coefficient on *personnel unavailability* appears significant yet has a positive coefficient, indicating an increase in prescribed burns when the number of unavailable personnel increases, contradicting the hypothesized relationship and previous qualitative research. Specifically, it indicates that for an additional 10 personnel that are unavailable, the likelihood of prescribed burning increases by 1 percentage point. However, this OLS is likely biased and inconsistent. This bias may come from correlation of personnel unavailability with the error term (endogeneity). Endogeneity in the OLS model may arise from measurement error from our personnel variable by using the unavailability rather than explicit availability of personnel resources to measure resource scarcity. Additionally, omitted variable bias could be driving the coefficient on personnel for prescribed burns, overestimating its impact. Picking up influencers from both omitted variables and measurement error, the OLS estimate can become biased and inconsistent which can be addressed with an instrumental variables approach which will yield consistent estimators.

Column (2) of Table 3 shows the second stage results from the instrumental variables regression without year dummies, instrumenting personnel with uncontained large wildfires to address endogeneity concerns. First stage regression results in Panel B of Table (3) confirms the hypothesis of a significant, positive relationship between personnel *unavailability* and *uncontained large Fires*, satisfying the relevance condition necessary for instrumental variables. Column (3) incorporates year dummy (YD) variables to the IV model resulting in the coefficients that further decrease in size and the standard errors increase as the year dummy specification causes variance reduction. Column (3), Panel A yields results with an insignificant coefficient on *personnel unavailability*; hence this research does not detect an effect of personnel unavailability on prescribed burns.

Table 3– OLS and IV Regressions of Prescribed Burns

	OLS (1)	*IV* (2)	*IV-YD* (3)
Panel A: Second Stage Left-hand side variable: Prescribed Burn			
Personnel Unavailability	0.00101** (0.000368)	0.000470 (0.00118)	0.000444 (0.00125)
Control Variables	Y	Y	Y
Year Dummies	N	N	Y
Panel B: First Stage Left-hand side variable: Personnel Unavailable			
Uncontained Large Fires		0.63125*** (0.0971)	0.78369*** (0.0981)
Control Variables		Y	Y
Year Dummies		N	Y
Observations	828	828	828
F-Statistic (Cragg-Donald Wald)		42.357	73.640

Robust Standard errors in parentheses
In all regressions, the dependent variable is Prescribed Burn.
Control variables used: Drought, Local Fire Activity Count, Smoke Ventilation, Early Season, PL3 and PL 4/5.
*p<0.05, ** p<0.01, *** p<0.001
Base year is 2015.

One potential issue to address is the possibility of weak instruments, where the selected instrument is weakly correlated with the endogenous variable resulting in unreliable estimations (Andrews et al., 2018). The Cragg-Donald Wald F statistic is included in Table (3) as a weak instrument identification test to demonstrate the validity of the Uncontained-Large-Fire instrument. A F statistic of 73.640 for the Cragg-Donald Wald F test was found for the IV-YD model, significantly higher than the Stock-Yogo critical value of 16.38, thus there is little statistical evidence of a weak instrument.

In addition to the use of IV regression, year dummy variables help account for unobserved differences across the years in the data. The year dummies account for time-invariant factors that are correlated with the independent variables. Year dummies can benefit the model in theory by controlling for factors that change each year that are common across the San Juan National Forest in a given year. The rationale for using year dummies is that administrative changes, policy directives restricting prescribed burns, and national directives to release personnel for suppression imply that each year is an entity of its own with unique trends.

5.1 Robustness Checks

The robustness of the results of the Instrumental Variables model with Year Dummies (IV-YD) in column (1) of Table (4) can be tested by incorporating additional controls or altering model specifications. The complete results of Table (4) can be found in the appendix. Column (4) includes a day of the year variable called *Date Count* to control for autocorrelation as is common in time series data. The results however indicate that although the coefficient on *personnel* unavailability becomes negative, improvements to the model are minimal and do not improve coefficients sufficiently to achieve statistical significance. Column (3) is presented without the *early* season variable due to the high degree of correlation between season and date count (-0.9456) but there is not a substantial change to the results. Lastly, column (2) incorporates the off-season *October* variable to account for seasonal personnel which results in the expected negative coefficient, but *Personnel* remains statistically insignificant. The Cragg-Donald Wald F-statistic is included again in Table (4) for each model as a weak instrument identification test to demonstrate the validity of the Uncontained-Large-Fire instrument. Values were all found to be significantly higher than the respective Stock-Yogo critical values, thus there is insufficient statistical evidence of a weak instrument.

Table 4: Robustness check regression results

	IV-YD (1)	*IV-YD-October* (2)	*IV-YD W/o Early* (3)	*IV-YD Date Count* (4)
Panel A: Second Stage — Left-hand side variable: Prescribed Burn				
Personnel Unavailable	0.000444 (0.00125)	-0.000469 (0.00139)	0.000489 (0.00133)	-0.000516 (0.00128)
Control Variables	Y	Y	N	Y
Year Dummies	Y	Y	Y	Y
October	N	Y	N	N
Date Count	N	N	N	Y
Panel B: First Stage — Left-hand side variable: Personnel Unavailable				
Uncontained Large Fires	0.78369*** (0.0981)	0.68499*** (.10472)	0.75898*** (0.0991)	0.74762*** (.09032)
Control Variables	Y	Y	Y	Y
Year Dummies	Y	Y	Y	Y
October	N	Y	N	N
Date Count	N	N	N	Y
Observations	828	828	828	828
F-Statistic (Cragg-Donald Wald)	73.640	51.826	66.395	83.809

Robust Standard errors in parentheses
In all regressions, the dependent variable is Prescribed Burn.
Control variables used: Drought, Local Fire Activity Count, Smoke Ventilation, Early Season, PL3 and PL 4/5.
* p<0.05, ** p<0.01, *** p<0.001
Base year is 2015.

6. Discussion

The results presented above suggest that the hypothesized effects of reduced resource capacity due to wildfire suppression cannot be confirmed to have reduced prescribed burning in the study area. One concern is the small number of prescribed burns (32) in the 828 days which represents approximately only 4% of the total. This limitation of the data makes modeling decisions regarding prescribed burning amidst resource competition challenging and helps explain the lack of a significant observed effect in the model.

However, it is unsurprising that prescribed burns are infrequent given the barriers to conducting them. It is possible that the small number of prescribed burns is the product of barriers unrelated to a lack of personnel such as disincentives, insufficient program funding, and risk aversion of decisionmakers (Schultz et al., 2019). However, it is also possible that the sample size creates difficulty in accurately determining the causal effect of personnel on prescribed burns. An additional potential data limitation is the personnel variable that measures unavailable personnel per day without, however, accounting for changes in the baseline availability. If personnel become unavailable due to reasons unrelated to reassignment, it would be not captured, violating the assumption that the baseline is relatively constant. Thus, measurement for personnel capacity would not capture the true value.

Although a small number of burns could be the primary inhibitor to providing a significant result, additional challenges exist for examining this question. In analyzing the effects of resource competition on the frequency and therefore ability of forest managers to conduct prescribed burns, it is important to note the difficulty in modeling this question due to the challenges facing decision-makers. A wide range of issues from overtime and hazard pay, burn-inhibiting wildlife regulations, and the overlap between resource training and burn windows can influence decisions on prescribed burns. These are examples of the many situation-specific challenges that can make modeling difficult. However, the role of known barriers such as funding limitations and multi-level risk aversion also deserve further examination. Under-investment in wildfire mitigation treatments like prescribed burning is a driver of funding issues (Burke et al., 2020) and is starting to be addressed with the Forest Service spending over $2 billion on fuels-related projects, $500 million for prescribed fire alone starting in 2022 through 2026 (Gabbert, 2022).

Although the results from this research did not yield conclusive evidence that resource competition has causally reduced the number of prescribed burns in the San Juan National Forest, it has provided a contribution to the framework for studying the effects of resource competition on prescribed burns can provide a reference for future research. Incorporating additional National Forests' data could bolster the sample size to provide a more robust and accurate estimates that demonstrate the tension from sharing personnel resources between suppression and prescribed burning assignments. A national study incorporating archived regional weather data as well as localized measures of the same key variables used in this study would be a feasible and informative next step. An instrumental variables probit model may be an additional model to run as a next step as it may improve the estimates. Probit models account for the binary nature of our response variable *Prescribed Burn* and may provide improved predicted probabilities for binary outcomes 0 and 1. This model assumes that the endogenous covariates are continuous, which is suitable for our *Personnel Unavailability* variable.

The choice between a linear probability model (LPM) with instrumental variables and an instrumental variables probit model depends partially on interpretability. The LPM, despite its simplicity, offers the distinct advantage of interpretable coefficients. Coefficients in an LPM can be directly understood as changes in the probability of the outcome occur due to a one-unit change in the predictor, making it easier for policy analysis and communication of results. In contrast, the coefficients in a probit model are less straightforward.

Another important aspect is how probit models handle situations where there are no observations for certain values, leading to perfect prediction issues. In a probit model, when the outcome is perfectly predicted by the explanatory variables (due to lack of variation in the dependent variable for some range of the independent variable), it will cause estimation problems. The LPM, however, does not suffer from this issue to the same extent, making it a more robust choice in the presence of limited variation in the dependent variable. This is especially important considering the lack of observations of prescribed burns on days at PL level 4/5. Overall, despite the drawbacks where the LPM may predict values that are greater than 1 or less than 0, it provides a constant marginal effect as well as interpretable coefficients.

Additionally, it is worth considering the incorporation of other hazardous fuel mitigation assignments into future analyses. National Forests who prioritize lower risk methods of fuel removal like mechanical thinning may only be reducing short-term wildfire risk as after a few years, surface fuels reaccumulate. (Johnston et al., 2021b). Johnston et al. also found that mechanical thinning has been a substitute treatment for forests in the absence of prescribed fire due to the risk-averse agency culture of the Forest service and resource capacity. Further research into whether increases in mechanical thinning results in decreases in prescribed burning in a given year would be a logical next step. This would further explore findings from Schultz et al. (2018) that found prioritizing mechanical thinning on some forests resulted in insufficient remaining funds to conduct prescribed burns. Figure 1 compares the frequency of treatment types in the given study period from 2014 to 2022 where the number of prescribed burns accounts for 12.5% of the overall treatment counts on the San Juan National Forest.

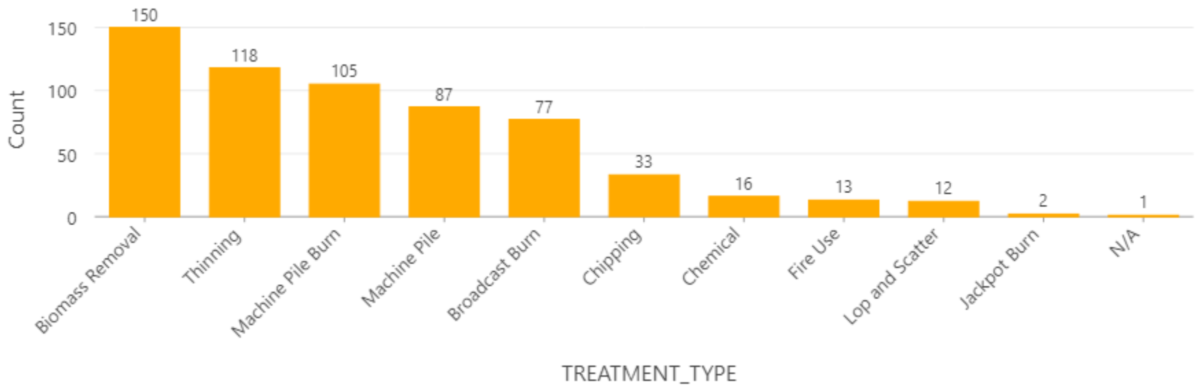


Figure 1: Hazardous fuel Treatment Type Counts for the San Juan National Forest (2014-2022)

Forests which are only able to conduct activities like thinning (which are not as dependent on specific burn windows or ample resource availability) could also struggle to mitigate wildfire risk and meet management objectives. Research suggests that the most effective fuel reduction treatment includes both mechanical thinning followed by prescribed burning as each remove different types of fuels (Kennedy et al., 2019) Thus, they should not be viewed as substitutes but complements in effective forest management for reducing wildfire severity. Future research thus could analyze whether treated areas receive both mechanical thinning and prescribed burning, and if these treatments are impeded by resource competition from wildfire suppression. This is especially important as it could demonstrate the role of resource competition from suppression in preventing fuel treatments and thus increasing wildfire deficits and risk.

Extending upon this study in the future with additional data such as daily personnel availability metrics could improve estimates. The San Juan National Forest standardized its personnel recording systems in 2021 allowing for future researchers to have an accurate assessment of the true number of personnel available without relying on personnel assignments to measure those who are unavailable. Changes in seasonal and permanent employee availability as well as changes in job vacancy rate could result in a fluctuating baseline of personnel, providing potential challenges to estimating the effect of resource unavailability on decisions to burn. It also would be worth investigating how the monsoon season in Southwest Colorado yields unique challenges to burn, with opportunities arising simultaneously with high PL levels and the end of most seasonal employees' availability. Future research may also incorporate other fire resource types into the analysis to account for issues related to not only having sufficient personnel, but sufficient qualified personnel. Schultz et al. (2018) noted that not having enough qualified personnel can pose challenges to conducting prescribed burns, emphasizing the need to have the right people available at the right time.

Furthermore, reflecting on Figures 2 and 3 below, the importance of this research is likely to be increasingly important as the fire deficit grows. A fire deficit is the result of insufficient prescribed burns measured by the number of fire cycles missed for a given acre of land results. Areas in a fire deficit are likely to have accumulated fuel due to a reduction in burning over a long period of time resulting in increased risk of large, severe wildfires. Both figures demonstrate the scale (hundreds of thousands of acres) and the scope of the problem (extending the width of the forest).

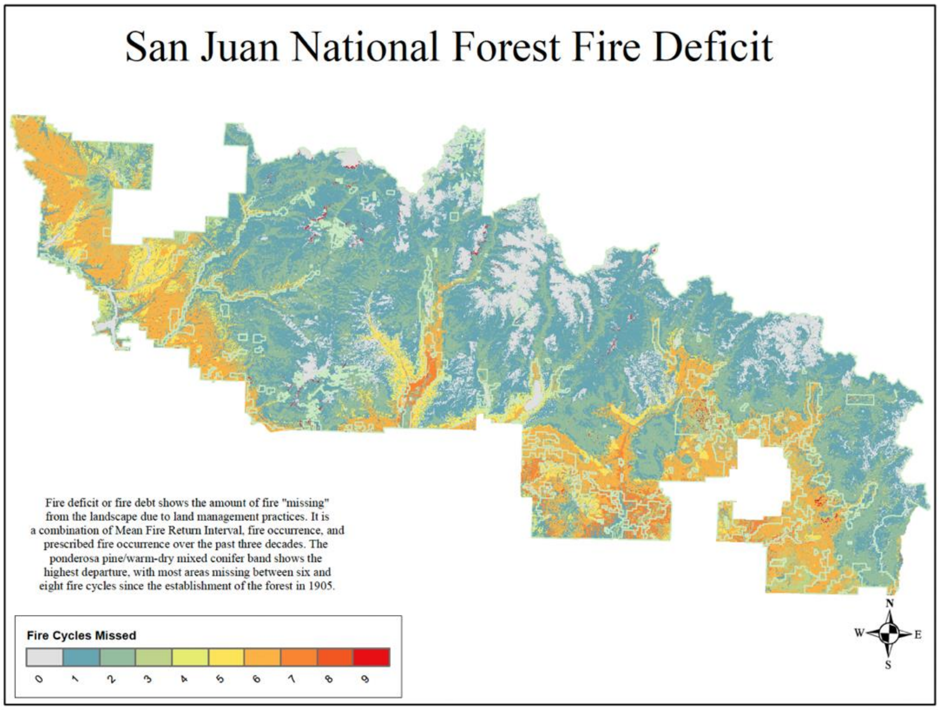


Figure 2: Source: San Juan National Forest: Brad Pietruszka, Fire Management Specialist, Rocky Mountain Research Station, US Forest Service. Data source: LANDFIRE, San Juan Land Resource Management Plan (LRMP), LANDFIRE Existing Vegetation Type Data, and SJNF 1905-2019 fire history of prescribed and wildfire. Pixel values are fire cycles missed.

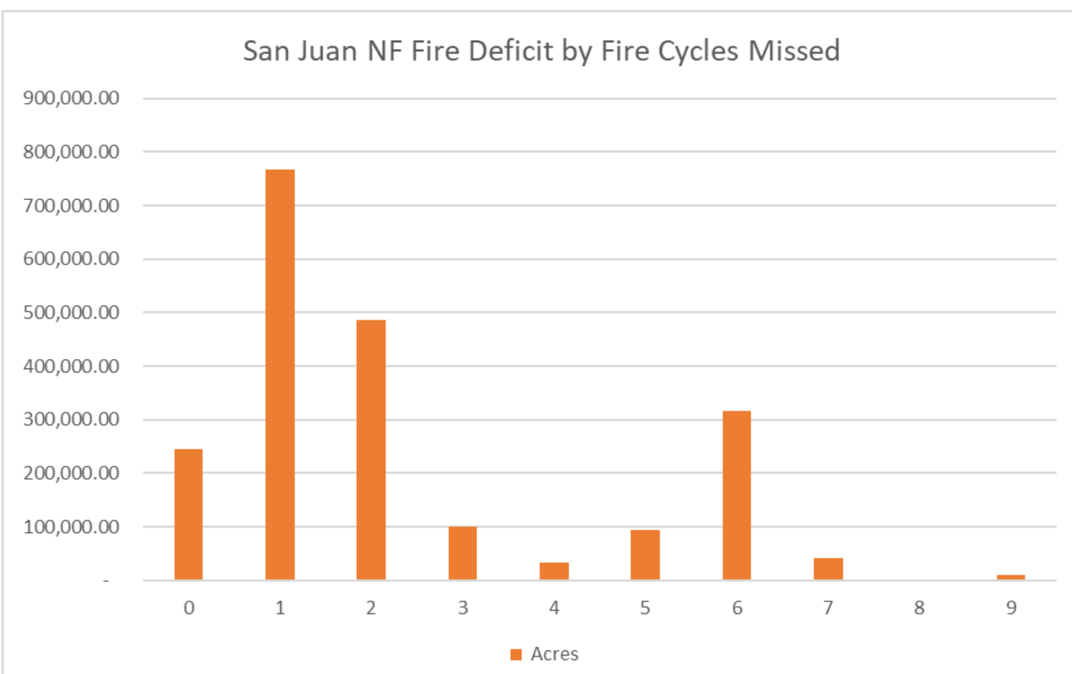


Figure 3: Source: San Juan National Forest: Brad Pietruszka, Fire Management Specialist, Rocky Mountain Research Station, US Forest Service. Data source: LANDFIRE, San Juan Land Resource Management Plan (LRMP), LANDFIRE Existing Vegetation Type Data, and SJNF 1905-2019 fire history of prescribed and wildfire. Y axis represents number of acres, x axis is the number of fire cycles missed.

6.1 Solutions to Prescribed Burn Resource Barriers

Although this study did not estimate a decrease in the likelihood of prescribed burns due to personnel limitations, it is important to understand the solutions to addressing personnel shortages for future research in the context of labor force planning to outline the potential challenges facing forest managers in achieving prescribed burning targets. Solutions to resource barriers in the context of suppression of wildfires has been studied providing potential insights for alleviating competition with prescribed burning. The scarcity of fire suppression personnel has been studied recently by Belval et al. (2020), noting the challenges from personnel availability in responding to the demand for these resources to suppress wildfires. The authors identified issues with how the forest service currently tracks resource use such that resource demand and scarcity metrics may mischaracterize the problem and make it hard to devise appropriate solutions. Three potential solutions were presented to address resource scarcity: (1) add more resources to the system, (2) improve the efficiency of existing resource use, and (3) restricting use of personnel in situations where they are likely ineffective. The solutions are not without caveats given that efficiency improvements cannot be made until an understanding of how they are used and how effective they are is researched. Furthermore, adding additional common pool wildfire personnel resources may simply incentivize managers to continue to over-order resources and restrictions on resource usage cannot be implemented easily without addressing conflicting agency priorities of fire management policy and varying inclinations for beneficial fire opportunities.

Schultz et al. (2018) recommends three solutions to ameliorate the personnel shortages that could be preventing prescribed fires from being conducted: create dedicated prescribed fire crews which would not be available to suppress wildfires, organize fire personnel so that they are easier to share between forests depending on the need and ability to conduct priority prescribed burns, and increase the involvement of outside organizations on prescribed burns like The Nature Conservancy and local fire departments. These solutions would help ensure resource capacity even during times of increased wildfire activity. One additional solution posed included incentives such as hazardous fuel reduction goals solely from treating acres with prescribed fire as well as creating dedicated funds for prescribed fire. Providing training to managers on how to navigate concerns over personal liability was also suggested to reduce hesitancy to burn. Schultz et al. (2019) also recommends creating financial incentives for qualified personnel to favor prescribed burning assignments to overcome the current incentives for wildfire suppression assignments. To meet the challenges of changing climate, declining budgets, and shrinking staffs, Striplin et al. (2020) suggested sharing financial and personnel resources with a unified program as Forest Service Region 5 does. Region 5's *One Region, One Program of Work* unites all National Forests in its region to share crews, personnel, and funding. The authors also recommend staggering seasonal personnel crew start and end dates allows for the possibility of increased staffing in the spring and autumn and is one potential solution along with dedicated crews for prescribed burning.

7. Conclusion

In conclusion, this research focused on quantitatively analyzing the impact of personnel availability on the likelihood of prescribed burns in the San Juan National Forest. The expected negative impact of personnel unavailability on prescribed burning from was not observed. While this paper cannot provide conclusive evidence that resource competition has causally reduced the number of prescribed burns, it provides a contribution to the framework for studying the effects of resource competition on prescribed burns primarily in empirically testing this problem, obtaining a causal estimate using an instrumental variables approach, and integrating a new and unqiue dataset.

Using personnel assignment data from 2014 to 2021, an instrumental variables model was used to analyze the impact of personnel unavailability on prescribed burns. The IV results revealed an unexpected small, positive, but statistically insignificant relationship between personnel unavailability and prescribed burns, failing to find the hypothesized negative relationship. This discrepancy could be attributed to limitations in the dataset, including relying on personnel unavailability as a proxy for the total availability of personnel. This study's results emphasize the complex dynamics in forest management, where factors such as financial incentives, risk aversion, and regulatory hurdles could significantly influence decisions to conduct prescribed burning. Additionally, public concerns over air quality, budget constraints, a lack of qualified personnel, and increasingly infrequent opportunities to burn could also be limiting prescribed burns. Future research could incorporate more comprehensive data sources, like daily personnel availability metrics, as well as examine the relationship between personnel availability and different fuel mitigation methods, such as mechanical thinning.

In order to address and overcome potential personnel-related barriers to prescribed burning to ensure resource capacity even during heightened wildfire activity, previous research suggests the following solutions: creating dedicated prescribed fire crews, enhancing resource sharing between forests, increasing involvement of external organizations, and the establishing financial incentives for personnel to prioritize prescribed burns. By clarifying the critical role of personnel in effective prescribed burning, future research on this topic can provide valuable insights for policy development and forest management to improve wildfire mitigation strategies.

Appendix

Glossary and List of Acronyms

1. **Risk:** Here, the mathematical relationship between a (usually scalar) measure of loss (such as number of people killed) and the frequency with which that level of loss is exceeded, e.g., in times per year.

2. **Wildland** : An area in which development is essentially nonexistent, except for roads, railroads, power lines, and similar facilities.

3. **Wildland-urban Interface:** The geographical area where structures and other human development meet or intermingle with wildland or vegetative fuels. (Glossary of Wildland Fire Terminology, 1996)

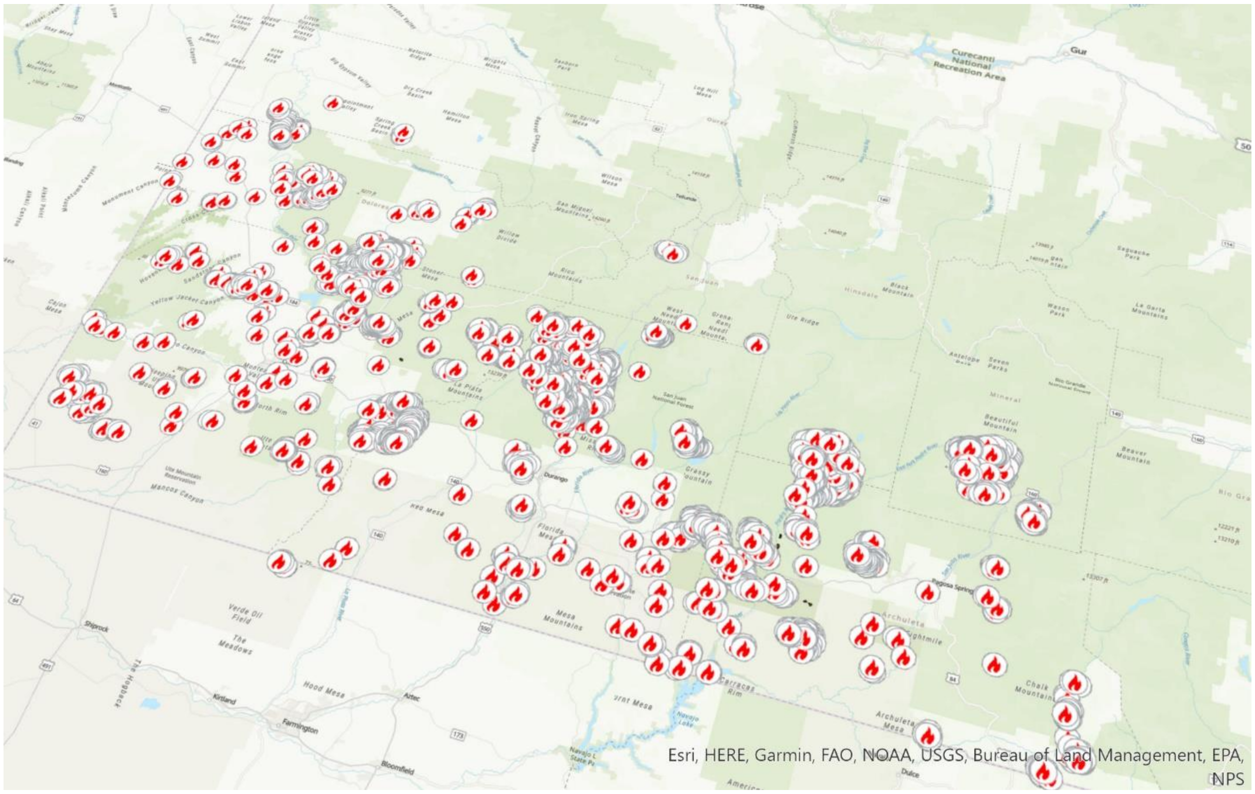
4. **Wildfire Suppression:** Also known as firefighting, is the procedure or activity of mitigating the results of fire that already has started.

5. **Broadcast Burning** – A type of prescribed burn. "Covers a majority of the unit: Prescribed burning activity where fire is applied to the majority or all of an area within well- defined boundaries for reduction of fuel hazard, as a resource management treatment, or both." (U.S. Forest Service, 2023).

regeneration.

6. **National Forest:** In the United States, National Forest is a classification of protected and managed federal lands that are largely forest and woodland areas. They are managed by the United States Forest Service, a division of the United States Department of Agriculture.

Appendix Figure A. Distribution of VIIRS satellite fire detections on the San Juan NF



Appendix Figure B. VIIRS Satellite detections of Wildfires and Prescribed Fires

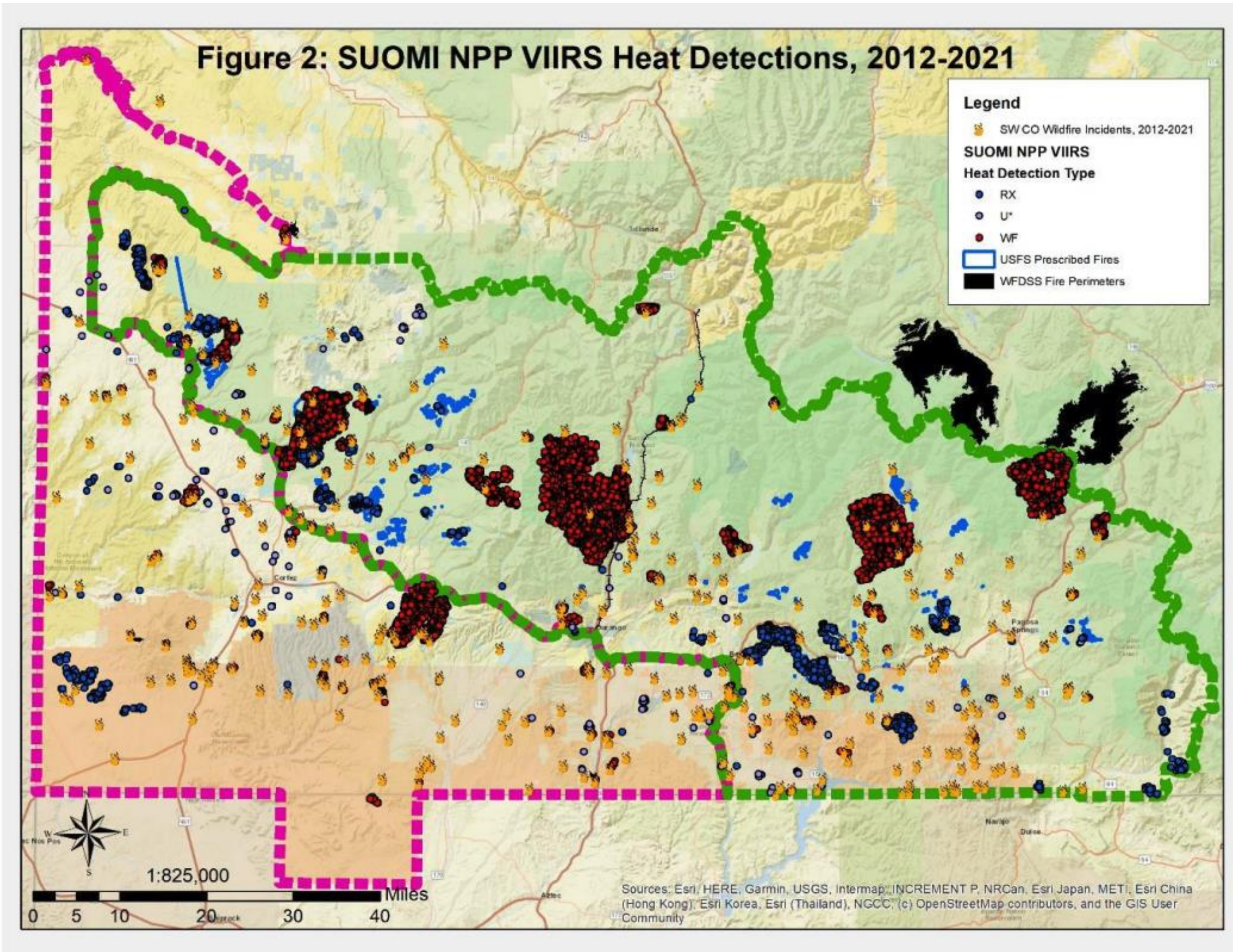


Figure B demonstrates the number of VIIRS fire detections in the San Juan, sorted by wildfire (red circles) and prescribed fire (blue circles).

Appendix Table 3– Full results for OLS and IV Regressions of Prescribed Burns

	OLS *(1)*	*IV* *(2)*	*IV-YD* *(3)*
	Panel A: Second Stage Left-hand side variable: Prescribed Burn		
Personnel Unavailable	0.00101** (0.000368)	0.000470 (0.00118)	0.000444 (0.00125)
National PL 4/5	-0.0839** (0.0263)	-0.0713* (0.0361)	-0.0560 (0.0415)
National PL 3	-0.0523* (0.0247)	-0.0473* (0.0228)	-0.0255 (0.0250)
Smoke Dummy	0.0253 (0.0189)	0.0313 (0.0173)	0.0436* (0.0208)
Drought	0.00000352 (0.0000391)	0.00000441 (0.0000352)	-0.000111 (0.000154)
Local Fires	-0.00471 (0.00448)	-0.00335 (0.00346)	-0.00329 (0.00346)
Early	-0.0337* (0.0167)	-0.0313 (0.0219)	-0.0123 (0.0256)
2014			0.103 (0.0529)
2016			-0.0398 (0.0268)
2017			-0.0372 (0.0294)
2018			0.00844 (0.0564)
2019			0.0494 (0.0408)
2021			0.0364 (0.0336)

Panel B: First Stage
Left-hand side variable: Personnel Unavailable

Uncontained Large Fires		0.63125***	0.78369***
		(0.0971)	(0.0981)
National PL 4/5		.1759237*	2.2106
		(4.3349)	(4.0255)
National PL 3		.5037849	2.8563
		(2.8934)	(2.5486)
Smoke Dummy		-.003236***	9.6651***
		(.003851)	(1.1691)
Drought		10.7574	-.01599
		(1.3984)	(.0096513)
Local Fires		2.40716***	2.2579***
		(.56827)	(.4497321)
Early		4.44517**	8.7887***
		(1.4710)	(1.2563)
2014			13.387***
			(2.2878)
2016			-6.9514**
			(2.1108)
2017			.877527
			(2.4668)
2018			11.8386**
			(3.9186)
2019			15.3758***
			(1.9521)
2021			-5.9069*
			(2.8104)
Observations	828	828	828

F-Statistic (Cragg-Donald Wald)	42.357	73.640

Robust Standard errors in parentheses
In all regressions, the dependent variable is (Prescribed Burn).
*p<0.05, ** p<0.01, *** p<0.001
Base year is 2015.

Appendix Table 4: Full results for robustness check regression results

	IV-YD (1)	*IV-YD-October* (2)	*IV-YD W/o Early* (3)	*IV-YD Date Count* (4)
Panel A: Second Stage Left-hand side variable: Prescribed Burn				
Personnel Unavailable	0.000444 (0.00125)	-0.000469 (0.00139)	0.000489 (0.00133)	-0.000516 (0.00128)
National PL 4/5	-0.0560 (0.0415)	-0.0602 (0.0416)	-0.0485 (0.0283)	-0.0645 (0.0370)
National PL 3	-0.0255 (0.0250)	-0.0226 (0.0252)	-0.0193 (0.0169)	-0.0253 (0.0214)
Smoke Dummy	0.0436* (0.0208)	0.0400 (0.0208)	0.0378 (0.0250)	0.0373* (0.0187)
Drought	-0.000111 (0.000154)	-0.000141 (0.000157)	-0.000111 (0.000153)	-0.000129 (0.000124)
Local Fires	-0.00329 (0.00346)	-0.00146 (0.00364)	-0.00379 (0.00417)	-0.00193 (0.00265)
Early Season	-0.0123 (0.0256)	-0.0332 (0.0273)		-0.104 (0.0650)
2014	0.103 (0.0529)	0.106* (0.0534)	0.110* (0.0497)	0.103* (0.0508)
2016	-0.0398 (0.0268)	-0.0468 (0.0270)	-0.0369 (0.0293)	-0.0466 (0.0264)

2017	-0.0372	-0.0325	-0.0369	-0.0311
	(0.0294)	(0.0297)	(0.0296)	(0.0281)
2018	0.00844	0.0262	0.00908	0.0242
	(0.0564)	(0.0588)	(0.0555)	(0.0466)
2019	0.0494	0.0643	0.0521	0.0635
	(0.0408)	(0.0432)	(0.0369)	(0.0391)
2021	0.0364	0.0466	0.0360	0.0448
	(0.0336)	(0.0358)	(0.0340)	(0.0294)
October		-0.0528		
		(0.0304)		
Date Count				0.000790
				(0.00105)

Panel B: First Stage
Left-hand side variable: Personnel Unavailable

Uncontained Large Fires	0.78369***	0.68499***	0.75898***	0.74762***
	(0.0981)	(.10472)	(0.0991)	(.09032)
National PL 4/5	2.2106	1.3517	-2.9942	-4.0397
	(4.0255)	(3.9306)	(4.187)	(3.8097)
National PL 3	2.8563	2.8967	-1.5746	-2.3007
	(2.5486)	(2.5070)	(2.712637)	(2.1776)
Smoke Dummy	9.6651***	7.9514***	13.395***	6.2477***
	(1.169148)	(1.2168)	(1.0919)	(1.1162)
Drought	-.01599	-.0181029	-.01519	.016802
	(.00965)	(.00965)	(.00993)	(.00792)
Local Fires	2.2579***	2.2254***	2.5315***	.725194*
	(.44973)	(.43395)	(.45059)	(.31607)
Early	8.7887***	4.7972**		19.565***
	(1.2563)	(1.7251)		(3.9237)
2014	13.387***	12.097***	8.3548***	6.0991**
	(2.2878)	(2.0969)	(2.1666)	(1.9538)

2016	-6.9514*** (2.1108)	-7.0291*** (2.1564)	-8.737*** (2.271)	-5.888** (1.9053)
2017	.87752 (2.4668)	1.4203 (2.4898)	.60927 (2.6307)	5.6302* (2.2982)
2018	11.838** (3.9186)	12.803** (3.8730)	11.021** (3.8696)	2.709 (2.9587)
2019	15.375*** (1.9521)	15.488*** (1.9552)	13.050*** (1.8924)	13.216*** (1.7374)
2021	-5.906* (2.810431)	-3.755 (2.8835)	-5.411 (2.8856)	-11.084*** (2.504602)
October		-7.283*** (1.5621)		
Date Count				.68148*** (.03941)
Date Count Squared				-.00260*** (.00018)
Observations	828	828	828	828
F-Statistic (Cragg-Donald Wald)	73.640	51.826	66.395	83.809

Robust Standard errors in parentheses
In all regressions, the dependent variable is (Prescribed Burn).
*p<0.05, ** p<0.01, *** p<0.001
Base year is 2015

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