Do Conservation Policies Work?

Evidence from Residential Water Use

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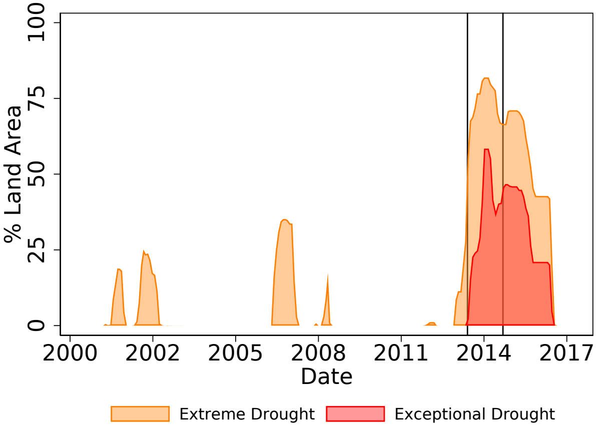
EEPE 2020
May 21, 2020

Policy-Making Is Often Messy

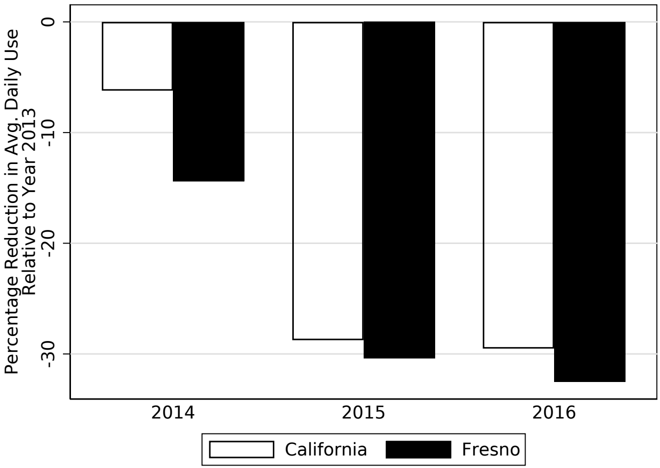
- Environmental goals, e.g. resource conservation, can be targeted with price and non-price instruments
- During crises, policymakers may be forced to adopt multiple policies simultaneously
- Ex-post, what mix of policies worked? Simultaneity makes it challenging to estimate the impact of individual policies

California Recently Faced an Exceptionally Severe Drought



Percent of California in Extreme and Exceptional Drought 2000-2018. Source: United States Drought Monitor

California Responded with Large Water Savings, and So Did Fresno



Source: California Water Board

These Savings Were Achieved through a Variety of Policies

- Between 2013-2016 Fresno implemented:
  - Rate changes
  - Reducing summer outdoor watering days from 3 to 2
- Two statewide announcements potentially increased awareness:
  - State of Emergency declaration (Jan 2014)
  - Mandatory 25% conservation goals (Apr 2015)

This paper

- Investigates the impacts of simultaneous price and non-price policies
  - To inform policy in light of climate change and more frequent droughts
- Uses hourly household water use data
  - Utility with universal smart metering
  - 82,300 single family households
  - Drought setting, 2013 to 2016
- Uses event-time designs
  - Controlling for week-of-year fixed effects and weather controls

Preview of Results

- **Rate increases** account for 49% of household water savings in Fresno
  - Elasticity of water demand of:
    - 0.20 wrt marginal rates
    - 0.44 wrt average rates

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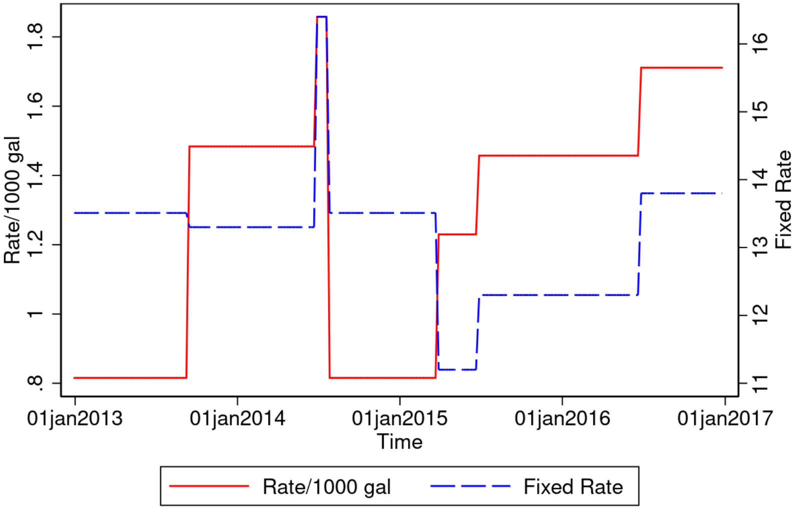
- **Drought awareness** does not explain water savings
  - State-wide announcements increase drought awareness
- These estimates rely on time-series variation in a single city

Outline

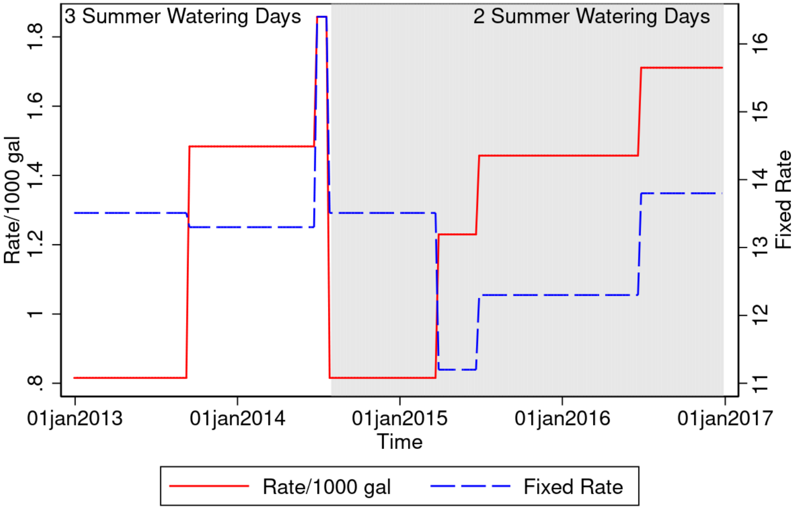
Data

- Hourly water use data from smart meters 2013-2016
    - All single-family households in Fresno
    - Drop movers, new constructions, abandoned homes, outliers
    - Obtain 31,400 observations for over 82,300 households
- Water rates and outdoor watering schedule data from the City
- Weekly Google Trends data: searches related to "drought" in the Fresno-Visalia region
    - 0-100: Measures relative number of searches, 100 when max, 0 when $<$ 1% of max
    - Use to measure changes in public awareness
- Temperature and precipitation data from NOAA

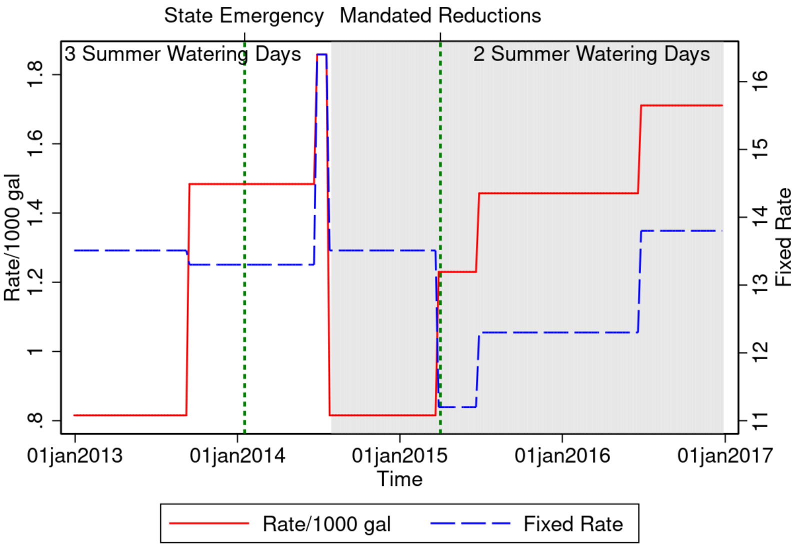
Policy 1: Six Rate Changes between 2013-2016



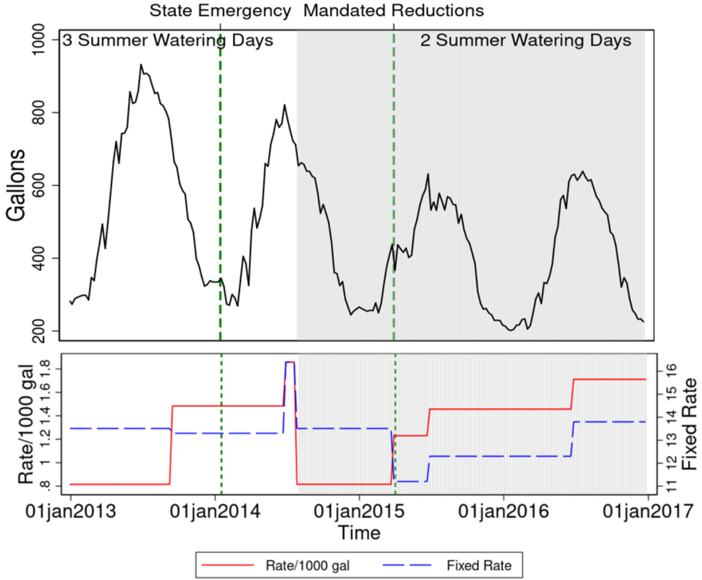
Policy 2: Reduction in Summer Outdoor Watering Days from 3 to 2



Policy 3: Statewide Announcements



Water Use and Simultaneous Policies in Fresno



Outline

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1. Background and Data
2. Evaluating Policies Individually
   - Rate Changes
   - Reducing Summer Outdoor Watering Days from 3 to 2
   - Public Awareness
3. Estimating Simultaneous Policy Impacts
4. Conclusion

Exploit Time-Series Variation in Water Rates

$$y_{it} = \text{f(Rates)}_{it} + \gamma_{woy} + \gamma_i + X_t\theta + \varepsilon_{it}$$

- y_{it}: Inverse hyperbolic sine (IHS) of HH average daily water use in week t
  - Robust to inclusion of 0s
  - Effects robust to using logarithm
- f(Rates)_{it}: IHS of marginal and fixed, or average water rate at week t
- γ_{woy}, γ_i: Week-of-year, and household fixed effects
  - But, year FE may absorb persistent policy effects
- X_t: Weather and seasonal controls
  - Summer schedule indicator
  - Precipitation indicators (binned over current day & past week)
  - Temperature indicators (binned over current day & past week)
- Standard errors are clustered at the household and sample month levels

Price Elasticity wrt Average Rates Double as wrt Marginal Rates

Dependent Variable	IHS of Average Daily Use (gallons)			
	(1)	(2)	(3)	(4)
IHS of Fixed Rate	0.938***		1.372***	
	(0.187)		(0.156)	
IHS of Marginal Rate per Gallon	0.043		-0.185***	
	(0.0371)		(0.0666)	
IHS of Average Rate per Gallon		-0.105		-0.424***
		(0.106)		(0.149)
Year FE	X	X		
Observations	17017841	17017841	17017841	17017841

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

- Implied elasticities: Marginal rate 0.19; Average rate 0.42
- In Orange County: Short-run elasticity to average water rates of 0.097-0.13, and 0 with respect to marginal rates (Ito, 2013)

Outline

A Change in Outdoor Watering Restrictions

- Winter:
  - Permitted only one day per week throughout the sample period
- Summer:
  - Outdoor Use banned between 9 A.M. and 6 P.M.
  - Before August 2014: Outdoor water use permitted 3 days per week
  - After August 2014: Outdoor water use permitted 2 days per week
- Flagrant outdoor water use violations in Fresno were subject to a $45 fine

Estimating Effects of Schedule Change over Time

$$y_{it} = \beta_1 \mathbb{I}_t^{\text{Post-Schedule Change}} + \beta_2 \mathbb{I}_t^{\text{Post-Schedule Change}} \times \mathbb{I}_t^{\text{Summer}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t\theta + \varepsilon_{it}$$

- y_{it}: Inverse hyperbolic sine (IHS) of HH average daily water use in week t
- $\mathbb{I}_{it}^{\text{Post-Schedule Change}} = 1$: After schedule change
- γ_i, γ_{yr}, γ_{woy}: Household, year, and week of year FE
- X_t: Seasonal and weather controls
- SE are clustered at the household and month levels

Water Use Decreases by a Third after Schedule Change

$$y_{it} = \beta_1 \mathbb{I}_t^{\text{Post-Schedule Change}} + \beta_2 \mathbb{I}_t^{\text{Post-Schedule Change}} \times \mathbb{I}_t^{\text{Summer}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t \theta + \varepsilon_{it}$$

	IHS of Average Daily Use (gallons)		
	(1)	(2)	(3)
1(Post-Schedule Change)			
1(Post-Schedule Change)*1(Summer)	-0.338***		
	(0.0331)		
Observations	17017841		

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Water Use Remains Low in Winter, When Schedule Change Does Not Bind

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1(Post-Schedule Change)		-0.317***	-0.255***
		(0.0270)	(0.0332)
1(Post-Schedule Change)*1(Summer)	-0.338***		-0.0828*
	(0.0331)		(0.0476)
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Effects in summer and winter may be due to:

- Increased drought awareness (Pratt, 2019)
- Investments: No discontinuous increase in rebate take-up for clothes washer or toilet
- Increased enforcement and City services (water audits, timer tutorials): Still very few
- Secular confounders

Exploring Timing of Water Savings

		Odd		Even	
		Before	After	Before	After
Monday	Always Banned	.	.	.	.
Tuesday	Always Allowed Summer Day	X	X	.	.
Wednesday	Always Allowed Summer Day	.	.	X	X
Thursday	Banned after 08/01/2014	X	.	.	.
Friday	Banned after 08/01/2014	.	.	X	.
Saturday	Always Allowed	X	X	.	.
Sunday	Always Allowed	.	.	X	X
	Total Watering Days	3	2	3	2

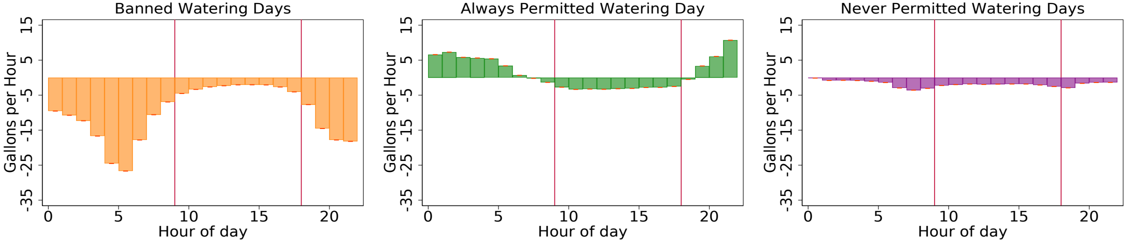
- Even- and odd-numbered houses can water on different days of week
- Compare houses on the same block with odd (1) and even (2) numbers
- Under perfect compliance, outdoor use is the difference between 1 and 2 at a given time
- With noncompliance, outdoor use and consequent savings are underestimated

Comparing Odd and Even Houses Identifies Effects across Hours and Days

$$
\begin{aligned}
y_{bnt} =& \beta_1 \text{BannedDay}_{nt} + \beta_2 \text{AlwaysPermitted}_{nt} \\
& + \beta_3 \text{PostBan}_t + \beta_4 \text{BannedDay}_{nt} \times \text{PostBan}_t + \beta_5 \text{AlwaysPermitted}_{nt} \times \text{PostBan}_t \\
& + \gamma_b + \gamma_n + \gamma_{dow} + \gamma_{woy} + \gamma_{yr} + \varepsilon_{bnt}
\end{aligned}
$$

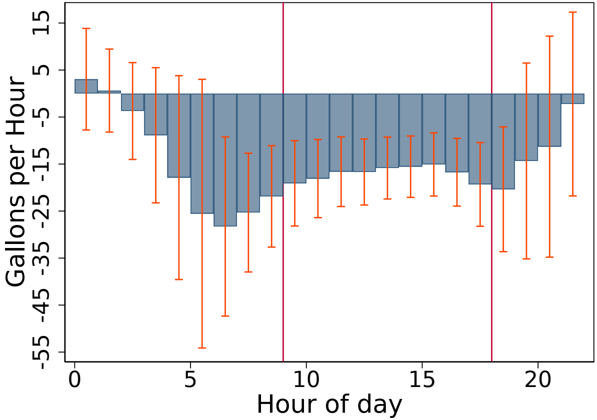
- y_{bnt}: IHS of **hourly** average HH water use in block group b, $n \in \{\text{odd}, \text{even}\}$
- $\text{BannedDay}_{nt} = 1$: Days banned starting 8/14
  $\text{AlwaysPermitted}_{nt} = 1$: Days when outdoor use is always allowed
  $\text{PostBan}_t = 1$: Weeks after August 2014
- γ_b, γ_n, γ_{dow}, γ_{woy}, γ_{yr}: Block group, odd/even, day of week, week-of-year, and year FE
- Weight observations by block-group size
- Restrict sample to summer months
- SE clustered at the block group and month level

Substitution between Banned and Permitted Hours



- Water use decreases by 223 gal on newly prohibited nights
- Households offset 37% of these reductions by substituting 94 gallons per week of irrigation to the two nights that remain permitted.

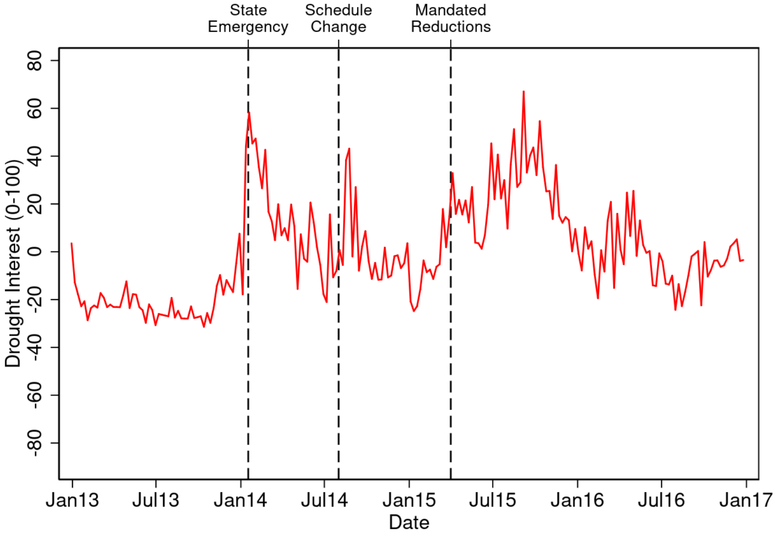
Weekly Water Use Decreases by 333 gallons (10%) after the Schedule Change



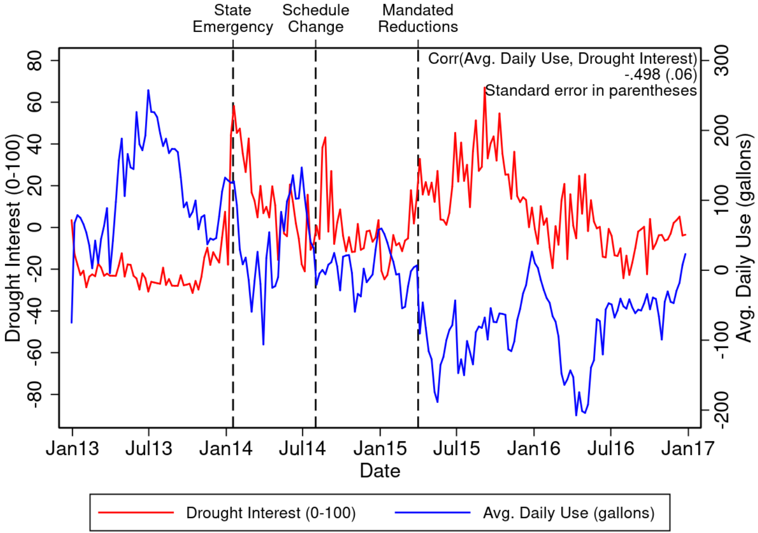
Net effect of schedule change on average weekly use in each hour.

Outline

Drought Awareness Seems to Increase with Policies



Drought Awareness and Water Use Are Negatively Correlated

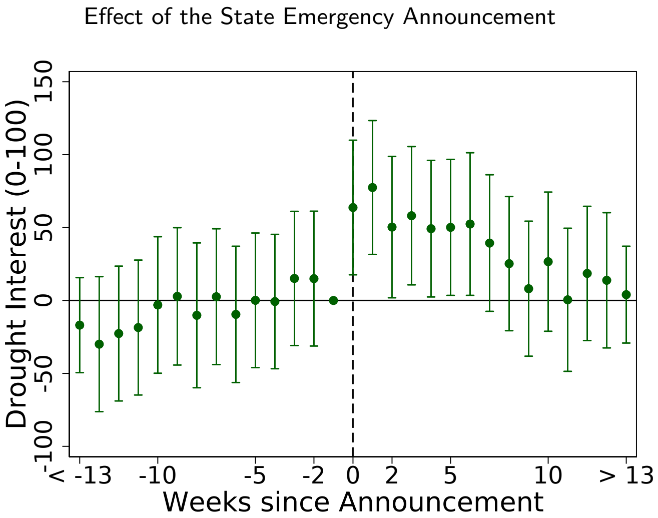


Estimating the Effect of State-Wide Announcements on Public Awareness

$$y_t = \sum_{s=-13}^{13} \beta_s \mathbb{I}_t^{\text{Weeks Post-Announcement}} + \gamma_{woy} + \gamma_{yr} + X_t\theta + \varepsilon_t$$

- y_t: Drought search index
- $\mathbb{I}_t^{\text{Weeks Post-Announcement}}$: Indicator if t is s weeks before/after State of Emergency announcement
- γ_{yr} and γ_{woy}: Year and week of year FE
- X_t: Weather controls

Public Awareness Appears to Increase after State-Wide Announcements



Do State-Wide Announcements Affect Water Use?

$$y_{it} = \sum_{s=-13}^{13} \beta_s \mathbb{I}_t^{\text{Weeks Post-Announcement}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t\theta + \varepsilon_{it}$$

- y_{it}: IHS of HH average daily water use
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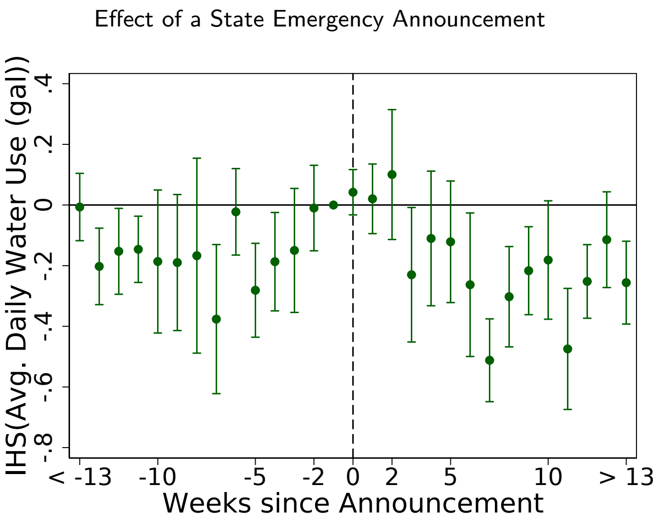
Water Use Appears to Decrease after Announcements



Outline

Estimating Simultaneous Policy Impacts

$$
\begin{aligned}
y_{it} = & \beta_1 \text{IHS(Rate)}_{it} \\
& + \beta_2 \mathbb{I}_t^{\text{PostScheduleChange}} \times \mathbb{I}_t^{\text{Summer}} \\
& + \beta_3 \text{Drought Interest}_t \\
& + \gamma_i + \gamma_{woy} + f(\text{Weather}_t) + \varepsilon_{it}
\end{aligned}
$$

- y_{it}: IHS of HH average daily use
- IHS(Rate)_{it}: IHS of the average rate or IHS of marginal and fixed rates
- $\mathbb{I}_t^{\text{PostScheduleChange}}$: Indicator for weeks after the schedule change
- $\text{Drought Interest}_t$: Google search index for the word “drought”
- Main specification only includes $\mathbb{I}_t^{\text{PostScheduleChange}} \times \mathbb{I}_t^{\text{Summer}}$
- Main spec excludes year FE to allow long-run policy effects: Susceptible to confounders

Simultaneous Impacts of Conservation Policies

Dependent Variable	IHS of Average Daily Use (gallons)	
	(1)	(2)
IHS of Fixed Rate	0.730***	0.963***
	(0.244)	(0.219)
IHS of Marginal Rate per Gallon	-0.200***	0.0189
	(0.0399)	(0.0485)
1(Post-Schedule Change)*1(Summer)	-0.252***	-0.0343
	(0.0347)	(0.0468)
Drought Interest	-0.000426	0.00200
	(0.0167)	(0.0132)
Year FE		X
Observations	17017841	17017841

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- Estimates are sensitive to including year FE

Policy Changes account for 88.9% of Observed Water Savings 2013-2016

- "Actual Changes": Difference between water use in 2016 and the first half of 2013 – before any policy was implemented
- Compute "Policy-Induced Changes" using regression estimates:

$$\text{Policy Induced Changes} = \sum_{j=1}^{3} \hat{\beta}_j (\text{Policy}_{jt} - \text{Policy}_{j0})$$

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	Year 2016 (1)
Outcome: IHS of Water Use	
Actual Change	-0.323
Policy Induced Change	-0.287*** (0.0275)
Policy-Induced Change / Actual Change	88.9%

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

Rates and Schedule Change Explain 49% and 40% of Observed Water Savings 2013-2016

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	Year 2016
	(1)
Panel A: Outcome: IHS of Water Use	
Actual Change	-0.323
Policy Induced Change	-0.287***
	(0.0275)
Policy-Induced Change / Actual Change	88.9%
Panel B: % Actual Change Explained by Each Policy	
Marginal and Fixed Rate Changes	49.31***
	(8.818)
1(Post-Schedule Change)*1(Summer)	39.58***
	(5.411)
Drought Interest	0.01
	(4.447)

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

Caveats

- Estimates are based on time-series variation for city-wide policies
- It is challenging to assess persistence with multiple, simultaneous changes
- Seasonal variation identified off small number of years
- If we allow for schedule change to affect water use in winter months, we over-predict water savings

Outline

Conclusion

- Climate change is increasing the pressure to conserve resources
- Exploiting time-series variation in policies in Fresno during most recent drought, we find:
  - Increasing water rates explain 49% of the water savings
  - Reducing summer outdoor watering days from 3 to 2 decreased water use in summer, despite intertemporal substitution
  - Announcements increase awareness, but cannot explain observed savings
- Teasing out the effects of policies enacted simultaneously in a crisis calls for quasi-experimental variation from multiple cities, or RCT
  - We recently completed city-wide RCT evaluating deterrence from automated enforcement

Thank You!

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