When Nature Turns Hazy

How Wildfire Smoke Affects Outdoor Recreation

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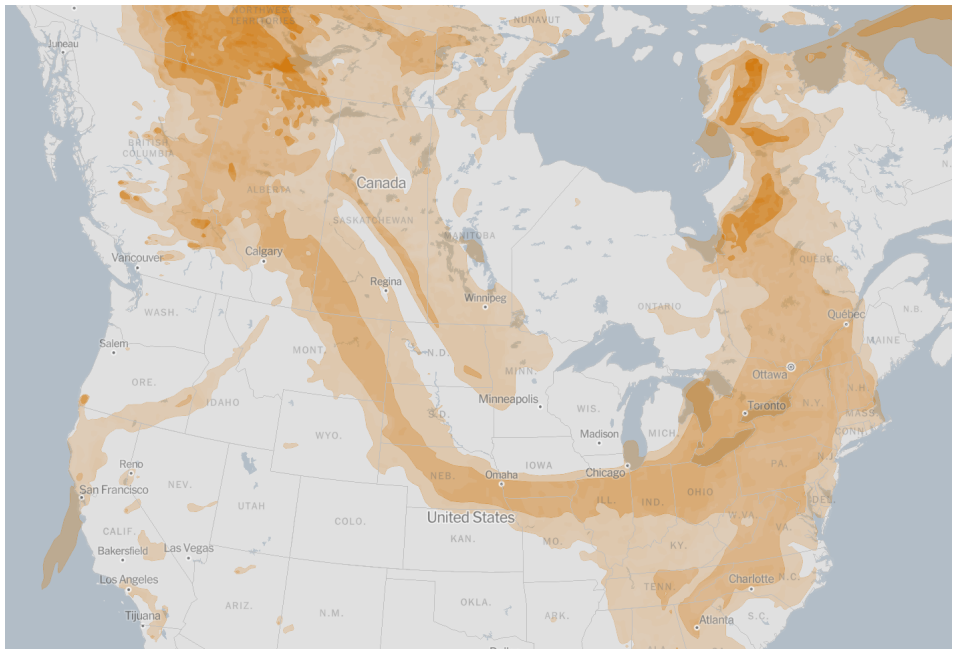
Escalating Frequencies of Wildfire Hazards

Maps: Tracking Air Quality and Smoke From Wildfires

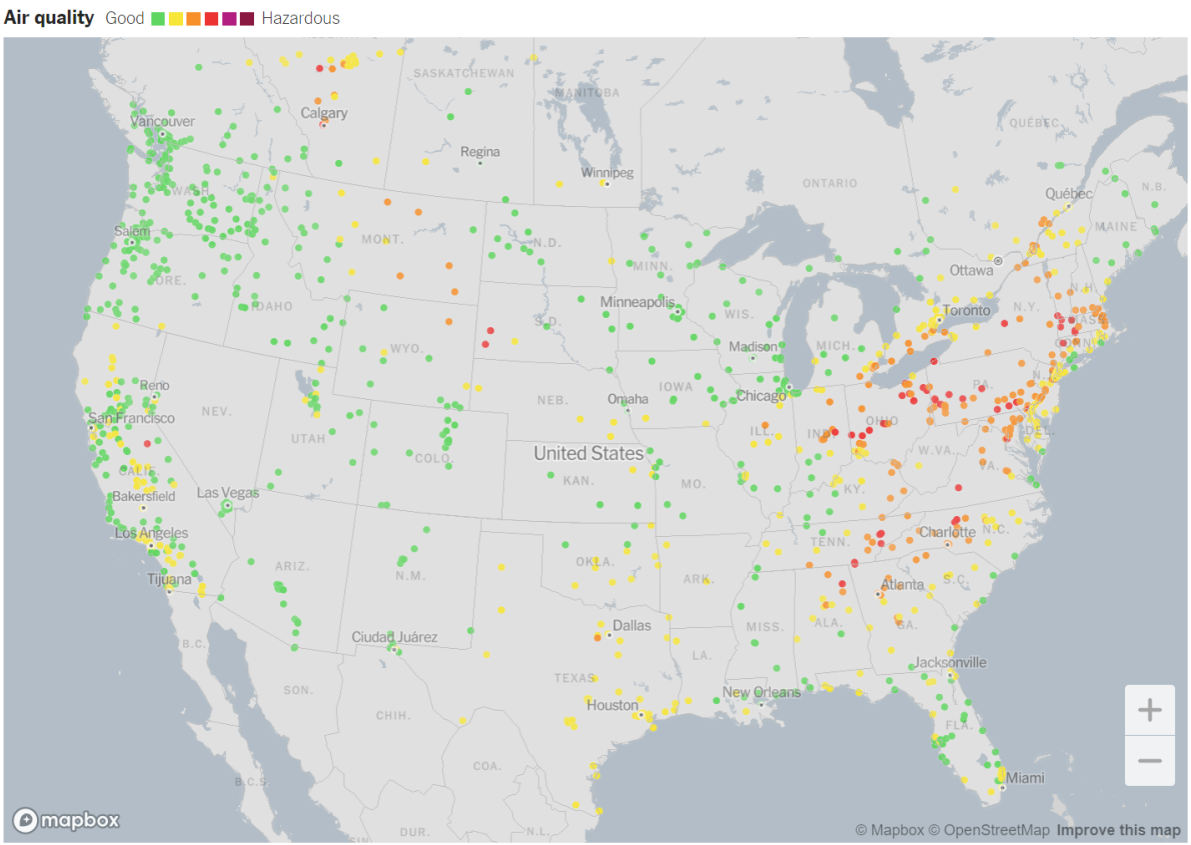
By Madison Dong, Bea Malsky, Lazaro Gamio, Matthew Bloch, Scott Reinhard, Leanne Abraham, Martín González Gómez, Judson Jones, John-Michael Murphy and Marco Hernandez Updated July 17, 2023



Escalating Frequencies of Wildfire Hazards

AQI Index

- Many U.S. cities set records due to this wildfire smoke.
- How does wildfire smoke affect recreational choices?



Source: AirNow • Note: Data is as of 2 p.m. Eastern on July 17, 2023

SELECT CITIES	AIR QUALITY	A.Q.I.
Pittsburgh	Unhealthy	160
Washington, D.C.	Unhealthy	151
New York	Unhealthy for some	149
Charlotte	Unhealthy for some	140
Baltimore	Unhealthy for some	139
Philadelphia	Unhealthy for some	138
Boston	Unhealthy for some	132
Atlanta	Unhealthy for some	132
Dallas	Unhealthy for some	131
Detroit	Unhealthy for some	131

Source: AirNow · Data is as of 2 p.m. Eastern

Recent Literature

- Recent literature examines changes to outdoor recreation
  - Survey: Richardson et al. (2012); Fowler et al. (2019), White et al. (2020)
  - Public campgrounds: Gellman et al. (2022), Gellman et al. (2023)
  - Air Pollution: Keiser et al. (2018), Graff-Zivin and Neidell (2011), Kochi et al. (2010)
- Most studies focus on urban areas, specific recreation types, or use survey data

Research Questions

- Estimate the impact of wildfire smoke on air quality and outdoor recreation nationwide

Preview

- Significant impact of wildfire smoke and air pollution on outdoor recreation: an additional day of smoke in a week is associated with a 4-6% reduction in recreation outcomes.
- Previous wildfire smoke records and current anomalies are negatively associated with recreational visit outcomes.
- Annual recreation costs of air pollution are around 309 million ($2018) per year.

Data

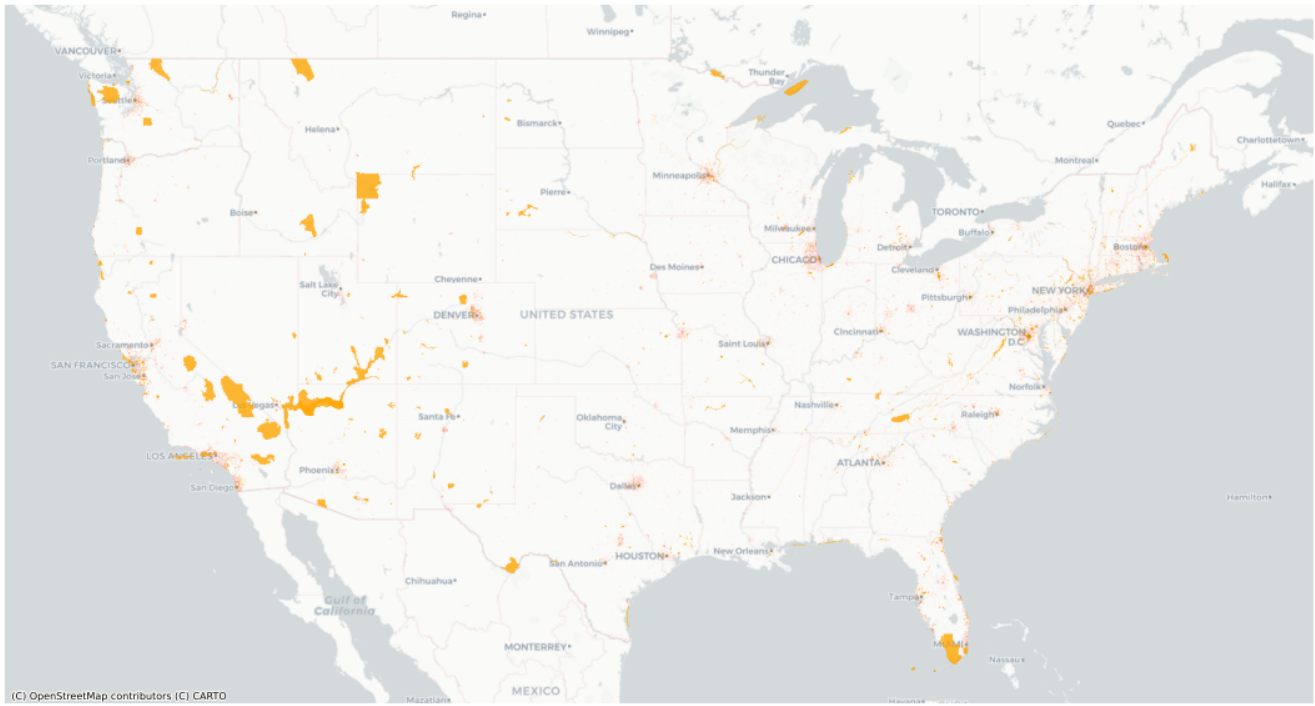
The analysis is based on four main sets of data during 2018-2019

- Outdoor Recreation Visits
- Wildfire Smoke
- Air quality
- Temperature and Precipitation

Data: Visit Pattern

Visit Pattern Data from Safe Graph

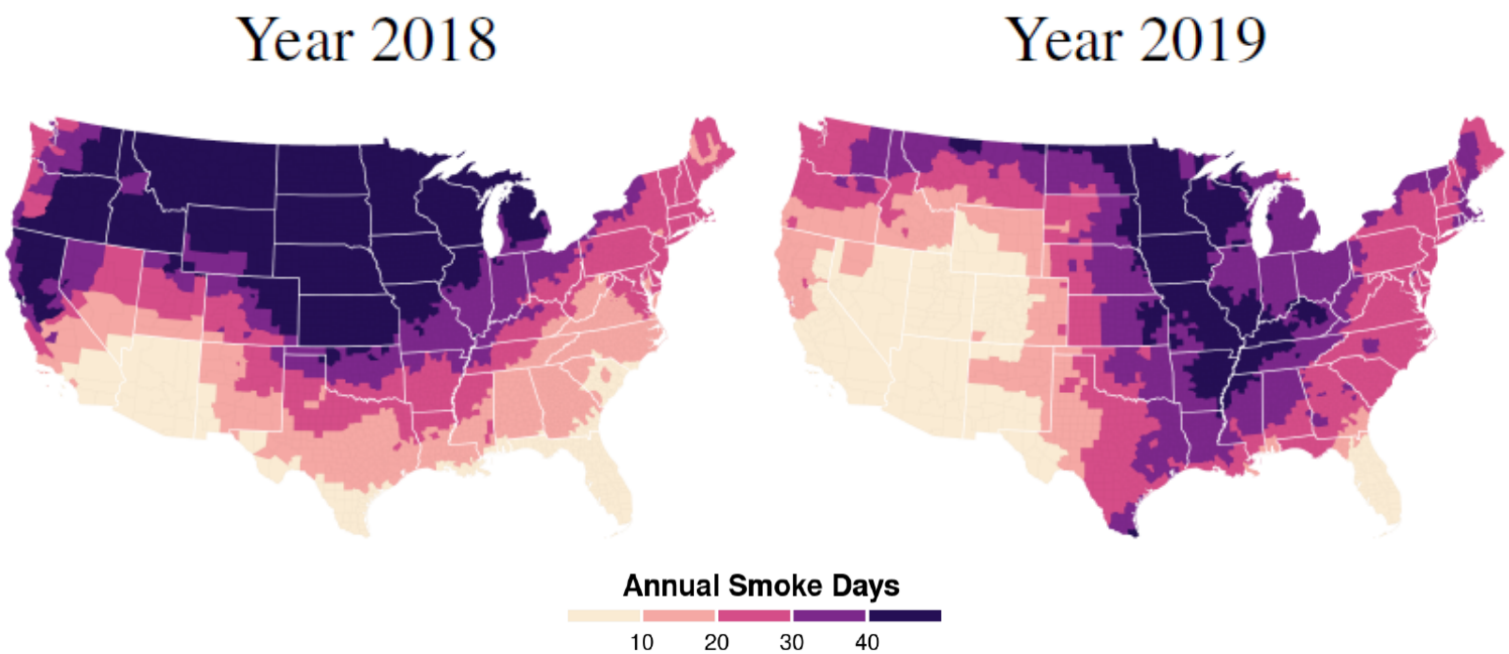
- 131k recreation sites with weekly visitation information
- Normalized visits and visitor counts by the number of devices in a county due to the increasing sample over time (Kurmann and Lalé 2022)



Data: Wildfire Smoke Plumes

Hazard Mapping System (HMS) by NOAA

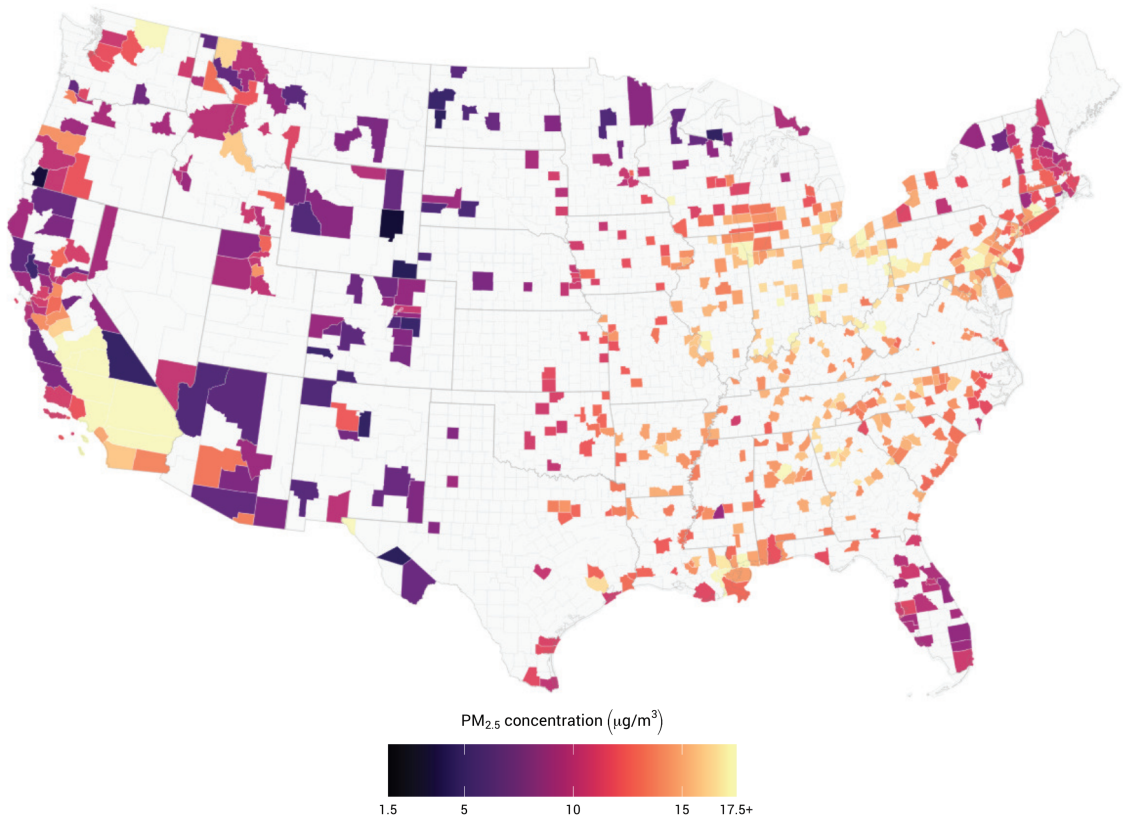
- Daily polygon files that represent the location of smoke plumes over North America
- Aggregate daily exposure to the number of days in the week site is covered by smoke



Data: Ground-level Air Quality

Air Quality System (AQS) by U.S. EPA

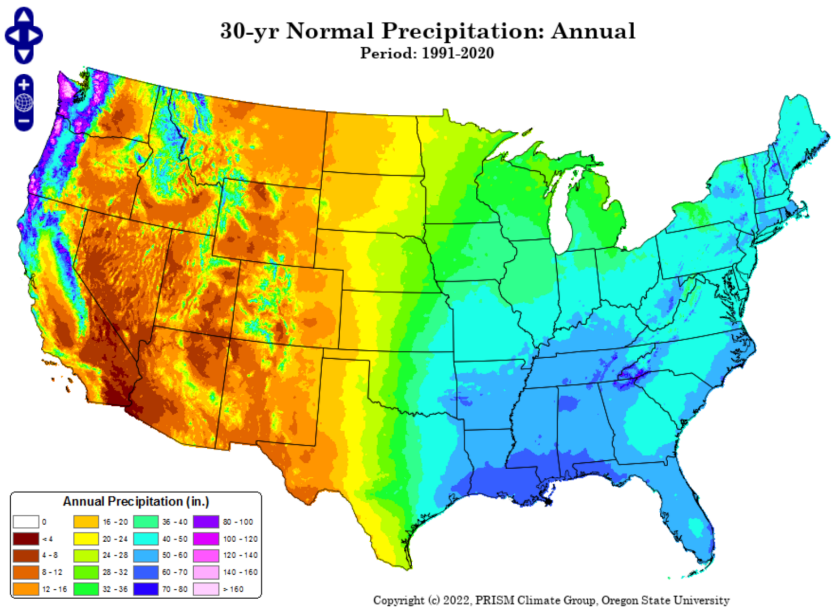
- Daily concentration data on six pollutants: PM2.5, PM10, O3, CO, NO2, and SO2
- Compute site-level pollution using inverse distance weighting within 20 miles of a site's centroid

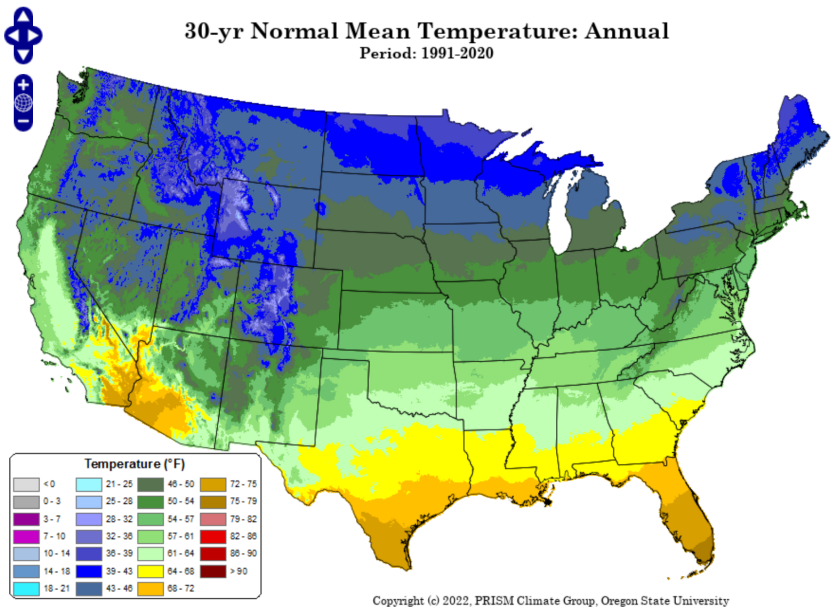


Data: Weather Conditions

PRISM Climate Group at Oregon State University

- Daily temperature and precipitation readings for all recreational sites
- Aggregate daily readings to site-specific weekly averages





Regression Analysis

Pollution regression:

$$AP_{iw} = \beta_1 SmokeDay_{iw} + \alpha_{countyxmonth\text{-}of\text{-}year} + \gamma_{statexyear} + X_{iw} + T_{cy} + \epsilon_{iw} \quad (1)$$

- AP_{iw}: Air pollutant concentration for recreational site i in week w.
- $SmokeDay_{iw}$: the number of days in a week that the recreational site is covered by smoke plumes.
- X_{iw}: decile bins of weekly precipitation, decile bins of weekly minimum temperatures, and decile bins of weekly maximum temperatures
- county-by-month and state-by-year fixed effects to control for seasonality
- county-by-year time trend T_{cy} to control for visitation trends over our study period
- The standard errors are clustered at both the county and state-by-week levels

Regression Analysis

Pollution Effects

- Significant relationship between wildfire smoke and air pollutant
- Wildfire smoke seems to have the largest impact on PM2.5

	PM2.5	PM10	Ozone	CO	NO2	SO2
Days of Smoke	1.016***	1.620***	0.001***	0.007***	0.130**	0.007**
	(0.194)	(0.339)	(0.000)	(0.002)	(0.061)	(0.004)
Observations	10336059	7344612	9427712	6812108	7439655	6872185
Outcome Mean	8.167	18.405	0.029	0.300	10.657	0.538

Table: The effect of wildfire smoke on air pollutants

Regression Analysis

Recreation outcomes regression:

$$\text{Rec}_{iw} = \beta_2 \text{SmokeDay}_{iw} + \alpha_{\text{countyxmonth-of-year}} + \gamma_{\text{statexyear}} + \text{X}_{iw} + \text{T}_{cy} + \epsilon_{iw} \quad (2)$$

- Rec_{im}: outcomes of interest such as the number of visits and number of visitors for recreational site *i* in week *w*.
  - Recreation Visits/Visitors
  - Median Travel Distance
  - Total Dwell Times (use the average dwell time of each bin to calculate the total time at a site)

Regression Analysis

Wildfire Smoke Effects

- One more day of smoke exposure in the week reduces weekly visits by 0.267 (or a 4% reduction) and visitors by 0.155 (or a 4% reduction)
- One more day of smoke exposure in the week reduces weekly dwell time by 26.496 mins (or a 4.5% reduction)

	Visits	Visitors	Mediam Distance	Total Dwell Time
Days of Smoke	-0.267***	-0.155***	-24.780	-26.496***
	(0.036)	(0.023)	(50.988)	(3.618)
Observations	8558518	8558518	7244909	8558518
Outcome Mean	6.7	3.9	25553.8	594.2

Table: The effect of wildfire smoke on recreation outcomes

Regression Analysis

Explore the effects of PM2.5 using wildfire smoke as instruments (IV)

- Assume wildfire smoke affects recreation outcomes ONLY through PM2.5

Reduced Form:

$$\text{Rec}_{iw} = \beta_2 \text{SmokeDay}_{iw} + \alpha_{\text{countyxmonth-of-year}} + \gamma_{\text{statexyear}} + X_{iw} + T_{cy} + \epsilon_{iw} \quad (3)$$

First Stage:

$$\text{PM2.5}_{iw} = \beta_1 \text{SmokeDay}_{iw} + \alpha_{\text{cxmonth-of-year}} + \gamma_{\text{statexyear}} + X_{iw} + T_{cy} + \epsilon_{iw} \quad (4)$$

Second Stage:

$$\text{Rec}_{iw} = \beta_3 \widehat{\text{PM2.5}}_{iw} + \alpha_{\text{countyxmonth-of-year}} + \gamma_{\text{statexyear}} + X_{iw} + T_{cy} + \epsilon_{iw} \quad (5)$$

Regression Analysis

IV Estimates: PM2.5 Effects

- a 1-ug/m3 increase in PM2.5 reduces weekly per capita visits by 0.221 (5.7%) and dwell time by 18.87 mins (5.5%); OLS estimates are an order of magnitude smaller than IV

	Visits	Visitors	Mediam Distance	Total Dwell Time
OLS Estimates				
pm2.5	-0.038***	-0.024***	13.270	-2.734**
	(0.014)	(0.009)	(25.384)	(1.142)
IV Estimates				
pm2.5	-0.221***	-0.135***	-36.203	-18.868***
	(0.052)	(0.032)	(57.527)	(4.562)
Kleibergen-Paap F	29.8	29.8	28.8	29.8
Observations	8558518	8558518	7244909	8558518
Outcome Mean	3.9	2.3	21840.5	344.7

Table: The effect of pm2.5 on recreation outcomes

Regression Analysis

Does visitors' beliefs on wildfire smoke exposure matter?

- Smoke exposure anomaly: Deviation from the average wildfire smoke in the past five years (2013-2017)
- a one-day increase in previous averages of smoke day leads to a 0.762 decrease in visits (11.4%)
- An additional smoke day deviating from previous averages is associated with a 0.164 visit reduction (2.45%), conditioning on the previous averages.

	Visits	Visitors	Mediam Distance	Total Dwell Time
Smoke Days Anomaly	-0.164***	-0.090***	38.421	-17.757***
	(0.029)	(0.019)	(48.252)	(2.901)
Prev. Smoke Days	-0.762***	-0.470***	-336.978***	-68.608***
	(0.061)	(0.038)	(76.458)	(6.294)
Observations	10733320	10733320	8910231	10733320
Outcome Mean	6.7	3.9	25553.8	594.2

Table: The effect of previous smoke days on recreation outcomes

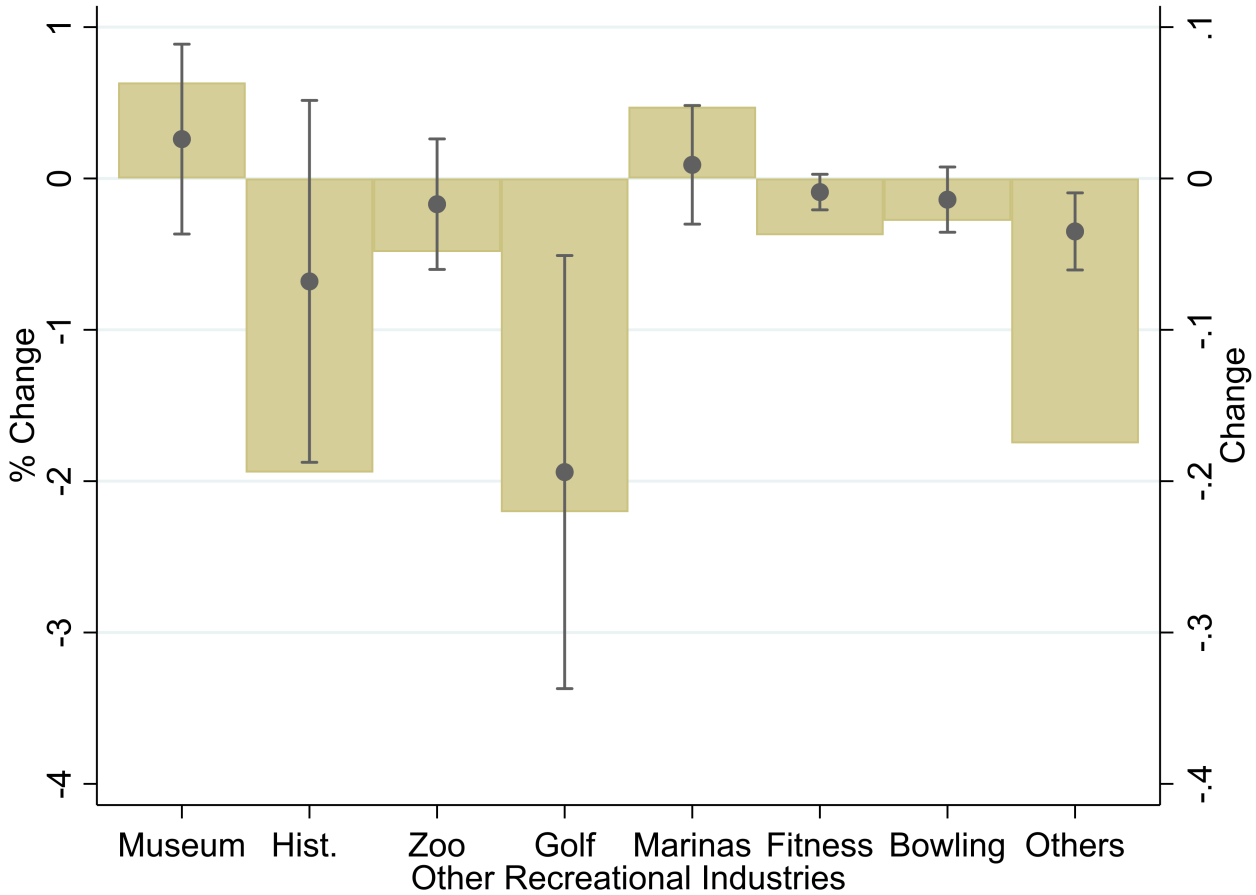
Regression Analysis

Spatial Substitutions as Adaptation

- Spatial Substitution: Other recreation options
  - Museum, Historical Sites, Zoos
  - Golf, Marinas, Fitness Center, Bowling, and All Other Recreational Industries

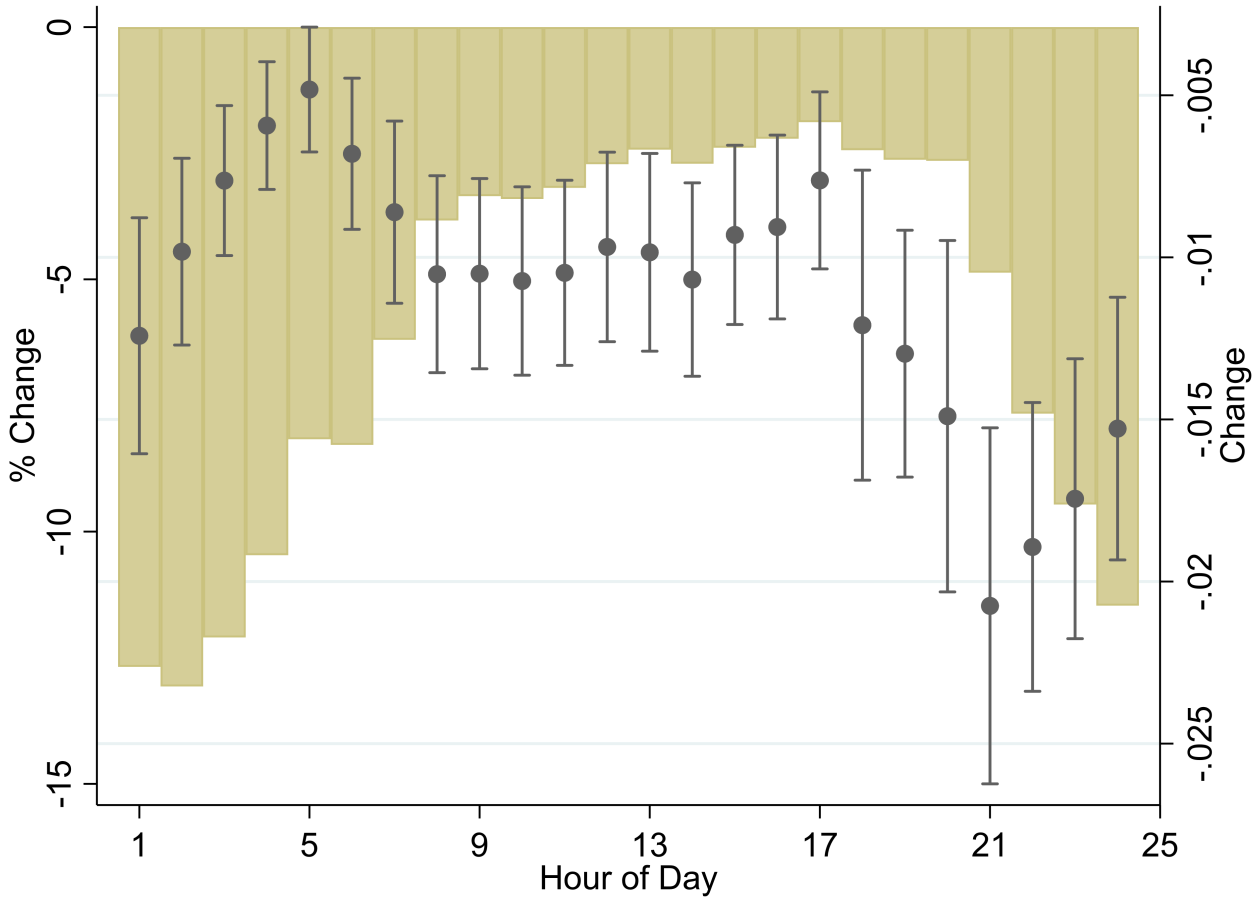
Regression Analysis

Spatial Substitution



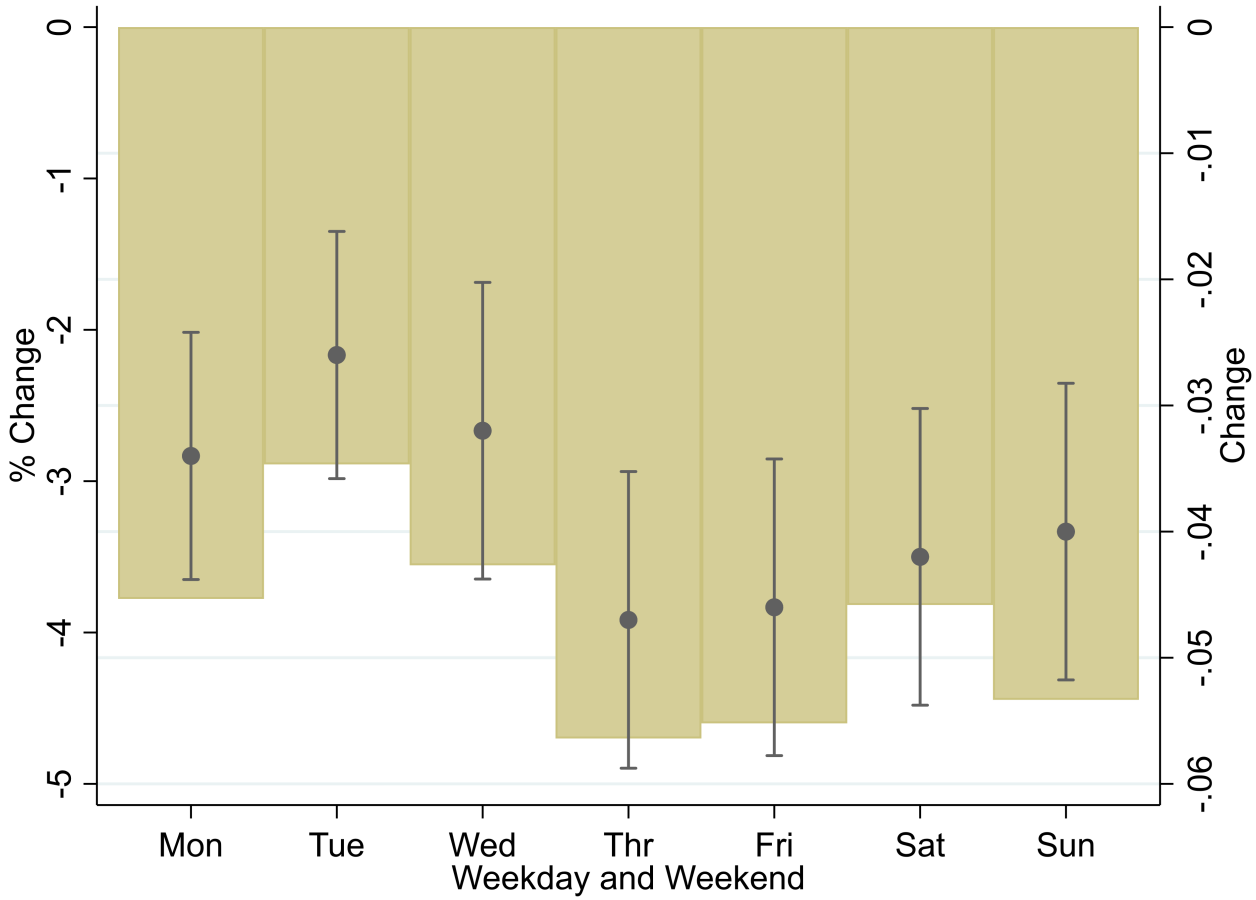
Regression Analysis

Heterogeneity: Hour of Day



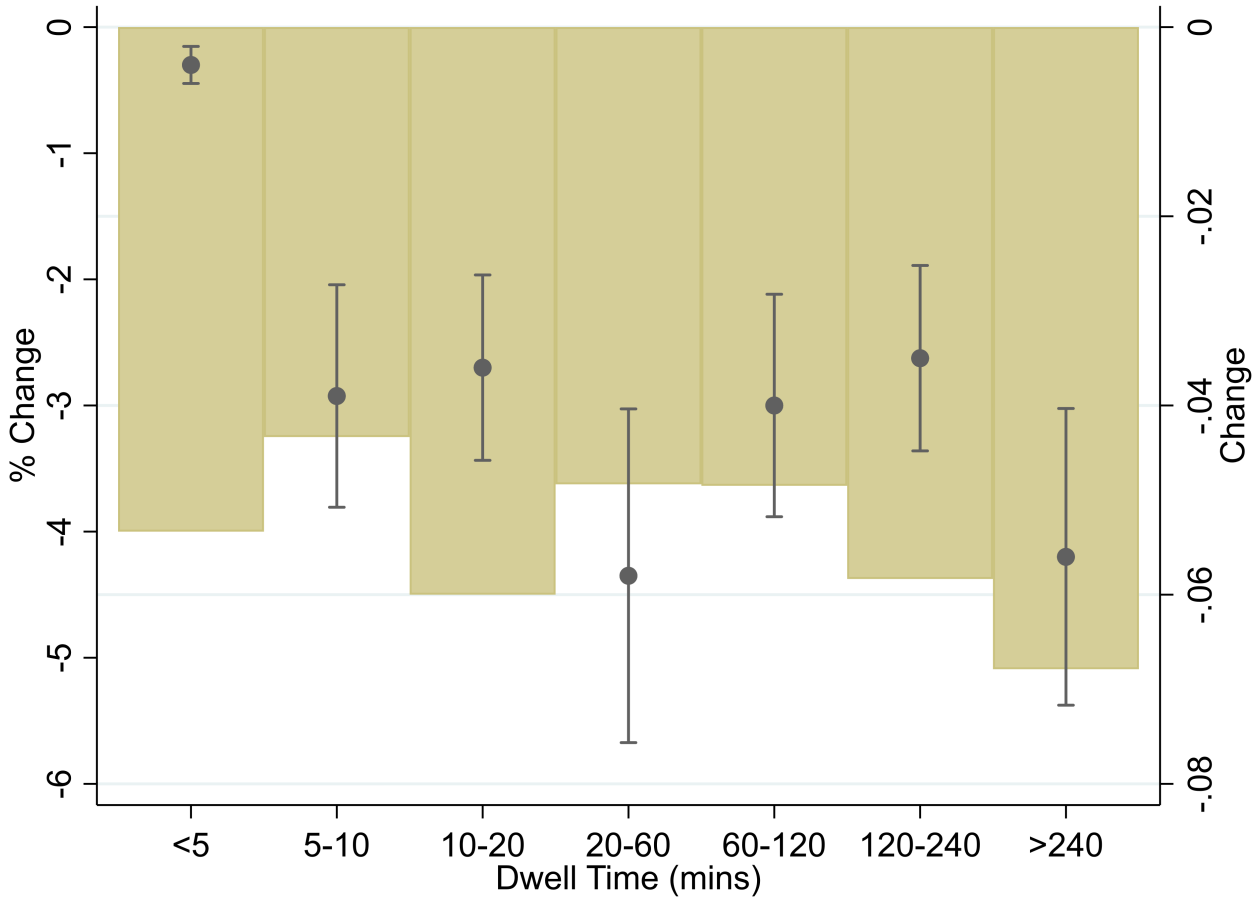
Regression Analysis

Heterogeneity: Weekday and Weekend



Regression Analysis

Heterogeneity: Dwell time



Comparison with Air Pollution Literature

Effect Size:

- The percentage change in a recreation outcome per one percent change in the level of pollution being studied: an elasticity of -0.463 (recreation-PM2.5)
- Not directly comparable with past literature on the effects of air pollution on recreation outcomes
  - 1.3% decrease in Occupancy rate due to a 1k increase in camper-day (Gellman et al. 2022)
  - 15% attendance declines due to additional smog alert (Graff-Zivin and Neidell 2011)
  - 4% visit decrease due to one unit increase in monthly average maximum ozone (Keiser et al. 2018)

Wildfire Smoke Scenarios

- Predict trip reduction based on the reduced form results
- Assume the average value of recreation activities is $38.85 per cap. per day (Recreational Use Values Database, $2018)

1. Scenario 1: additional day of smoke in a week would lead to 19.47 billion ($2018) in recreational costs
2. Scenario 2: 50% increase in the average number of smoke days in a week would lead to 5.84 billion ($2018) in recreational costs

Comparison with PM2.5 Literature

Costs Comparison per 1 ug/m3 increase in Annual PM2.5

- Average value of recreation activities is $38.85 per cap. per day (Recreational Use Values Database, $2018)
- The predicted trip reduction due to a 1 ug/m3 increase in PM2.5 is 78.8 million
- The back-of-envelope calculation suggests the recreational costs are 309 million per year ($2018)
- Labor market costs: $31 billion - $92 billion per year (Zou et al. 2022)
- Mortality costs: $8 billion - $ 31 billion per year (Zou et al. 2022)

To Conclude

- Significant impact of wildfire smoke and air pollution on outdoor recreation: an additional day of smoke in a week is associated with a 4-6% reduction in recreation outcomes.
- Previous wildfire smoke records and current anomalies are negatively associated with recreational visit outcomes.
- Annual recreation costs of air pollution are around 309 million ($2018) per year.

To Conclude

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Any Comments/Questions?