Inefficiencies in Environmental Infrastructure: Evidence from Drinking Water in California

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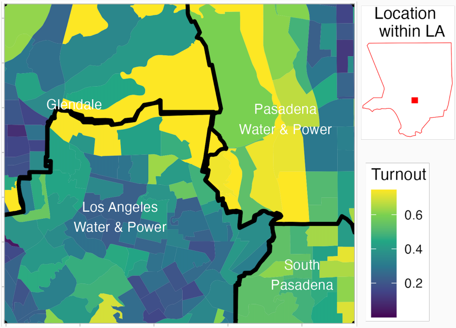
Drinking water infrastructure

- Local governments make drinking water investment decisions
- Growing concerns on investment lagging behind
  - much of the infrastructure was built in the 1970s and 1980s
  - 10% of Americans served by water systems with health-based quality standard violations (Allaire et al, 2018)
  - pathogens in drinking water causes 7 million cases of illness and 600,000 emergency department visits a year (CDC)
  - new issues regarding climate resiliency, water scarcity, etc.
- This paper: local governments' incentives and constraints when investing in drinking water infrastructure
  - context: California

Electoral accountability and drinking water infrastructure

Turnout rate in local elections

- low (median 23%)
- not necessarily representative of community demographics



We show that weak electoral accountability is associated with higher pollution and lower investment, curtailing effectiveness of federal funding policy (RD design)

What this paper does (1/3)

1. **Are residents' preferences represented in drinking water infrastructure investment? Whose preferences?**

What this paper does (1/3)

1. **Are residents' preferences represented in drinking water infrastructure investment? Whose preferences?**
    - estimate residents' heterogeneous preferences on water quality from house transactions
    - construct new data on local govts' investment
    - build a model of politicians' investment choice and estimate politician's preferences

What this paper does (2/3)

1. Are residents' preferences represented in drinking water infrastructure investment? Whose preferences?
2. **Does limited or uneven preference aggregation lead to inefficient investment?**

What this paper does (2/3)

1. Are residents' preferences represented in drinking water infrastructure investment? Whose preferences?
2. **Does limited or uneven preference aggregation lead to inefficient investment?**
    - point out inefficiency may arise depending on politician preferences when constrained by water rate schedule
    - quantify inefficiency based on the model estimates

What this paper does (3/3)

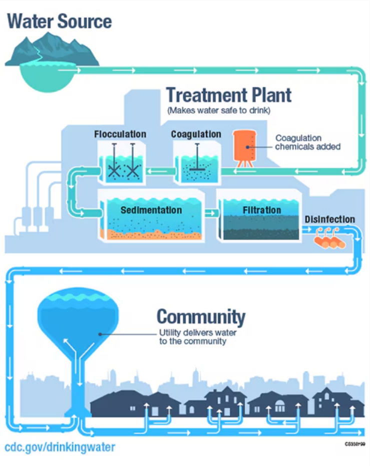
1. Are residents' preferences represented in drinking water infrastructure investment? Whose preferences?
2. Does limited or uneven preference aggregation lead to inefficient investment?
3. **What policies can help local governments' investment decision-making?**
    - alternative water pricing (e.g., more progressive schedule)
    - alternative federal/state subsidies for investment

Related research

- Inefficiency in infrastructure investment: Cellini et al (2010), Fajgelbaum et al. (2023), Sileo (2023), Bordeu (2023)
- Estimation of government officials' preferences: Timmins (2002), Lim and Yurukoglu (2018)
- Role of electoral accountability in government policy: Besley and Case (1995), Besley and Burgess (2002), List and Sturm (2006), Sieg and Yoon (2017; 2022), Gavazza et al (2019)
- Estimation of the value of non-market goods: Bayer, Ferreira, and McMillan (2007), Ito and Zhang (2020)
- Determinants of drinking water quality: Keiser et al (2023), Agrawal and Kim (2021), Posenau (2022)

Setting & Data

Provision of drinking water



- Predominantly local govs (∼90%)
  - 273 **cities** serving ∼20M people
  - 551 **special districts** serving ∼14M people
    - * independent single-purpose governments
- Decision-makers
  - mayors and city council (cities); board members (water districts)

Drinking water quality

- The 1974 Safe Drinking Water Act (amended in 1996)
  - regulates about 90 pollutants by maximum contaminant levels (MCL): microorganisms (e.g., coliforms), disinfection byproducts, inorganic chemicals (e.g., arsenic, lead, nitrate), organic chemicals (e.g., pesticides), radionuclides
  - mandates timely public notifications of violations: within 24 hours for acute health risks like E.coli (Tier I)
- Residents are responsive to violations (e.g.,17-22% increase in bottled water sales (Zivin et al, 2011))

Financing drinking water infrastructure investments

- Local governments fund capital projects predominantly through municipal bonds and long-term debts
- Federal/State assistance as secondary source of funding
  - Safe Drinking Water Act (1996) provides subsidized loans and grants, esp. for *disadvantaged communities*
- Cost of investment is paid for through water rate/fee increase
  - Water rate schedule typically consists of a fixed charge + a consumption-based service charge
  - strict cost-of-service requirements limit cross-subsidization; water revenue increases must be distributed proportionally across rate components

Local government elections

- City mayors/council members and water district board members are elected
- Turnout rate is lower than national/statewide elections (50% for gubernatorial elections vs. below 30% for local elections)
  - concerns about special interests, and overall lack of accountability
- Key driver for local election turnout is election timing
  - most local elections happen on the Election Day ("on-cycle")
  - some happen on "off-cycle" days (30% in mayor/council)
  - on-cycle vs. off-cycle turnout rate differ significantly: 34% vs. 25% (mayor); 27% vs. 16% (council)

Data sources, 2003-2022

- **Government investment** and **revenues**
  - Financial Transactions Reports (on water activity)
  - CDAIC: All local govt debt issuance + issuance costs
  - EPA DWSRF subsidy records (FOIA)
  - water rates from local officials
- **Water pollution**: yearly pollution readings for water system
- **Preferences for water quality**: house prices and house/buyer attributes from CorLogic and HMDA/ACS; California SWRCB's water service area boundaries
- **Local official's incentives**: CEDA on elections; ICMA on local government form and term limits; L2 voter files on turnout

Investment frequency and finances

	Cities	Special districts
Any investment (2003-2022)	0.87	0.70
Annual investment frequency	0.23	0.22
Conditional on any investment		
Amount debt-financed or externally funded		
Mean (in $ millions)	26.0	12.4
Median (in $ millions)	2.2	1.3
Per household, Mean (in $)	665	2,585
Per household, Median (in $)	162	184
Financing or external funding sources		
% financed via municipal bonds	70.17	70.12
% financed via federal/state loans	19.76	8.51
% externally funded (i.e., grants)	10.07	21.37
Number of governments	273	551

Motivating Evidence

Government officials' electoral incentives and water quality

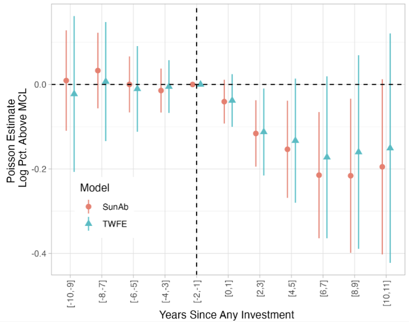
- High local election turnout is negatively correlated with pollution
- Cities with on-cycle election schedules have lower pollution
- Higher pollution when mayors are term-limited
  - suggesting govt actions matter

	Percent above MCL		
	(1)	(2)	(3)
Median household income	-0.067*	-0.078**	
	(0.032)	(0.033)	
Local election turnout	-0.125***		
	(0.041)		
On-cycle elections		-0.100***	
		(0.026)	
Term-limited			0.104*
			(0.057)
Other demog., seasonality, size, primary water source	Yes	Yes	Yes
County×Chemical FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Mayor FE	No	No	Yes
Observations	82,054	82,054	67,300
R^2	0.209	0.209	0.083

SE clustered at county, chemical and primary source level

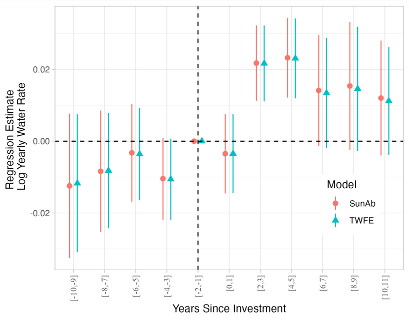
Investment can tackle pollution but is costly

Pollution: readings above MCL (%, average)



20% decrease in the long run (Keiser et al, 2023: 33%)

Rate: (total sales+taxes)/# households



2% increase in the long run

(Keiser et al, 2023: 33%)

(Local) Effectiveness of federal funding for investment

- Policy focus on financial constraints
- Drinking Water State Revolving Fund (DWSRF)
  - below-market interest rate (50% of state GO bond rate)
  - principal forgiveness (below 80% state median household income, MHI)
- **Effective?**
  - compare the frequency of (subsidized) investment for local govs with just above vs. below the MHI threshold (for the eligibility for "free money")

$$Investment_{et} = \beta \mathbf{1}\{MHI_{et} > m_t\} + f(MHI_{et} - m_t) + \mathbf{x}'_{et}\delta + \mu_t + \epsilon_{et}$$

(Local) Effectiveness of federal funding for investment

	Any (1)	Subsidized (2)
RD estimate	-0.012	0.004
	(0.028)	(0.022)
CCT-optimal bandwidth	9,912.8	8,706.6
Effective number observations	3,517	3,107

Notes: This table reports RD estimates using the approach developed by Calonico et al. (2014, 2019) to select the MSE-optimal bandwidth around the cutoff. We use a triangular kernel around the cutoff and a linear polynomial in the running variable, allowing for different slopes on each side of the cutoff. Controls include primary source of the water, year fixed effects, population size, percent white, and the logarithm of population density.

- No local treatment effect for the eligibility for advantageous DWSRF assistance ("free money")
- Hansen et al (2021): 7% of eligible systems received funding (in part due to lack of applications)

Government officials' electoral incentives matters

	All Govs		High Turnout	
	Any	Subsidized	Any	Subsidized
	(1)	(2)	(3)	(4)
RD estimate	-0.012	0.004	-0.097***	-0.087***
	(0.028)	(0.022)	(0.038)	(0.030)
CCT-optimal bandwidth	9,912.8	8,706.6	9,835.9	12,876.9
Effective number observations	3,517	3,107	1,479	1,486

Notes: This table reports RD estimates using the approach developed by Calonico et al. (2014, 2019) to select the MSE-optimal bandwidth around the cutoff. We use a triangular kernel around the cutoff and a linear polynomial in the running variable, allowing for different slopes on each side of the cutoff. Controls include primary source of the water, year fixed effects, population size, percent white, and the logarithm of population density.

- Focusing on high-turnout governments only, "free money" increases investment

Government officials' electoral incentives matters

	Off-cycle Cities		On-cycle Cities	
	Any	Subsidized	Any	Subsidized
	(1)	(2)	(3)	(4)
RD estimate	0.035	0.181	-0.350***	-0.211***
	(0.140)	(0.096)	(0.100)	(0.085)
CCT-optimal bandwidth	8,539.8	8,705.4	5,738.5	5,679.8
Effective number observations	123	125	308	305

Notes: This table reports RD estimates using the approach developed by Calonico et al (2014, 2019) to select the MSE-optimal bandwidth around the cutoff. We use a triangular kernel around the cutoff and a linear polynomial in the running variable, allowing for different slopes on each side of the cutoff. Controls include primary source of the water, year fixed effects, population size, percent white, and the logarithm of population density.

- Incentives to use"free money" depend on electoral incentives
- Points to a potential inefficiency in investment and limits of current policy

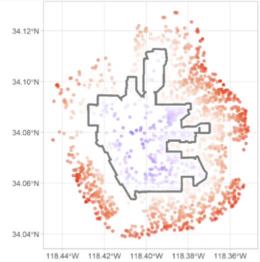
Turnout and policymaking

- Voter turnout
  - may affect the composition of voters that "matter" (Anzia 2011; Fujiwara 2015)
  - is correlated with electoral competitiveness (likely contested; smaller support for incumbent; tighter vote margins)
- Why are high-turnout (or on-cycle) cities more responsive to funding opportunities than low-turnout (or off-cycle)?
  1. participating voters care about water quality more
  2. incumbent's winning prob. is more sensitive to his policy actions, incentivizing him to take costly actions
  3. politicians are more competent
- Our structural approach quantifies investment inefficiency

Do residents care about water quality?

- Boundary discontinuity design (Black, 1999)

- Isolate neighboring water systems with different water quality
- Focus on houses close to the boundary (500 meters)



- Controlling for water system border area, school district, and city fixed effects, as well as house characteristics and demographics, are house prices different?

Do residents care about water quality?

- 1 SD increase in water pollution leads to 1.6% decrease in house price
- Muehlenbachs et al (2015): nearby shale gas development in PA (groundwater risk) → 9.9-16.5% decrease
- Bayer et al (2016): 10% increase in ozone pollution → 0.1% decrease

	House price + water expenses (log)		
	(1)	(2)	(3)
Water pollution	-0.0117**	-0.0115**	-0.0135**
	(0.0053)	(0.0046)	(0.0054)
Mandatory violation notification			-0.0349**
			(0.0103)
Border × Year FE	Yes	Yes	Yes
School FE		Yes	Yes
City FE		Yes	
Observations	910,209	910,209	910,226
R^2	0.805	0.810	0.805
Pollution: mean (sd)	0.33 (1.23)	0.33 (1.23)	0.33 (1.23)

Clustered (border - year) standard-errors in parentheses

Model

Dynamic model of the water infrastructure investment

- The politician decides whether to invest in upgrading the system ($a_t = 1$ or 0)
  - infinite-horizon (we abstract away from turnover)
- Investment involves a key trade-off for residents:
  - may improve water quality $q_{t+1} \sim F_q(\cdot|q_t, a_t, \mathbf{x}_t)$
  - may increase total water charges $\bar{r}_{t+1} \sim F_p(\cdot|q_t, \bar{r}_t, a_t, \mathbf{x}_t)$
  - $\mathbf{x}_t$: water system attributes (e.g., source of water), demographics, extra revenue sources
- Politician considers residents' preferences (with potentially unequal weights) and her cost of effort (e.g., rate hearing preparation, grant applications etc.) under the water rate schedule constraints

Residents preferences for water quality

- Politician takes her residents $\mathcal{I}_t$ and their propensity to vote v_{it} as given
  - fraction of movers is small, often driven by work or school
  - no competition among neighboring jurisdictions
- Resident $i \in \mathcal{I}_t$'s indirect utility with income y_{it}, in \$:

$$u(q_t, r_{it}; y_{it}, \omega_{it}) = \beta_q(y_{it}) \log q_t - r_{it} + \omega_{it}$$

  - $\beta_q(y_{it})/100$: willingness to pay for a 1% increase in water quality, allowed to vary flexibly with income
  - r_{it}: annual water rate for resident i
  - ω_{it}: individual income and other public goods/amenities, which are out of the politician's control (water enterprise runs on a separate, dedicated budget)

Politician's per-period payoff

$$\sum_{i \in \mathcal{I}_t} \lambda(v_{it}) \left[\beta_q(y_{it}) \log q_t - r_{it}\right] - \left\{c(\mathbf{x}_t, z_t) + \epsilon_t\right\} a_t$$

- Politician weighs in each resident's payoff with $\lambda(v_{it}) \geq 0$
  - each resident's weight λ_{it} depends on their turnout rate, v_{it}
  - $\lambda_i \neq \lambda_j$ in part because of heterogeneous propensity for turnout (or donations) in local elections
  - probabilistic voting model with binding policy commitments, where voter preferences are uncertain
- Politician bears her own cost from investment: $c(\mathbf{x}_t, z_t) + \epsilon_t$
  - depends on both physical/economic circumstances $\mathbf{x}_t$ and electoral environment (e.g., on-cycle vs. off-cycle), z_t
  - $\epsilon_t \sim F_\epsilon(\cdot)$ is a random, transitory cost known to the politician

Politician's problem

- Water rate schedule constraints ensure a balanced budget and cost-of-service rule

$$r_{it} = \rho_i \bar{r}_t$$

  - house-specific component, $\rho_i \geq 0$, is fixed
  - balanced budget: $\sum_{i \in \mathcal{I}_t} \rho_i = 1$
  - total cost to be recouped from revenues, $\bar{r}_t$, depends on investments (+ maintenance/operation costs)

- The politician's value function is

$$\begin{aligned} V_t(q_t, \bar{r}_t) &= \max_{a_t \in \{0,1\}} \sum_{i \in \mathcal{I}_t} \lambda_i(\beta_{q,i} \log q_t - \rho_i \bar{r}_t) - c_t a_t \\ &\quad + \delta \mathbb{E}\left[V_{t+1}(q_{t+1}, \bar{r}_{t+1}) | q_t, \bar{r}_t, a_t\right] \end{aligned}$$

Sources of inefficiency

- Benchmark investment:

$$\max_{\{a_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \delta^t \mathbb{E}\left(\sum_{i \in \mathcal{I}_t} \beta_{q,i} \log q_t - \bar{r}_t - c_t a_t \middle| q_{t-1}, \bar{r}_{t-1} \right)$$

  - efficiency condition equates the sum of MRS with the MC associated with water quality

- Politician's investment:

$$\max_{\{a_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \delta^t \mathbb{E}\left(\sum_{i \in \mathcal{I}_t} \lambda_i \left(\beta_{q,i} \log q_t - \rho_i \bar{r}_t\right) - c_t a_t \middle| q_{t-1}, \bar{r}_{t-1} \right)$$

  - under-investment if $\lambda_i < 1$ for all i
  - depends on which residents are weighed more, especially when cross-subsidization across residents is limited

Next Steps

Estimation (1/2)

- Value of investment depends on resident's preferences over water quality and rates

$$u(q_t, r_{it}; y_{it}, \omega_{it}) = \beta_q(y_{it}) \log q_t - r_{it} + \omega_{it}$$

- Approach:
  1. Recover the water quality and rate elasticities from demand for houses across jurisdictions
  2. Map these demand estimates to $\beta_q(\cdot)$

Residents preferences for water quality

- Individual i's indirect utility from a house h in period t:

$$U_{iht} = \boldsymbol{\gamma}_{x,i}\boldsymbol{x}_{ht} + \gamma_q(y_{it})\log q_{j(h)t} - \alpha(y_{it})(p_{ht} + r_{ht}) + \xi_{ht} + \epsilon_{iht}$$

  - $q_{j(h)t}$: water quality provided by h's jurisdiction, $j(h)$
  - r_{ht}: annual water rate specific to house h
  - p_h: annual user cost of housing except for r_{ht}

- Utility parameters estimated using Bayer, Ferreira, and McMillan (2007) based on house transactions, exploiting discontinuity design

Residents preferences for water quality

- Resident i's indirect utility at her chosen house at t, in \$:

$$u_i(q_t, r_{it}) = \underbrace{\frac{\gamma_q(y_{it})}{\alpha(y_{it})}}_{\equiv \beta_q(y_{it})} \log q_t - r_{it} + \omega_{it}$$

  - r_{it}: annual water rate at i's chosen house
  - $\omega_{it} \equiv (\gamma_{x,i} \boldsymbol{x}_{h(i),t} - \alpha_i p_{h(i),t} + \xi_{h(i),t} + \epsilon_{i,h(i),t})/\alpha_i$

Estimation (2/2)

- State transitions estimated directly from observed states
  - water quality transitions $F_{q'|(q,a)}$
  - effect of investment on rate $F_{r'|(r,q,a)}$
- Politician's preference: $\lambda(\cdot)$ and $c(\cdot)$

$$\sum_{i \in \mathcal{I}_t} \lambda(v_{it}) \left[\beta_q(y_{it}) \log q_t - r_{it}\right] - \left\{c(\mathbf{x}_t, z_t) + \epsilon_t\right\} a_t$$

  - $v_{it} = v(y_{it}, z_t)$ is estimated using voter files
  - investment choices, exploiting exclusion restriction that electoral cycle z_t doesn't directly affect resident preferences while it affects politician preferences
  - variation in resident preferences (e.g., moves in/out) and water system/investment costs (e.g., federal funding eligibility, drought, labor/materials) also help

Counterfactual analyses

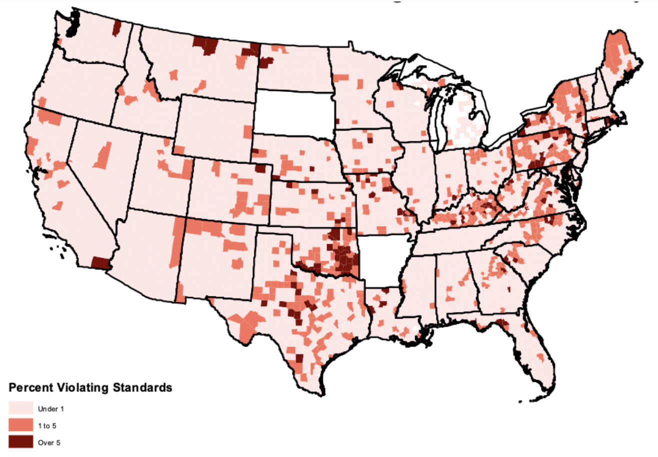
- Quantify inefficiency in investment by comparing with the benchmark
    - how does investment efficiency differ across communities based on their demographics, income levels, and voter turnout?
    - how does uncertainty about investment outcomes or cost increase—particularly from factors like climate change—affect these patterns?
- Evaluate policies to help address investment distortions
    - alternative pricing (e.g., progressive water rate)
    - alternative federal/state subsidies

Conclusion

- We present suggestive evidence that
  - drinking water investment in California is potentially inefficient
  - local political participation and gov officials' incentives matter in investment and water quality
- We provide empirical framework to
  - quantify inefficiency and the extent to which resident preferences on water quality vs rate are represented by local officials in their investment
  - evaluate policies to address inefficiency

Appendix

Share of water below health standards, 2009-19 Back



Source: Kaiser et al (2023), Figure 1-C

City of Cupertino: Notice of water rate hearing Back

Bi-Monthly Base Charges (Charge per Acct)

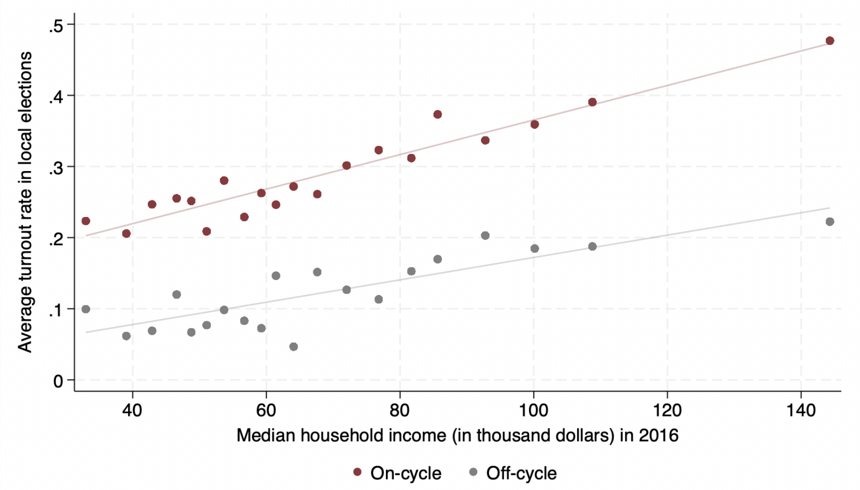
Meter Size	Current ($/bi-month)	Proposed Bi-Monthly Base Charges FY 2023-24	FY 2024-25	FY 2025-26	FY 2026-27	FY 2027-28
	% Increase	*4%*	*4%*	*4%*	*4%*	*4%*
	effective date	*7/1/2023*	*7/1/2024*	*7/1/2025*	*7/1/2026*	*7/1/2027*
5/8" or 3/4"	$54.41	$56.59	$58.85	$61.20	$63.65	$66.20
1"	$82.94	$86.26	$89.71	$93.30	$97.03	$100.91
1 1/2"	$148.91	$154.87	$161.06	$167.50	$174.20	$181.17
2"	$230.66	$239.89	$249.48	$259.46	$269.84	$280.63
3"	$493.77	$513.52	$534.06	$555.42	$577.64	$600.75
4"	$848.66	$882.61	$917.91	$954.63	$992.81	$1,032.52
6"	$1,735.88	$1,805.32	$1,877.53	$1,952.63	$2,030.73	$2,111.96
8"	$3,278.89	$3,410.05	$3,546.45	$3,688.31	$3,835.84	$3,989.27
10"	$5,207.64	$5,415.95	$5,632.58	$5,857.89	$6,092.20	$6,335.89
12"	$6,866.36	$7,141.01	$7,426.65	$7,723.72	$8,032.67	$8,353.98

Bi-Monthly Quantity Charges (Charge per HCF)

Current Rates				Proposed Bi-Monthly Quantity Charges						
Tier size			$/HCF	Tier Size (HCF)		FY 2023-24	FY 2024-25	FY 2025-26	FY 2026-27	FY 2027-28
					% Increase	*4%*	*4%*	*4%*	*4%*	*4%*
					effective date	*7/1/2023*	*7/1/2024*	*7/1/2025*	*7/1/2026*	*7/1/2027*
Tier 1	0 – 13	HCF	$6.83	0 - 13	HCF	$7.10	$7.39	$7.68	$7.99	$8.31
Tier 2	14 – 26	HCF	$9.04	14 - 26	HCF	$9.40	$9.78	$10.17	$10.58	$11.00
Tier 3	27+	HCF	$12.48	27+	HCF	$12.98	$13.50	$14.04	$14.60	$15.18

HCF - hundred cubic feet (1 HCF = 748 gallons)

Income and turnout for local elections Back



Electoral competitiveness and turnout for local elections Back

	High Turnout	Low Turnout	Difference
Uncontested	0.096	0.143	−0.045
	(0.005)	(0.005)	(0.007)
Incumbent vote share advantage	0.055	0.091	−0.036
	(0.003)	(0.004)	(0.005)
Average vote margins	0.127	0.165	+0.038
	(0.002)	(0.002)	(0.003)

Notes: This table reports summary statistics for the mayoral and city council elections in California, from 1995 to 2021 (8,572 observations). We divide the elections into two groups based on the turnout rate, with the median value in the data (23%) being the threshold.