Heat and Bottled Water Expenditures: Evidence from California

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Abstract

This study examines how Californians adapt to rising temperatures through bottled water consumption. Using a county-week panel from 2014–2023, I estimate the causal impact of heat exposure on bottled water sales. Results indicate that average weekly maximum temperatures above 90°F drive a 35% increase in expenditures compared to moderate temperatures (60–70°F), with each additional day above 95°F raising sales by 2.9–3.8%. While acute heat stress amplifies demand, drought severity correlates negatively with purchases. Private water supply shocks from dry wells show mixed associations, potentially reflecting a needs gap in underserved communities. These findings highlight bottled water as an adaptation mechanism to heat, with implications for water access policies in groundwater-depleted regions under climate change.

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1 Introduction

In this paper, I document how Californians adapt to hot days by increasing bottled water expenditures. I match retail scanner data from bottled water transactions with maximum temperature exposure, accounting for drought and domestic water supply shocks.

This work contributes to a growing literature on climate adaptation to drought and heat. Drinking water is a key adaptive margin to heat. A study of Chinese households documents that municipal water consumption increases significantly during periods of high heat, with this effect amplifying during extended heatwave events (Qin et al. (2022)).

This is the first paper to my knowledge that documents the causal impacts of hot days on bottled water sales. Bottled water purchases have been studied as a pollutant-averting response to salient water quality violations. Water purchases spike in response to notifications of Safe Drinking Water Act violations (Graff Zivin et al. (2011), Hadachek (2024)) and salient information about lead contamination in Flint, Michigan (Christensen et al. (2011)).

In the empirical context of a water stressed region, my analysis of domestic well water supply disruptions is situated within a broader multidisciplinary literature concerning groundwater scarcity and natural resource allocation. California is one of many regions around the globe that is losing freshwater over time Carleton et al. (2024).

Public water systems provide residential and drinking water to most California residents, but many rural communities source their drinking water from private domestic wells instead. Between 3.4 and 5.8% (1.3 to 2.25 million) Californians rely on domestic wells to meet their water needs (Pace et al. (2023)). These wells are primarily located outside the bounds of public water infrastructure and are concentrated in low-income and Hispanic communities. Private wells are typically drilled to shallower depths than agricultural wells that draw groundwater from the same aquifers. This leaves domestic wells vulnerable to failing, or running dry, as groundwater tables decline. Hadachek et al. (2024) document that farmers in California extract more groundwater in response to heat and drought, which increases domestic well failures and imposes substantial externalities on low-income and minority rural communities. Dry private wells impose financial burdens on vulnerable households from the costly construction of new, deeper wells[1]. While a household is in the process of restoring its water supply, it faces additional costs to meet its water needs.

[1] Domestic wells cost approximately $10,000 and are typically between 100 and 300 feet deep. Construction cost increases with well depth.

In the California Central Valley, several counties have local services to provide households with dry wells with trucked in non-potable water and bottled drinking water[2]. Other water distressed households may borrow water from a neighbor's well with a hose and/or substitute to purchased bottled water to meet their water needs.

Given the unobserved water aid supplied to households with dry domestic wells, an uptick in bottled water sales at stores in water-stressed regions can be interpreted as an unmet needs gap indicating insufficient water aid.

The risk of well failure will be exacerbated as groundwater tables continue to fall. The Sustainable Groundwater Management Act (SGMA), enacted in 2014, requires the development and implementation of groundwater sustainability plans to mitigate overdraft by 2040. However, analysis of the proposed plans in California's Central Valley aquifer system finds that nearly 10,000 private domestic wells and about 1,000 public supply wells would be impacted by declining groundwater levels allowable under the current proposals (Bostic et al. (2023)).

2 Data and Summary Statistics

I assemble a panel dataset covering 2014-2023 that includes county-weekly level measures of temperature exposure, drought severity, water supply shocks, and store level scanner data on bottled water transactions. Table 1 summarizes the main variables, which I describe in detail below.

2.1 Data Sources

Bottled Water Sales. I use a weekly retail panel with bottled water purchases from Nielsen for my baseline analysis[3]. The Nielsen Retail Scanner panel includes weekly transaction level data for bottled water (and other beverage products)[4] from participating retail chains. For each store and week in the sample, I compute the number of transactions, the volume and value of bottled water sales, the average price per gallon paid, and the number of transactions exceeding 100 gallons.

Store locations are identified at the county level in the Nielsen panel. I merge this data with county-weekly aggregated weather and domestic well failure data.

[2]Self-Help Enterprises offers emergency water assistance to low-income households in the San Joaquin Valley. This service is avaiable in Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, and Tulare County.

[3]I access the data through the Kilts Center for Marketing at the University of Chicago Booth School of Business

[4]In this paper, I restrict my analysis to UPCs of unflavored bottled water products and exclude all other beverages. For more details, see Appendix II: Data.

Temperature. The empirical strategy will leverage variation in bottled water sales and heat exposure within a store after flexibly controlling for seasonal sales patterns. I aggregate daily maximum temperature data from PRISM to the county-week level using population density spatial weights and averaging across days in the week. In addition to the average maximum temperature, I create county-weekly measures of the number of days in the week exceeding a maximum temperature of 90°F and 95°F. I further aggregate these measures into a dummy variable of 10°F bins.

Drought. I control for drought with the Drought Severity and Coverage Index (DSCI)[5]. The DSCI is a weighted spatial average metric developed by the National Drought Mitigation Center to quantify drought exposure across geographic regions. Calculated from the U.S. Drought Monitor's categorical classifications (D0-D4), the DSCI assigns numerical weights to each drought category based on intensity, then sums the weighted percentages of land area in each category. The underlying classifications are based on physical indicators of precipitation, temperature and soil moisture as well as local impact reports from experts familiar with region-specific climate normals.

I scale the continuous DSCI to take values between 0 (no area in the county in drought) and 5 (entire county classified as severe drought). Including the DSCI in my analysis allows me to account for drought conditions that may amplify heat impacts to isolate acute heat stress that drives immediate water demand spikes.

Dry Well Reports. Groundwater is an important source of domestic water supply in California. In 2014, the California Department of Water Resources (DWR) set up the Dry Well Reporting System to collect data on drought impacts on domestic water supply[6]. Households that navigate to the Reporting System website can find their county's emergency drought contact and technical service provider, as well as other contacts for local assistance. Reports are often filed by administrators on behalf of households experiencing an outage, but households can also submit a report to document an issue. The publicly available reports data contain the latitude and longitude coordinates for malfunctioning wells, the approximate date the issue started, and whether the issue was resolved.

Nearly 6,000 domestic well failure reports were filed between 2014 and 2023. Figure **??** shows the reported dry wells across California reports across space and time. Domestic wells draw from the same groundwater basin as their near neighbors, so there is spatial correlation in failures. If an

[5] Information about the DSCI can be found here.

[6] Well failure reporting data is publicly available from 2014 through the present, accessible here.

unreported dry well is drilled as deep as a neighboring well with the same depth-to-groundwater, the two wells would experience issues around the same time.

These data are an undercount of the true number of dry wells. Households that self-finance well replacements are unlikely to submit a dry well report voluntarily. Wealthier well-owners and households that are unaware of the resources available to them are underrepresented in the sample relative to the households that seek public resources for assistance. The completeness of the reports improves over time as knowledge of the reporting system spreads and the system becomes accessible in additional languages.

Aggregating well failures to match with stores at the county level introduces a potential bias to the relationship between water supply shocks and bottled water expenditures. Lacking the specific spatial store location, I cannot distinguish between stores near well failure hotspots or a county border. I implicitly assume that dry well-owning households purchase bottled water at retail stores within their county. However, there are potential spillover effects from households purchasing bottled water from a store across the county line. Therefore, I interpret the results of this effect with caution[7].

3 Estimation Strategy

My estimation strategy will identify the causal impact of hot temperatures on bottled water expenditures. I use OLS to estimate:

$$Y_{it} = \beta T_{ct} + \delta DSCI_{ct} + \eta W_{ct} + \gamma_i + \tau Year + \mu_{cm} + \epsilon_{it} \tag{1}$$

In my baseline specification, the dependent variable Y_{it} is the log of the total bottled water expenditures at store i in week t. The main independent variable T_{ct} is the average daily maximum temperature exposure in county c in week t, binned in 10°F bins.

In all regressions, I control for drought severity ($DSCI_{ct}$) and W_{ct}, the reported number of dry domestic wells (per 10,000) in each county in week t. All reported standard errors are two-way clustered on both store and county-by-month to allow for correlations within stores and within county-month groups.

[7] I am pursuing a collaboration with colleagues at the USDA Economic Research Service that would allow me to access Circana weekly retail data from participating stores with longitude and latitude coordinates. In future work, I plan to match the precise store location information with nearby well failure reports to address this shortfall and estimate the relationship between well failures and bottled water purchases more precisely.

The store fixed effect γ_i adjusts for time-invariant factors that affect bottled water sales, such as income and preferences of the store's consumer base. I include μ_{cm} to soak up county-specific monthly seasonality in bottled water purchases and a linear annual time trend. This estimation strategy allows me to isolate variation in weekly bottled water sales within the same month across years in the sample. The annual time trend accounts for slow-moving changes in bottled water sales trends.

An identifying assumption of this framework is that fluctuations in average weekly temperature uncorrelated with unobserved confounders affecting bottled water sales after controlling for store fixed effects, county-by-month fixed effects, drought severity, and domestic well failures. Although well failure reports indicate critical groundwater depletion, they do not reflect all water supply shocks. Not all private well failures are captured in the reports, and public well failures are not captured in the data. Salient water quality violations are also unobserved and may cause a problem for identification.

I assume adaptation behaviors are constant over time. Persistent heat exposure might lead to long-term investments in water filters, which could lower expenditures on bottled water.

4 Results

Figure 3 displays the results of OLS estimation of Equation (1) for four dependent variables. Each panel shows the marginal causal effects of average daily maximum temperature relative to a week with an average between 60°F and 70°F. Panel (a) shows a clear positive relationship between temperatures above 70°F and bottled water expenditures. Most notably, weeks with average maximum temperatures exceeding 90°F show the largest increases in bottled water expenditures. The 90-100°F temperature bin is associated with approximately a 35% increase in bottled water sales compared to the reference temperature range.

Panel (b) shows that the average price per gallon also increases with high temperatures. However, variation in the mean price per gallon does not necessarily reflect price changes in bottled water products. For example, the average price per gallon would increase if sales of individual artisanal bottled water bottles products, which tend to be much more expensive per volume, increase holding all else equal.

These results provide strong evidence that consumers respond to heat exposure by increasing their bottled water purchases, suggesting an important adaptive behavior to high temperatures.

The results robustly demonstrate that high temperatures drive increases in bottled water expenditures, with each additional day above 95°F increasing sales by approximately 2.9-3.8%. These findings are consistent with the hypothesis that bottled water serves as an important adaptation mechanism during periods of heat stress. The negative coefficient on drought severity suggests different consumer responses to acute versus chronic water stress. The varying effect of well failures across specifications indicates complex relationships between water supply disruptions and bottled water purchasing behavior that merit further investigation.

5 Conclusion

This paper provides the first causal evidence linking elevated temperatures to increased bottled water expenditures.

These findings carry policy relevance for California's Sustainable Groundwater Management Act (SGMA) and similar frameworks globally. As groundwater depletion threatens water supply in rural communities dependent on overdrafted groundwater, targeted interventions—such as expanding emergency water aid—could mitigate reliance on costly market alternatives. Limitations in spatial retail data and underreported well failures warrant future research using precise geolocation to disentangle supply-chain spillovers and unmet needs.

More broadly, this study advances understanding of market-based climate adaptation, emphasizing the equity implications of escalating bottled water demand in marginalized, heat-vulnerable regions.

References

Bostic, D., Mendez-Barrientos, L., Pauloo, R., Dobbin, K., and MacClements, V. (2023). Thousands of domestic and public supply wells face failure despite groundwater sustainability reform in california's central valley. *Scientific Reports*.

Carleton, T., Crews, L., and Nath, I. (2024). Is the world running out of fresh water? *AER:PP*.

Christensen, P., Keiser, D., and Lade, G. (2011). Economic effects of environmental crises: Evidence from flint, michigan. *American Economic Journal: Economic Policy*.

Graff Zivin, J., Neidell, M., and Schlenker, W. (2011). Water quality violations and avoidance behavior: Evidence from bottled water consumption. *AER:PP*.

Hadachek, J. (2024). Benefits of avoiding nitrates in drinking water. *Working Paper*.

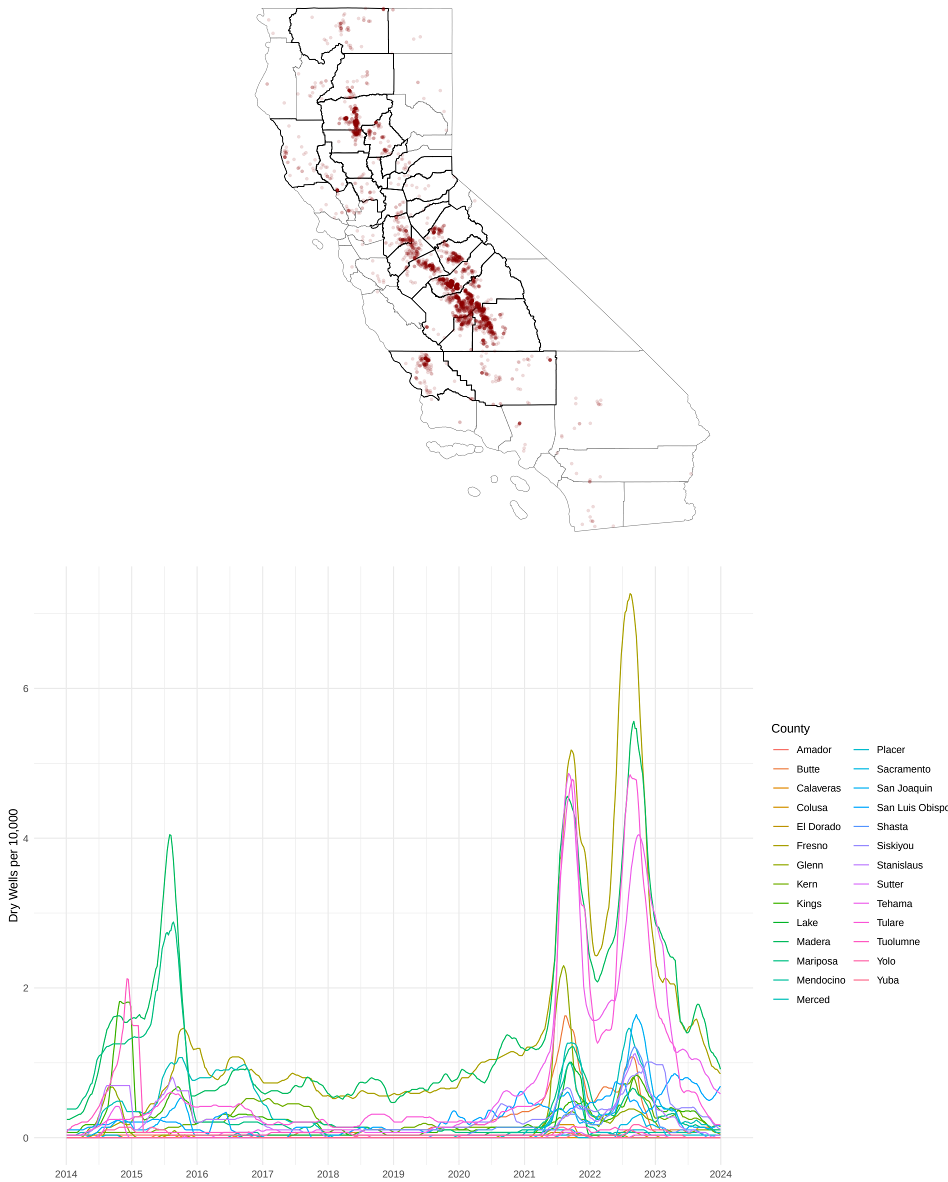
Hadachek, J., Bruno, E. M., Hagerty, N., and Jessoe, K. (2024). External costs of climate adaptation: Groundwater depletion and drinking water. *Working Paper*.

Pace, C., Balazs, C., Bangia, K., Depsky, N., Renteria, A., Morello-Frosch, R., and Cushing, L. (2023). Inequities in drinking water quality among domestic well communities and community water systems. *Scientific Reports*.

Qin, P., Chen, S., Tan-Soo, J.-S., and Zhang, Z.-B. (2022). Urban household water usage in adaptation to climate change: Evidence from china. *Environmental Science and Policy*.

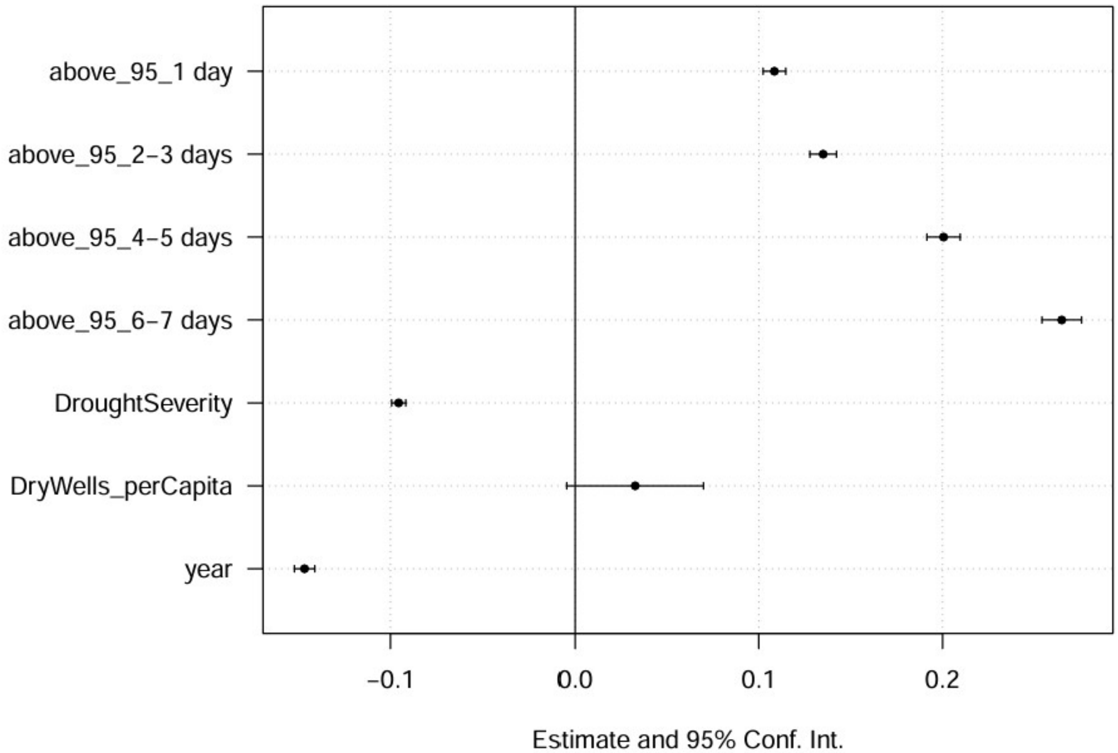
6 Tables and Figures

Figure 1. Reported Domestic Well Failures



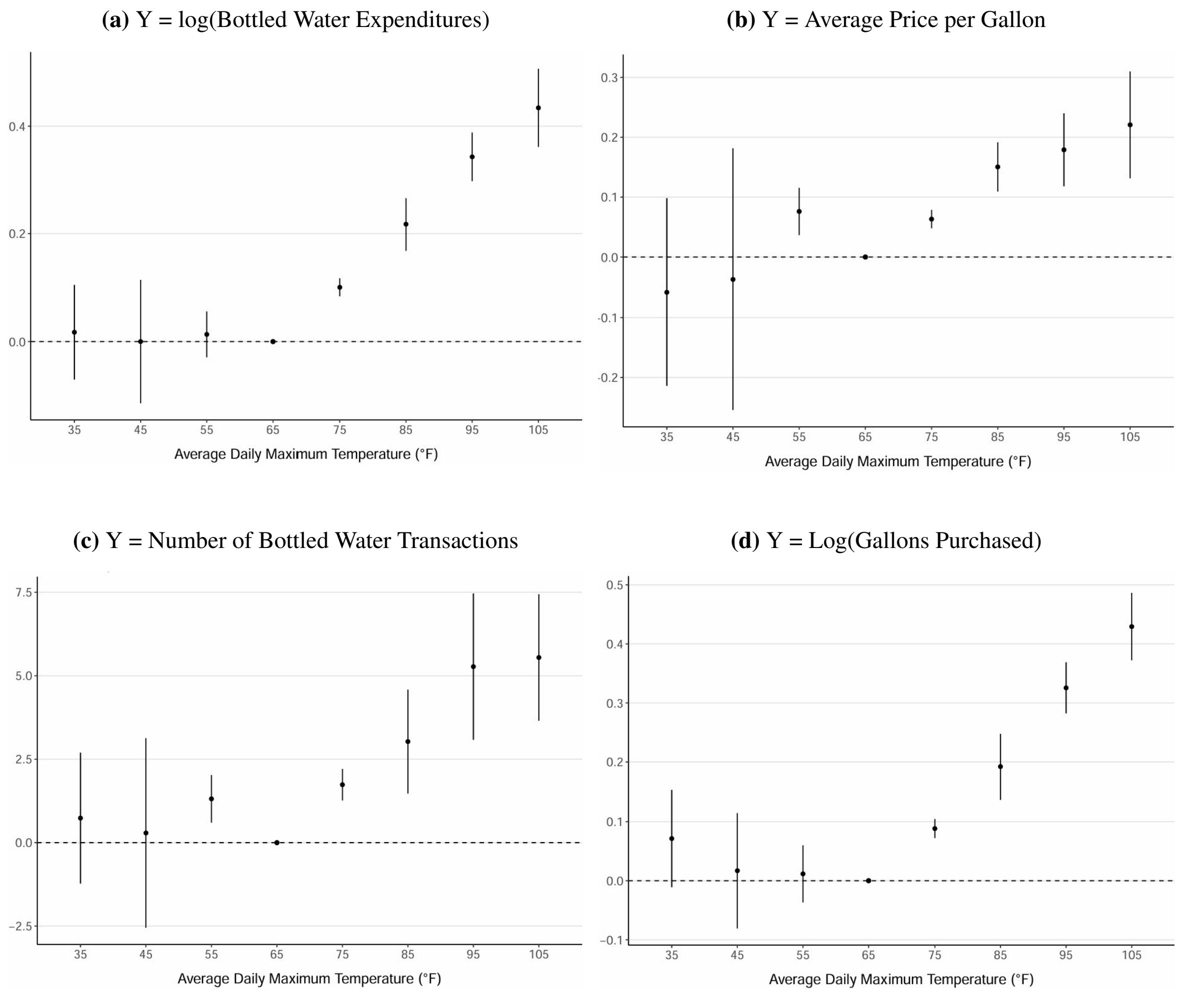
Note: The top panel displays the well failures reported across California between 2014 and 2023. Counties included in my sample are outlined in bold. The bottom panel plots the 4-week rolling average of reported domestic well failures per 10,000 residents for each county in the sample.

Figure 2. Effect of Extreme Heat Days on Log(Bottled Water Expenditures)



Presents the results from OLS estimation of Equation (1), including store and county-by-month fixed effects.

Figure 3. Marginal Effects of Binned Temperature



Note: Presents results from OLS estimation of Equation (1) for for different dependent variables Y. The point estimate of β and 95% confidence interval are plotted for the dummy variables corresponding to temperature bins. The dependent variable is the log of bottled water sales, and the effect is the causal impact on Y of the weekly average maximum temperature falling in the 10 degree bin relative to a week in the 60-70 degree bin. Regression includes store and county-by-month fixed effects and controls for a linear annual trend, drought severity, and well failures per capita.

Table 1. Summary Statistics of Main Variables

Variable	N	Mean	Sd	Min	Max
Y_{it}					
Bottled water expenditures ($)	400218	1675.86	2256.53	0.01	36824.01
Volume (gallons)	400218	171999.20	287011.42	16.50	4986072.86
Transactions	400218	32.13	23.98	1.00	126.00
Transactions 100 gallons	400218	2.30	2.82	0.00	21.00
Avg price per gallon	400218	5.25	1.74	0.02	19.65
T_{ct}					
Avg daily max temp	12838	74.81	14.90	32.48	108.35
Days over 90 degrees	12838	1.54	2.44	0.00	7.00
Days over 95 degrees	12838	0.84	1.78	0.00	7.00
W_{ct}					
Dry wells	12838	7.85	19.23	0.00	216.00
Total wells	12838	7139.72	4168.37	1013.00	20164.00
Percent dry	12838	0.10	0.23	0.00	2.80
Dry wells per 10,000	12838	0.11	0.27	0	2.94

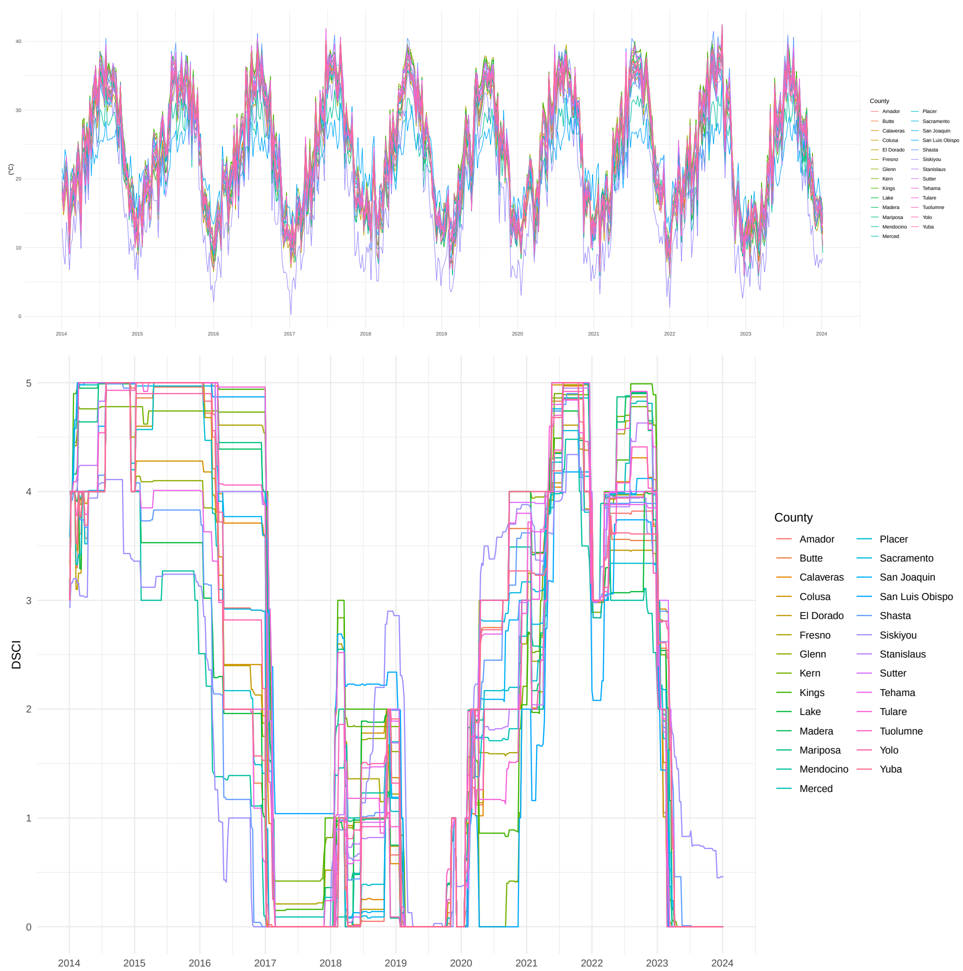
Table 2. Alternative Specifications

Dependent Variable:	log(Bottled Water Expenditures)				
	(1)	(2)	(3)	(4)	(5)
Variables					
95+ degree days	0.0702***	0.0368***	0.0377***	0.0376***	0.0286***
	(0.0009)	(0.0062)	(0.0010)	(0.0008)	(0.0005)
Drought severity	-0.0983***	-0.0249***	-0.0177***	-0.0953***	-0.0061***
	(0.0019)	(0.0038)	(0.0022)	(0.0019)	(0.0019)
Dry wells per 10,000	0.0340*	-0.6398***	-0.5291***	0.0305	0.0929***
	(0.0183)	(0.0605)	(0.0219)	(0.0190)	(0.0182)
Year	-0.1479***			-0.1470***	
	(0.0028)			(0.0028)	
Fixed Effects					
Store ID	Yes		Yes	Yes	Yes
County by month		Yes	Yes	Yes	
County by month of sample					Yes
Fit statistics					
Observations	400,218	400,218	400,218	400,218	400,218
R^2	0.91300	0.05326	0.87010	0.92017	0.94654
Within R^2	0.44482	0.01887	0.08035	0.43479	0.00780

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

A Appendix I: Additional Figures

Figure A1. Climate Variation



Note: The top panel displays the variation in average daily maximum temperature exposure across counties in the sample, and the bottom panel plots the variation in drought severity.