Fire's Immediate and Residual Effects on Adolescent Mental Health

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Team

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Agenda

- Motivation
- Abstract
- Natural Experiment Design
  - Data
  - Model Design
- Model Results
  - Stage 1
  - Stage 2
- Conclusion

Motivation

Problem:

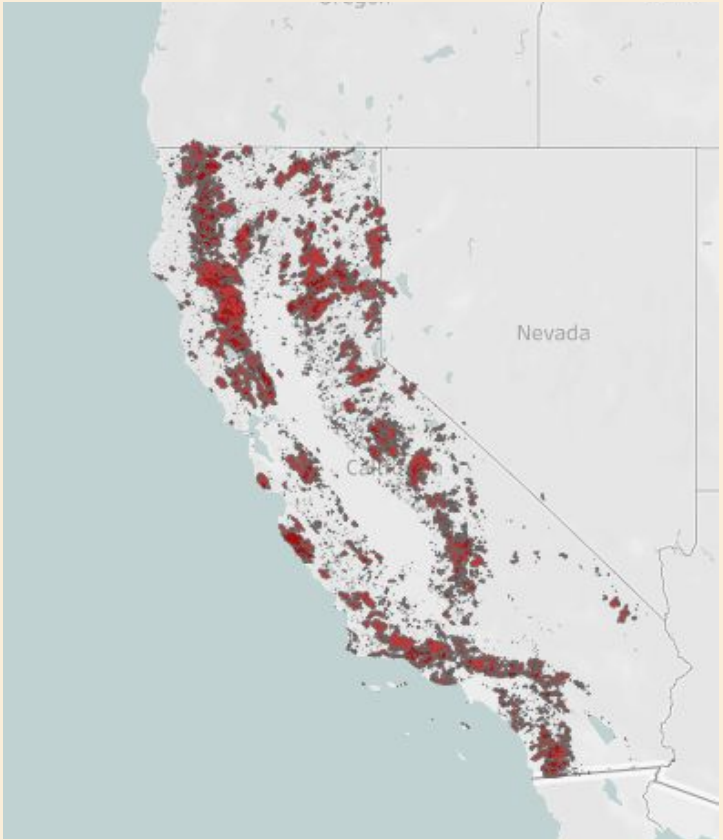
- Effects of wildfires on **physiological health** are well documented but there is little research that quantifies the **causal effect on youth mental health**

Wildfire trauma:

- Witnessing your home burning / property damage
- Fear for one's life or losing a loved one
- Feeling lack of support from family/govt
- School closures / disruption of social life
- Displacement

This research has important implications for:

- Protecting children's mental health
- Resource planning for hospitals and clinicians
- Designing better disaster responses



What Sets Our Work Apart

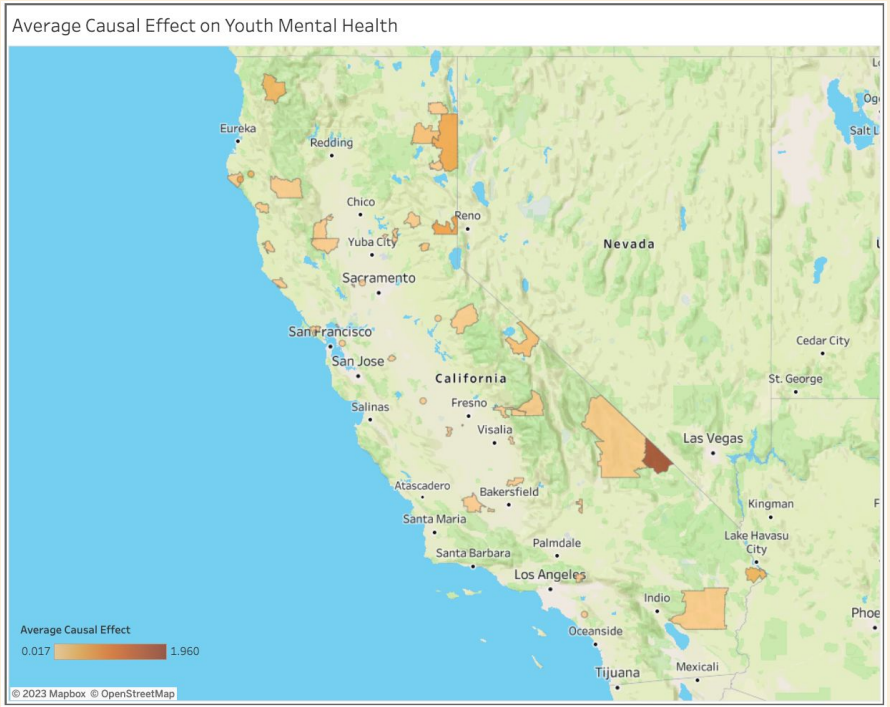
- ★ California Hospital Medical Diagnoses
- ★ Causal Effects with Novel Instrumental Variable
- ★ Childhood to Adolescence 0-19
- ★ Reproducible Model informed by Research

Diagnosis Categories

- ★ Anxiety
- ★ Depression
- ★ Self-Harm

Abstract

- Our natural experiment research suggests that wildfires in California **have a causal effect** on youth mental health through the impact on PM2.5.
- For every 10 micrograms per cubic meter monthly increase in PM2.5, the mental health incidence rate was found to increase by 1.36 percentage points on average
- The magnitude of the effect of PM2.5 on youth mental health outcomes **varies by geography**
- **Effects were similar** across anxiety, depression and self-harm
- Seasonality and zip code-specific effects are key drivers in understanding the impact of PM2.5



1. Tufts Medical Center and One Mind at Work | GoodTherapy.org

Experimental Design

RESEARCH
- Review literature on wildfires and youth mental health
- Research wildfire response programs
- Conduct expert interviews to inform our work

DESIGN
- Use a natural experiment to establish causality

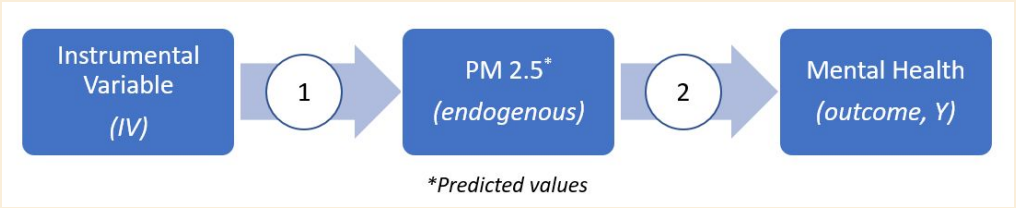
DATA
- Use panel data on wildfires, particulate matter (PM2.5) in the air, wind, and demographics at zip code level over time

MODEL
- Requires a causal modeling approach using an instrumental variable and 2 stage OLS regression

Domain Expert

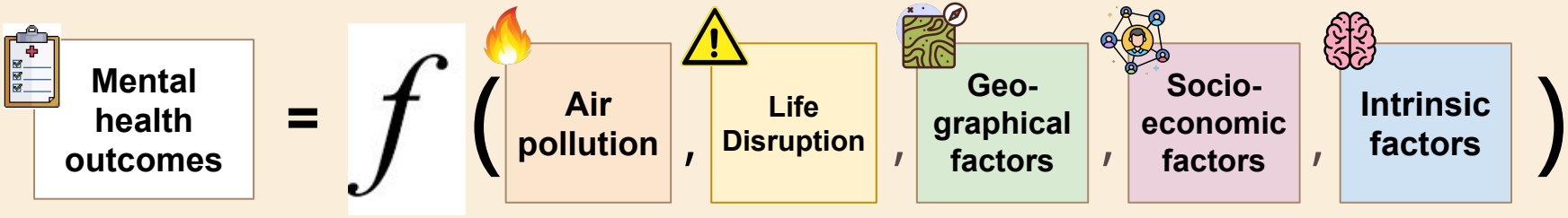
Dr. Shannon Wiltsey Stirman, PhD
Associate Professor in Psychology

2 Stage Least Squares Regression



Modeling Approach

Our mental health model



Data

Geospatial

- Wind speed and direction
- Temperature
- Elevation

PM2.5 & Wildfires

- PM 2.5
- California wildfires

Demographic

- 2010 Census Data
  Ex: mean/median income per household by zip

Hospital Patient Data (2000-2016)

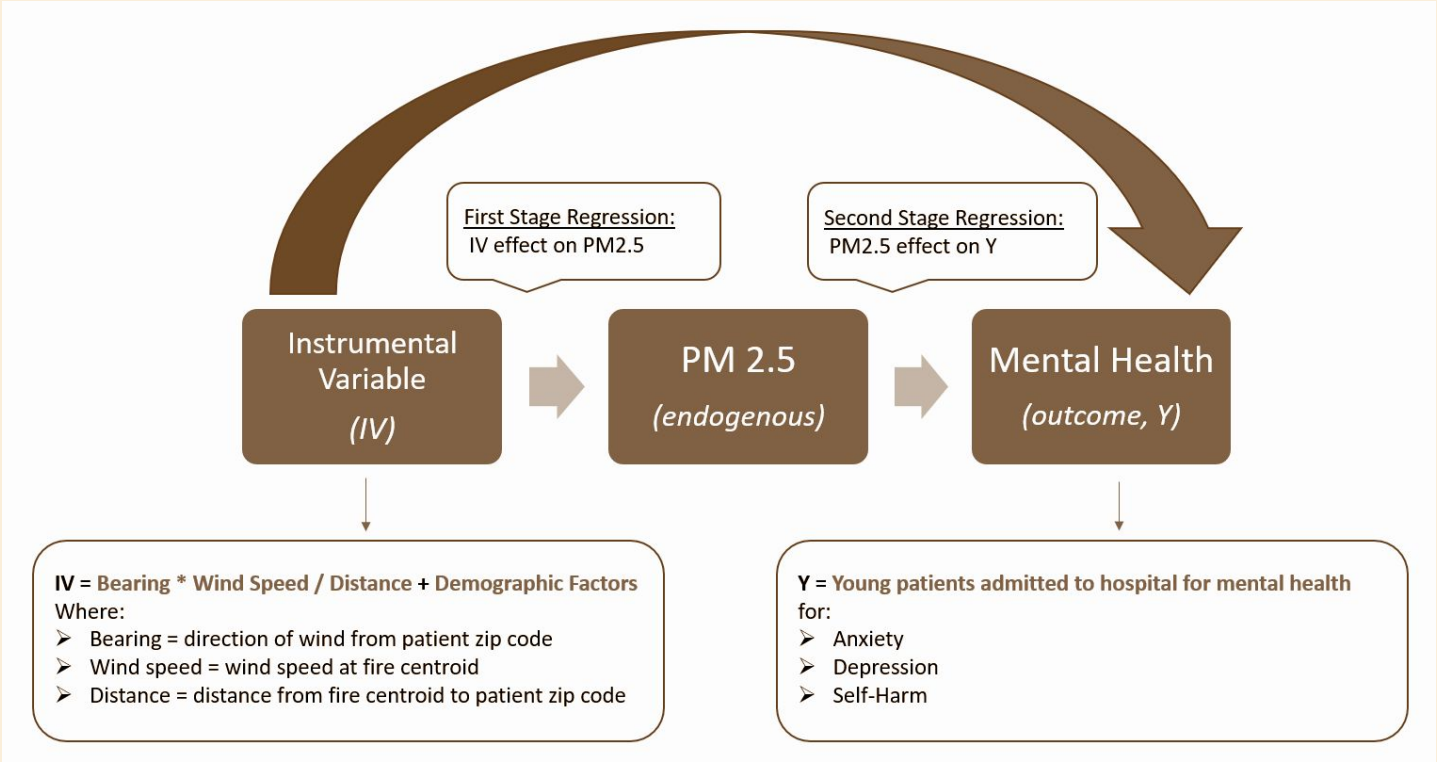
- Hospital visits for California patients under 19
- Medical diagnosis codes

Data: Medical Diagnosis Codes

Anxiety	Depression	Self-Harm
Neuroses: Anxiety, Stress, OCD, Phobias,	**Psychoses**: Bipolar, Manic, Depressive	**Self Harm**: Cutting, Suicide Attempts
300 Neurotic Disorders 308 Acute reaction to stress	296 Affective Psychoses	E95 Self-Harm & Suicide Attempts
F40 Phobic anxiety disorders F41 Other anxiety disorders F42 Obsessive-compulsive disorder F43 Reaction to severe stress, and adjustment disorders	F30 Manic episode F31 Bipolar disorder F32 Depressive episode F33 Major depressive disorder, recurrent F34 Persistent mood [affective] disorders	X78 Intentional self-harm by sharp object X80 Intentional self-harm by jumping from a high place X83 Intentional self-harm by other specified means T14.91 Suicide Attempt

ICD-9-CM & ICD-10-CM Codes

Modeling Approach



Model Equations

Stage 1

Predict $PM_{2.5}$ that is uncorrelated with the omitted variables in the error term but correlated with PM2.5

$$\widehat{PM_{2.5}} = \gamma_0 + \gamma_1 * instrument + \gamma_2 * year + \gamma_3 * month + \gamma_4 * zipcode + \gamma_5 * elevation + \gamma_6 * windspeed + \gamma_7 * income + \gamma_8 * Demographics + \gamma_9 * interactions(zipcode, instrument, month)$$

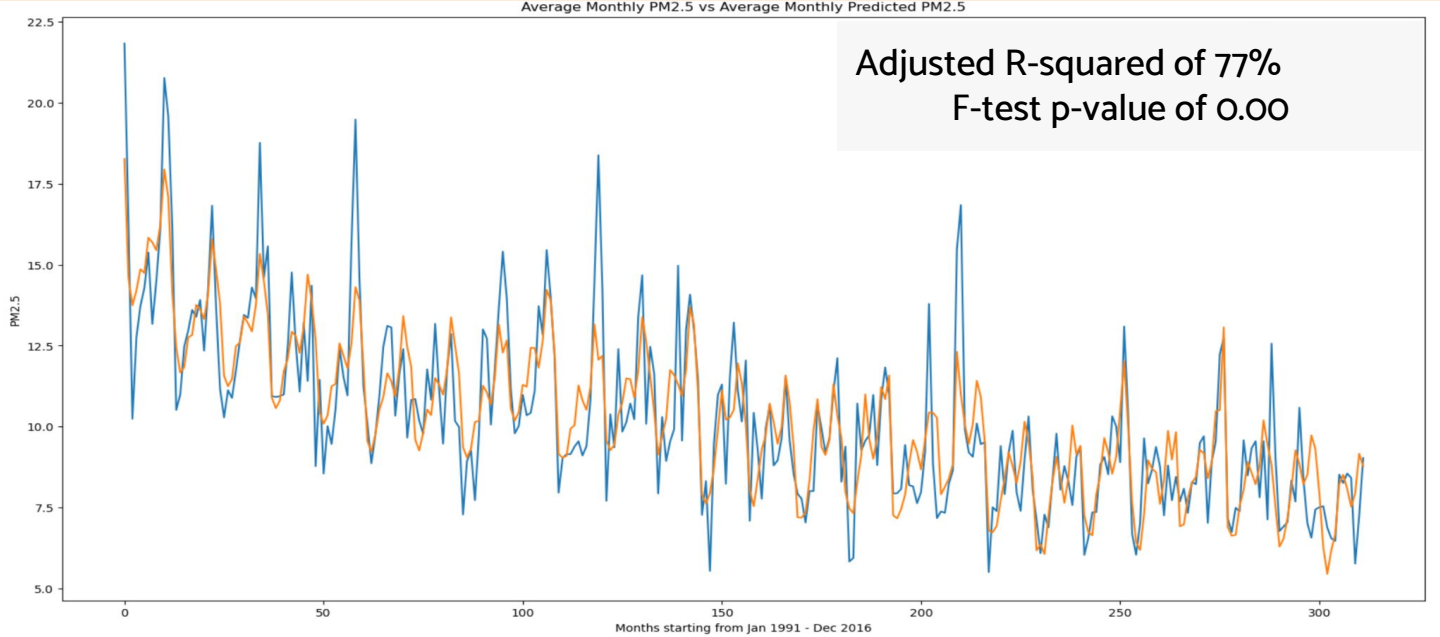
Stage 2

Use ***Predicted $PM_{2.5}$*** with other features to predict mental health outcomes

$$\left(\frac{youth\ \mathrm{ER}\ visits}{zipcode\ \mathrm{pop}}\right) = \beta_0 + \beta_1 * \widehat{PM_{2.5}} + \beta_2 * year + \beta_3 * month + \beta_4 * zipcode + \beta_5 * elevation + \beta_6 * windspeed + \beta_7 * income + \beta_8 * Demographics + \beta_9 * interactions(zipcode, instrument, month)$$

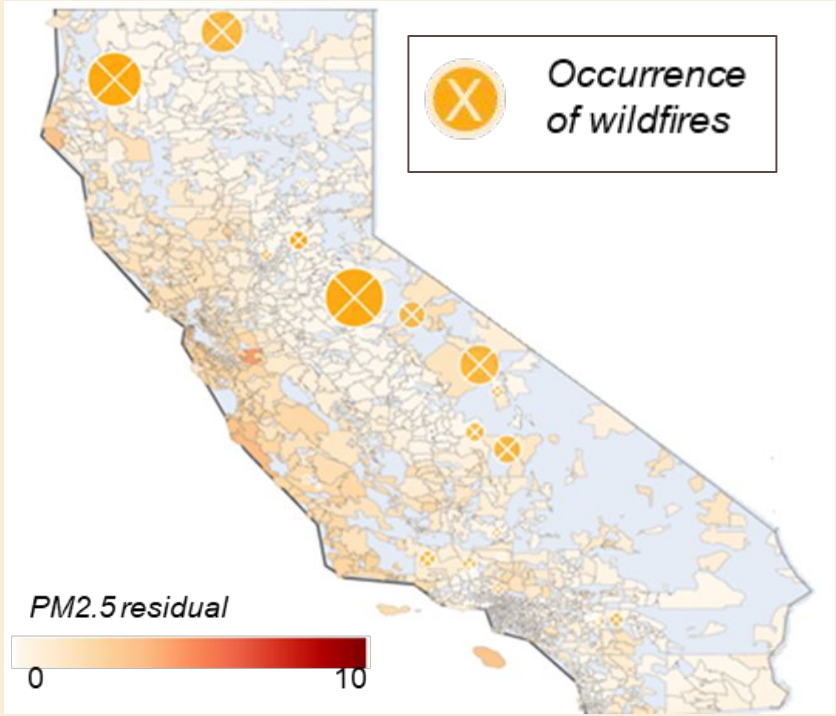
Stage 1 Regression Results

Goal: Predict PM2.5 using an Instrumental Variable



Stage 1 Regression Results

Adding Interaction Effects Improved Ability to Predict PM 2.5



- Generally able to predict PM2.5 in areas with and without neighboring wildfire
- Residuals exist but are not sizeable for the given context

Stage 2 Regression Results

Causal Effect Masked by Interaction Effects

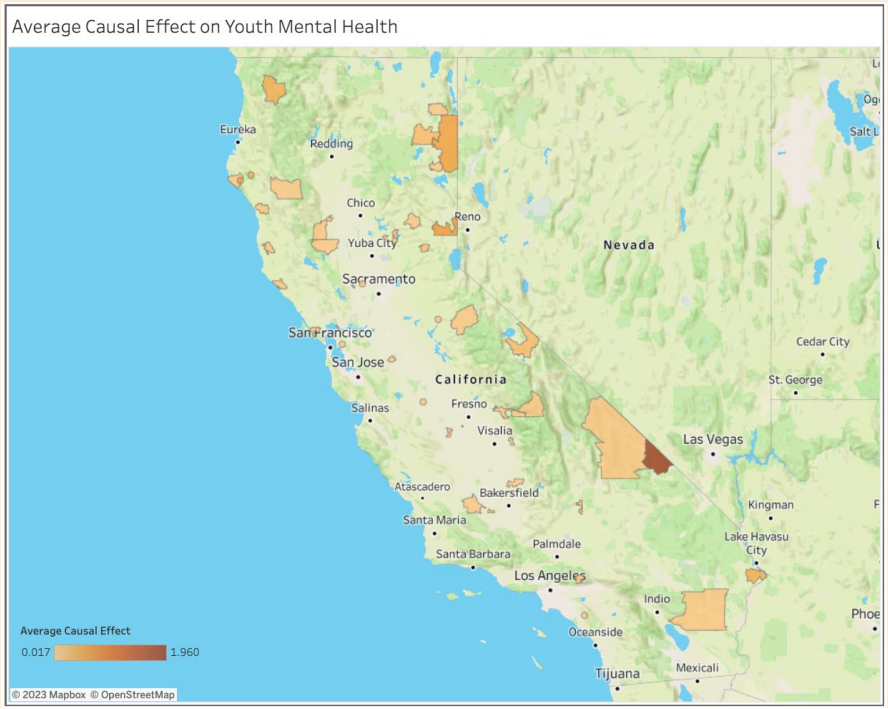
Average Impact of PM2.5 on Youth Mental Health Incidence[1]

Mental Health Outcome	Impact of PM2.5	95% CI	Model Metrics
Anxiety	0.084	[0.02, 1.4]	F-statistic:35.58 Prob (F-statistic): 0.00 R-squared: 70%
Depression	0.071	[0.02, 1.3]	F-statistic:25.04 Prob (F-statistic): 0.00 R-squared: 62%
Self-harm	0.063	[0.01, 1.2]	F-statistic:21.7 Prob (F-statistic): 0.00 R-squared: 58%

1. Zip Codes with positive Interaction effect and statistically significant at 5%

Conclusions

- Wildfires in California have **a causal effect** on youth mental health
- The magnitude of the effect **varies by geography**
- Effects, on average, were **similar** across Anxiety, Depression and Self-Harm
- On average, a **1. 36** percent point increase in mental health incidence rate would increase mental health cost by ~$250k per year per zip code
- Seasonality and zip code specific effects are key drivers in understanding the impact of PM2.5



Recommendations & Next Steps

- This model framework enables policy makers to predict the impact of wildfire pollution on youth mental health

- Understanding causal effects can help policy makers and clinicians design/implement effective solutions in response to wildfires

- Further research areas include:
  - Cumulative impact of pm2.5 from wildfires on youth mental health outcomes
  - Effects of wildfires on adult mental health
  - Zip code-specific studies to better understand the micro-level impact and solutions

Acknowledgements

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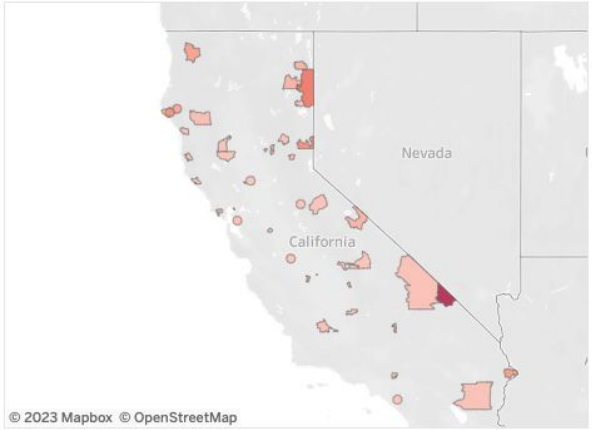
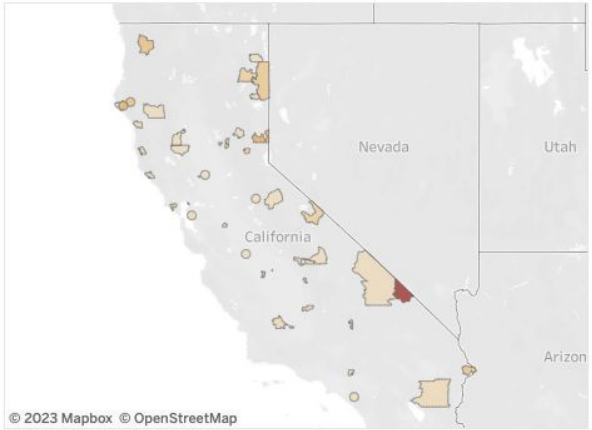
Appendix

Average Causal Effect on Anxiety Disorders



Average Causal Effect on Depressive Disorders



Average of Neurotic Disorders

0.010 — 1.720

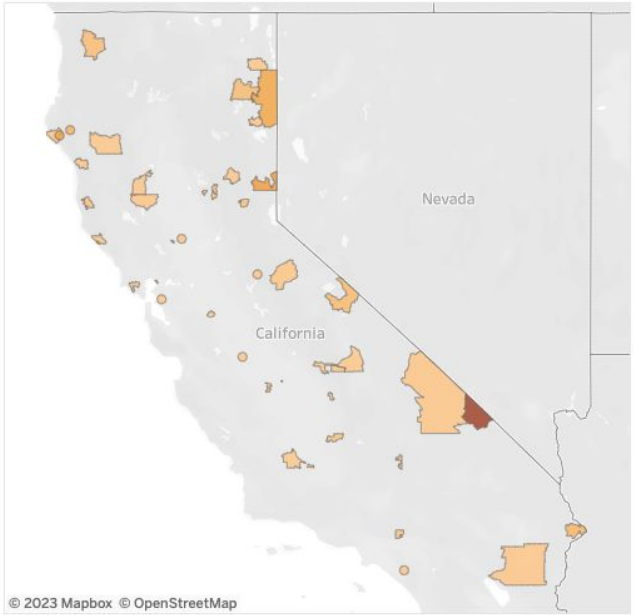
Average of Psychoses

0.020 — 2.050

Average of Suicide

0.010 — 2.110

Average Causal Effect on Self-Harm



Recommendations

- Based on our research, we recommend using this model framework to predict and assess the impact of wildfires (via PM2.5) on youth mental health outcomes
- Policy makers and clinicians can more appropriately design/implement differentiated solutions to mitigate anticipated adverse effects of wildfires via PM2.5 taking into consideration location specific factors

Limitations / future research

Limitations

- Data granularity (monthly->daily)
- Fire data quality
- Outside PM2.5 =/= actual exposure. Inside PM2.5 better but hard to collect
- Lag effect - Mental health diagnoses can occur many months or years after the traumatic event/PM2.5 exposure
    - Cumulative PM2.5 is not in scope

Future studies

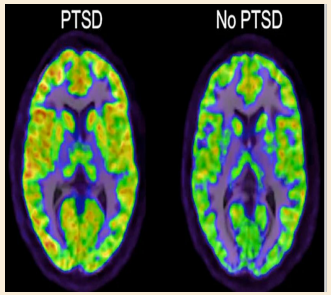
- Individual-level studies
- Look at non-ER mental health outcomes
- Next step: After proving causality, now need to test & prove effectiveness of intervention

Mental health illnesses are among the most common health conditions in California

- Nearly 1 in 7 California adults experiences a mental illness, and 1 in 26 has a serious mental illness that makes it difficult to carry out daily activities
- One in 14 children has an emotional disturbance that limits functioning in family, school, or community activities

Research has shown that there are significant mental health effects from wildfires

In a scoping review published in ***Behavioral Sciences***, To et al examined 63 studies pertaining to mental health effects of exposure to wildfires and found significant rates of PTSD among children and adults



- Rates of PTSD in children and adolescents after wildfire exposure ranged from 9% to 29.4% at 6 months and 27% to 37% at 12 months post wildfire
- Rates of post-traumatic stress disorder (PTSD) after wildfire exposure among adults ranged from 24% to 60% at 3 months and 10.2% to 13.6% at 18 months

- In pediatric populations, rates of depression were 4.7% to 20% at 6 months, and 17% at 18 months post wildfire
- Among adults the rates of depression range from 25.5% to 33% at 3 months and 18.3% to 24.8% at 18 months

Access to mental health care is costly and limited

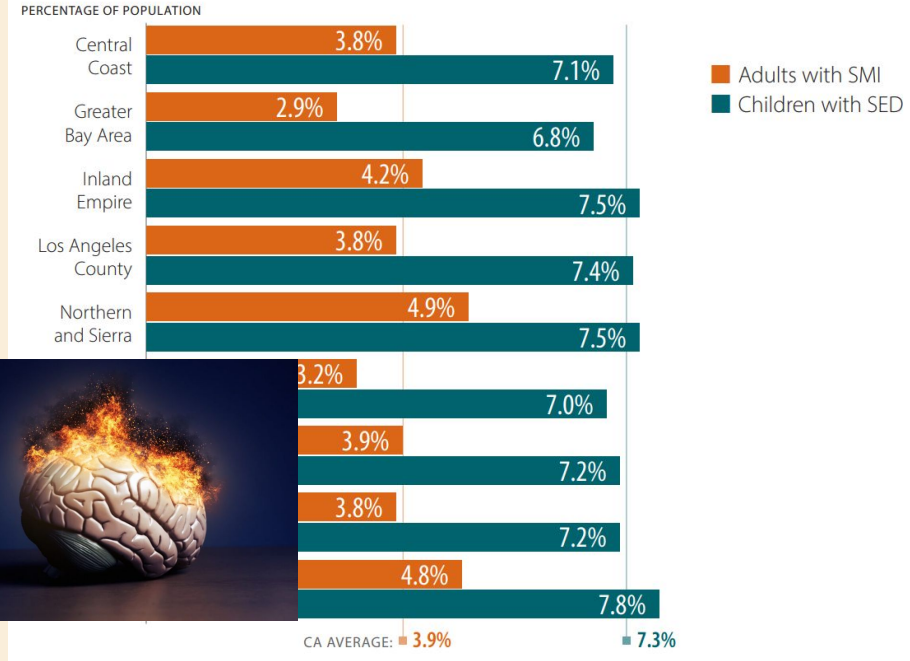
- Mental health treatment and services reached $225 billion in 2019 in the US
- Depression alone is estimated to account for $44 billion in losses to workplace productivity[1]
- An hour-long traditional therapy session can range from $65 to $250 for those without insurance[2]
- A patient with major depression can spend an average of $10,836 a year on health cost

1. Tufts Medical Center and One Mind at Work
2. GoodTherapy.org
3.

Stages	OLS	Random Forest
Model selection	Multiple instruments Cross validation Information criterion	Multiple instruments Cross validation
	Multiple instruments Cross validation	
Model evaluation	Adj. R-squared	RMSE, MAE
	RMSE, MAE	
Coefficient inference	T-test, F-test	Feature importance
	Permutation importance, SHAP values	
Diagnostics	OLS assumptions	Discrepancy in train-test results

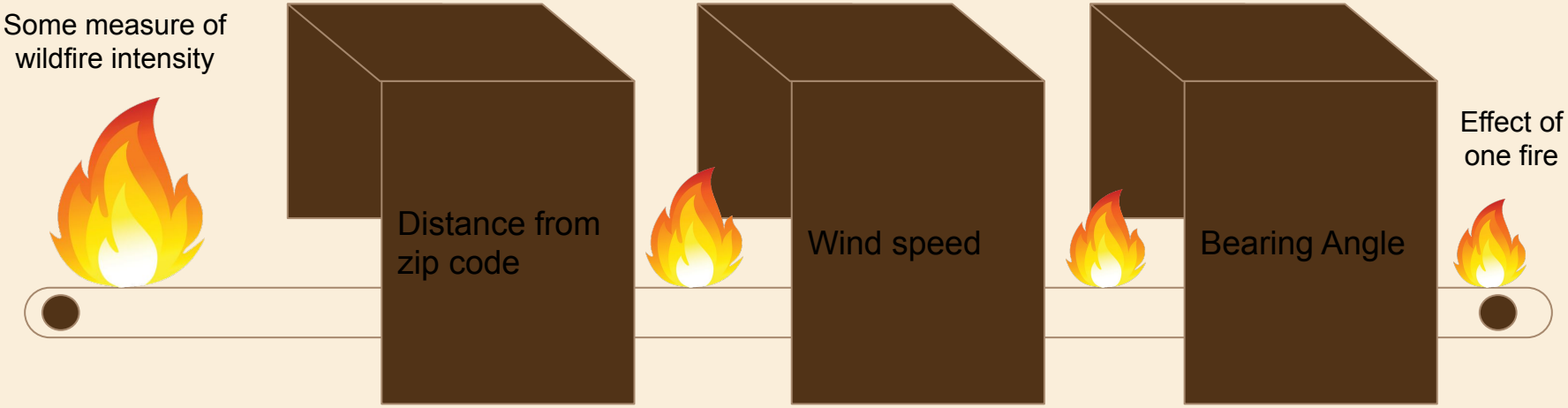
Adults with SMI and Children with SED, by Region

California, 2019



Instrumental variable constructed to estimate effect of wildfire air pollution on zip code

For one fire:



Instrumental variable: Aggregated effect of X nearest wildfires per month

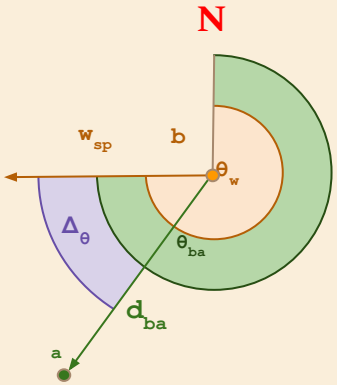
First Stage Instrumental Variable

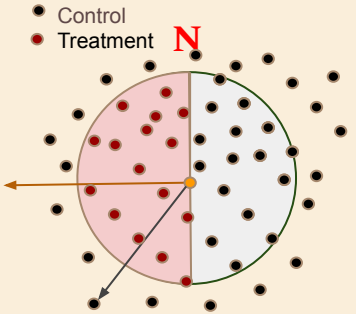
The instrumental variable in Stage 1 model aims to measure the effect of a wildfire on the PM2.5 of a nearby zip code for each month and year over the study period

$$I_{ZMY} = f(Bearing, Distance, Area, Duration, Wind\ Speed, Treatment)$$

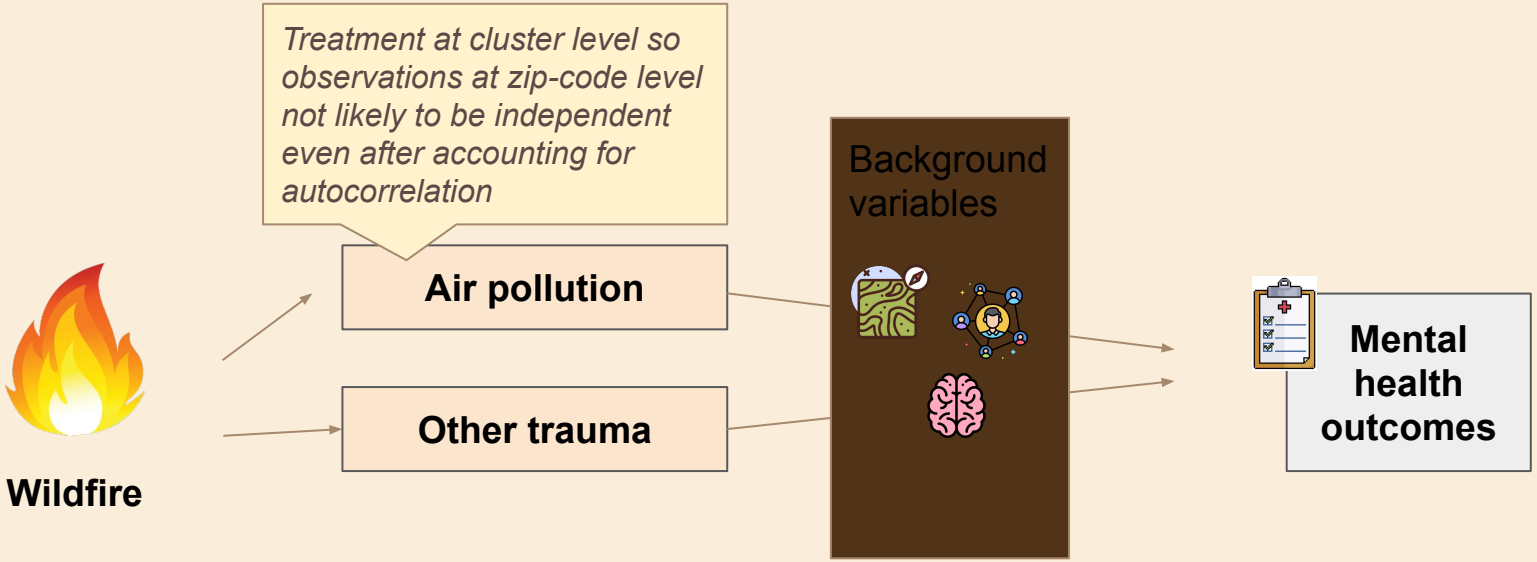
- Bearing difference of wind and locations to determine upwind and downwind effects
- Distance between zip codes and fires
- Fire Area
- Fire duration
- Treatment flag

$$Treatment_{ZMY} = f(Bearing, Distance)$$





Modelling approach



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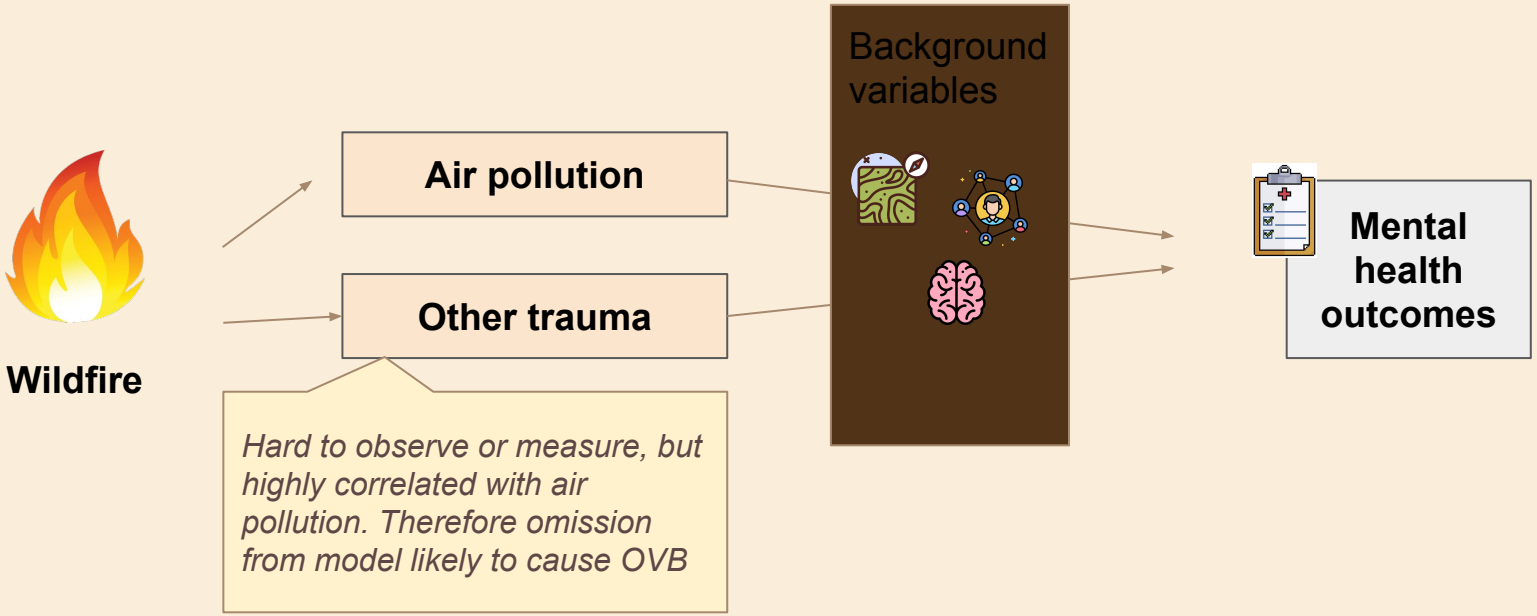


Issues addressed through 2SLS OLS model architecture

$$\%\ youths\ visiting\ ER\ for\ mental\ health\ issues = \beta_0 + \beta_1 * \widehat{PM_{2.5}} + \beta_2 * year + \beta_3 * month + \beta_4 * zipcode + \beta_5 * elevation + \beta_6 * windspeed + \beta_7 * agegrp + \beta_8 * income + \beta_9 * ethnicity + \epsilon_{second.stage}$$

$$\frac{\#\ youth\ ER\ visits}{\#\ youth\ population}$$

Issues addressed through 2SLS OLS model architecture

$$\%\ youths\ visiting\ ER\ for\ mental\ health\ issues = \beta_0 + \beta_1 * \widehat{PM_{2.5}} + \beta_2 * year + \beta_3 * month + \beta_4 * zipcode + \beta_5 * elevation + \beta_6 * windspeed + \beta_7 * agegrp + \beta_8 * income + \beta_9 * ethnicity + \epsilon_{second.stage}$$

$$\frac{\#\ youth\ ER\ visits}{\#\ youth\ population}$$

- Actual air pollution variable correlated with confounding variable
- What we used is instead an estimate of air pollution that is uncorrelated with confounding variable
- Estimate derived using instrumental variable in a first stage regression

$$\widehat{PM_{2.5}} = \gamma_0 + \gamma_1 * instrument + \gamma_2 * year + \gamma_3 * month + \gamma_4 * zipcode + \gamma_5 * elevation + \gamma_6 * windspeed + \gamma_7 * agegrp + \gamma_8 * income + \gamma_9 * ethnicity + \epsilon_{first.stage}$$

The importance of understanding the impact of wildfires on youth mental health

- Resource planning for Emergency Rooms
  - Nationwide 6.4% short of psychiatrists, predicted to nearly double by 2025
- Cost of prevention < cost of treatment:
  - More holistic crisis response effort
  - Better allocation of funds

Conviction in our results backed by rigorous approach to data collection, model selection & evaluation, and secondary research

DATA

>540K data points
consisting of geospatial, demographic, wildfire data aggregated at zipcode level from established institutions and public agencies spanning 1991 to 2018

MODELS

Measured “step-up” approach to modelling

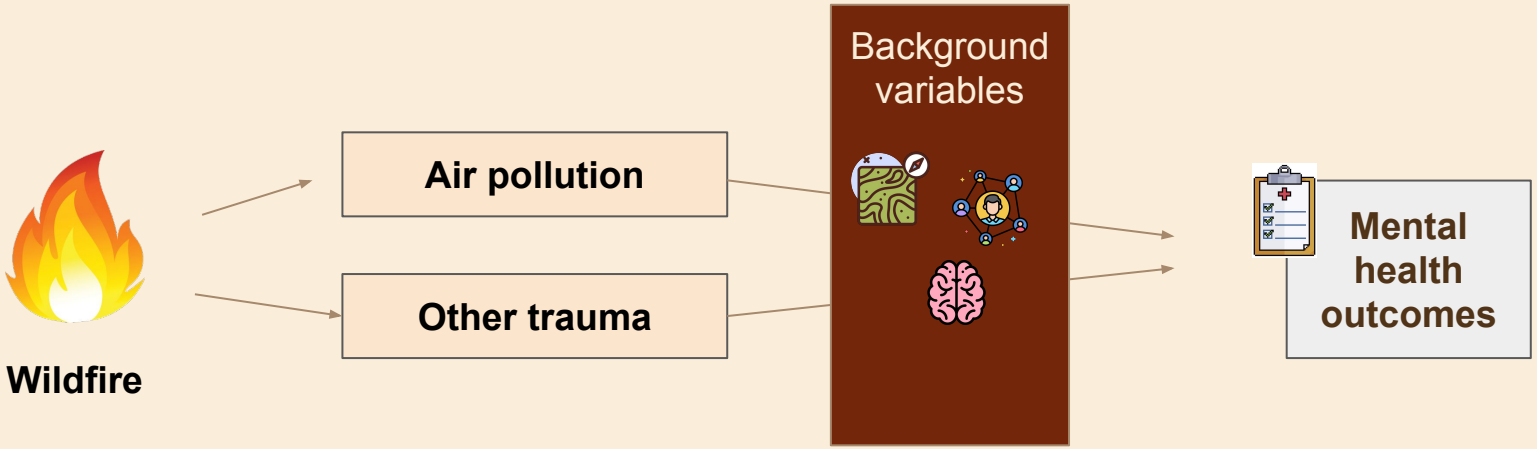
Correcting for OVB and intra-cluster correlation

2° RESEARCH

Wide-ranging review of literature on drivers of youth mental health, impact of wildfire intervention programs, etc.

Expert interviews with …

Modeling Approach



Results corroborated by alternative modelling approaches

Naive OLS

- **Our expectation:** Impact of OVB lead to larger coefficient
- **Result:** [XXX]

Baseline 2SLS

2SLS Elastic Net

- **Our expectation:** Expect XX variables to be dropped
- **Result:** [XXX]

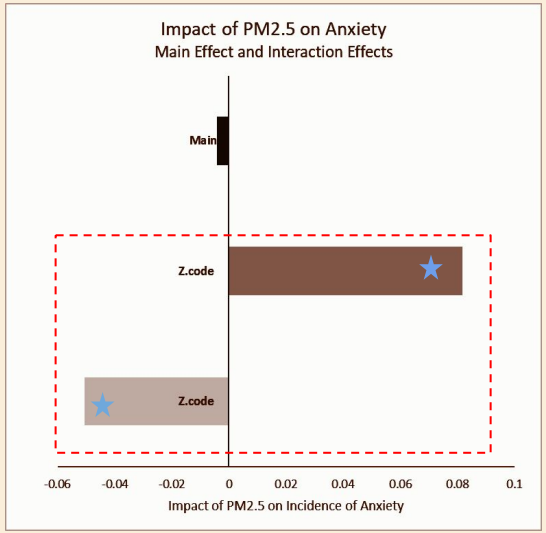
2SLS Random Forest

- **Our expectation:** Non-linearity to produce better model performance
- **Result:** [RMSE, MAE]

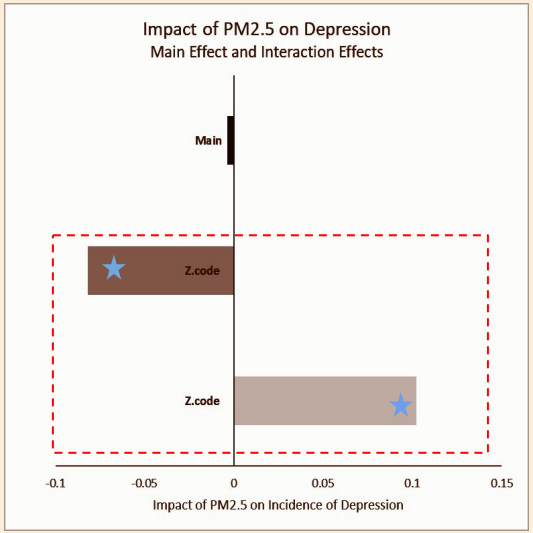
Stage 2 Model Results

Goal: Estimate change in medical outcomes using predicted PM2.5

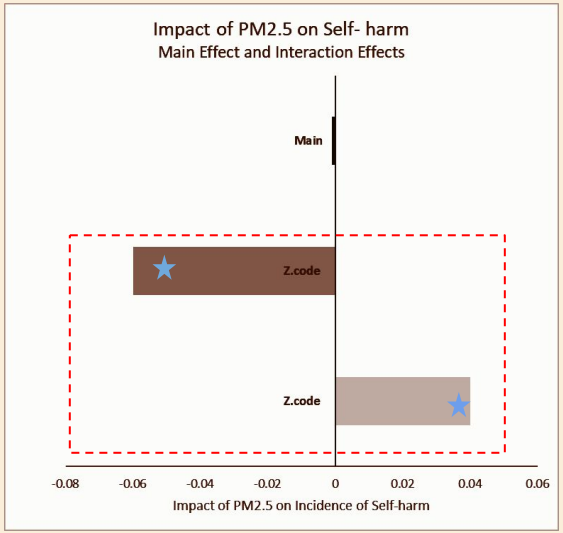
Main effect of PM2.5 masked by significant interaction effects



F-statistic:35.58
Prob (F-statistic): 0.00



F-statistic:25.04
Prob (F-statistic): 0.00



F-statistic:
Prob (F-statistic): 0.00

★ Statistically significant at 5%

Interaction: zip code-specific impacts vary

Distribution of Incidence of Mental Health Outcome