Bottled Water Demand in a Water Stressed Region: Evidence from California's Central Valley

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March, 2025

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Abstract

To do: write an abstract.

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1 Introduction

To do: rewrite intro and split into literature subsection

Make sure intro, conclusion and abstract are unambiguous in terms of what I do in the paper and how readers should think about it

it should emphasize what I accomplish with the work and how it fits into broader literature

Key question:

How does the impact of an extra 90+ degree day impact water demand? Does the effect vary with drought severity?

Motivation:

This work contributes to a growing literature on climate adaptation to drought and heat. Drinking water is a key adaptive margin to extreme heat. Climate adaptation, and specifically, the relationship between weather/climate and water demand is understudied in the literature.

This is the first (?) paper to date that documents the bottled water demand response to extreme temperatures in drought-prone areas.

Lit review:

The secondary analysis using domestic well failures is situated within a broader multidisciplinary literature concerning groundwater scarcity and natural resource allocation. The HBHJ work uses the domestic well report data to document a causal link between agricultural groundwater extraction and domestic well failures. Carleton et al. have work forecasting geographic water stress hotspots, highlights the global pervasiveness of water scarcity.

Most similar work looks at water quality violations. Dry wells similarly have reduced water quality, which might be detectable to the households (look through notes to see if dry well report comments have any patterns) Cite Hadachek and Shapiro work on pollution/nitrate violations.

Initial (now secondary) question, context-specific:

How do domestic water supply failures (dry wells) from groundwater depletion impact demand for bottled water?

Note: In the context of the Central Valley, some counties have local on-the-ground services designed to respond to household well failures with bottled drinking water and trucked-in water to meet the needs of families who cannot afford to finance solutions. Given the (unobserved, potentially heterogeneous) water aid supplied to these households, a (causal) uptick in bottled water sales at stores in water-stressed regions could be interpreted as an unmet needs gap indicating insufficient water aid.

Policy Relevance

Under heroic assumptions, the additional money spent on bottled water during periods of groundwater scarcity can be interpreted as the willingness to pay for bottled water to bridge the needs gap. This number could be used to calculate a suggestion for increased spending for local programs supplying bottled water.

(Old intro from proposal)

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 Latino 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. Sometimes, local governments supply water or offer bottled water. Else, households must pay to truck in water, borrow water from a neighbor's well with a hose, or purchase bottled drinking water.

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)).

This paper will investigate the bottled water demand response to domestic well failures. I will match reported well failure reports with retail scanner data from nearby

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

stores to quantify the impact of domestic well failures on bottled water purchases. Additionally, I will explore whether the price of bottled water products responds to well failure shocks.

1.1 Prior Work and Contribution

To do: Review papers in the lit folder; characterize contribution relative to other work and motivate policy relevance.

2 Data

To do: add all summary stats and description of variation in exposure to water supply shocks, demographics, population concentration, agricultural land use.

2.1 Scanner Data

For my baseline analysis, I use a store panel of retail bottled water purchases from Nielsen.

There are two sources for water bottle purchase data I plan to use in the analysis. Both sources contain data from a subset of retail stores which are not representative of all stores in the area. Household purchases made at other stores will not be captured in either dataset.

Nielsen Retail Panel

The Nielsen Retail Scanner panel includes store-level weekly purchase data for bottled water and other beverage products from participating retail chains. The data include the price, number of units, and volume (ounces) of water sold at each store for weeks through the end of 2020. The store locations are identified by county and three-digit zip code.

While most three-digit zip codes span multiple counties, the zip codes for the cities of Fresno and Bakersfield lie entirely inside Fresno and Kern counties. I will separate the stores in city zip codes in these counties from those outside of the city zip codes.

To do: Insert plot with purchase volumes over time, see if any spikes

Using aggregated store data could lead to several potential issues. Lacking the specific spatial store location, I cannot distinguish between stores near groundwater depletion hotspots or a county border. For the county-level analysis, I implicitly assume that dry well-owning households will purchase bottled water at retail stores within their county. However, I acknowledge the potential for spillover effects from households purchasing bottled water from a store across the county line.

TO DO: hypothesize the impact of the bias from different spillover shopping behavior, (whether we care depends on specific question and estimate)

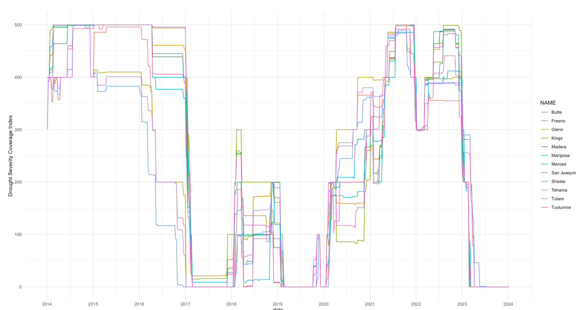
To address this concern, I plan to repeat the analysis in the future using retail scanner data linked to store coordinates. I outline the details in Appendix I: Future Work.

2.2 Weather

I will control for weather using weekly drought severity maps from drought.gov and weekly average temperature maximums with data from PRISM. I plan to interact the drought indicator and temperature bins with the well failure index to explore how the treatment effect varies in different weather conditions.

Insert plot showing variation of weather variables over time and space

Figure 1. Drought Severity Coverage Index



This figure plots the Drought Severity Coverage Index, a function of the geographic exposure of the county to drought. This figure includes the top counties with the most reported dry well failures, and I plan to replace it with a figure with all the counties. ...

2.3 Well Reports

Dry Well Reports

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. [2] These data contain the latitude and longitude coordinates for malfunctioning wells, the approximate date the issue started, and whether the issue was resolved.

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

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.

Nearly 6,000 domestic well failure reports were filed between 2014 and 2023.

Domestic wells draw from the same groundwater basin as their near neighbors, so there is spatial correlation in failures, particularly for wells drilled to similar depths. Figure A1 plots the patterns in dry well reports across space and time. Well failure reports are concentrated in the San Joaquin Valley and (other hotspots).

Known Data Quirks

1) Quality improves over time The data improve over time as knowledge about the reporting system spreads, and the report is made accessible in Spanish (not sure when that was made available). The website was re-done around the pandemic (between drought periods) and there are many more reports submitted during the second drought period compared to the first (refer to figure) TO DO: use Wayback machine to see what the well reporting system website looked like back in 2014.

2) 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, households that are unaware of the resources available to them, and renters will be underrepresented in the sample relative to the households that seek public resources for assistance.

Completion and Destruction Reports The DWR also collects records for new well construction, repair, and destruction of wells. I use these data to estimate the share of domestic wells in each county that experience issues at time t.

I use this dataset to estimate of the number of active wells in each week and divide by the estimated number failing

The construction reports are generally considered complete, but the destruction reports are known to substantially undercount the true number of wells taken out of commission.

These data contain the coordinates of each well[3], whether it was created for agricultural irrigation or domestic water supply, and the date the work was completed.

[3]The DWR notes that most of the points have been spatially registered to the center of the 1x1 mile Public Land Survey System section that the well is located in.

I use these data to measure the total number of domestic wells in an area and the share of domestic wells that fail in a given week.

Well completion reports are used to create an

Demographic Controls

I also obtain a set of demographic controls from the American Community Survey. These variables are available at both the county level and granular census block level. For three-digit zip code or location-specific Circana data, I will aggregate census block data to obtain estimates for the area of analysis. The variables I will include are population, median income per capita, median age, percent white non-Hispanic, percent Hispanic, unemployment rate, labor force participation rate, and percent of adults with at least college-level education.

Add paragraph discussing how the demographics vary across the counties I use as treatment/controls. Discuss potential geographic distribution of the stores across counties

3 Model and Empirical Strategy

3.1 Model

Include DAG of various elements of the problem

Discuss how aggregated store data of Nielsen limits the analysis to county-level

The data restrictions and complex interplay of variables inform the empirical strategy.

3.2 Empirical Strategy

Discuss treatment and control counties for DID analysis.

DEFINE ALL NOTATION

4 Results

Table **??** text

Figure **??** text

The top panel of Table **??** text

5 Conclusion

To do: write conclusion

To do: add citations to bibliography/lit review

References

Bostic, Darcy, Linda Mendez-Barrientos, Rich Pauloo, Krisin Dobbin, and Victoria MacClements, "Thousands of domestic and public supply wells face failure despite groundwater sustainability reform in California's Central Valley," *Scientific Reports*, 2023.

Hadachek, Jeffrey, Ellen M. Bruno, Nick Hagerty, and Katrina Jessoe, "External Costs of Climate Adaptation: Groundwater Depletion and Drinking Water," *Working Paper*, 2024.

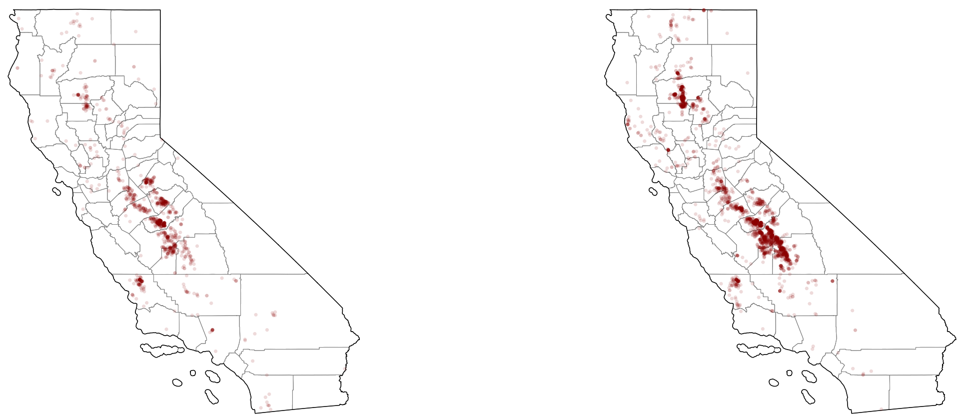
Pace, Clare, Carolina Balazs, Komal Bangia, Nicholas Depsky, Adriana Renteria, Rachel Morello-Frosch, and Lara Cushing, "Inequities in Drinking Water Quality Among Domestic Well Communities and Community Water Systems," *Scientific Reports*, 2023.

A Tables and Figures

Figure A1. Reported Domestic Well Failures

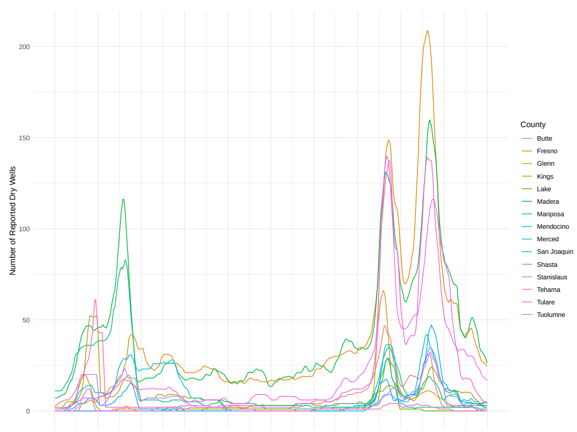
(a) 2014-2020

(b) 2021-2023



Note: The top left panel (a) displays the well failures reported in the early sample (2014-2020) and the right panel (b) displays failures reported in the later sample (2021-2023).

Figure A2. Domestic Well Failure Reports



This figure shows the 4-week rolling average of reported domestic well failures in the ten counties with the highest number of well failure reports in the sample.

B Appendix I: Future Work

This section describes the data I plan to analyze for a future iteration of this work.

I plan to use store-level retail scanner data from Circana. This data includes the retail data at the precise coordinate location for a different national subset of stores. I will repeat and expand upon the analysis above with the new dataset.

I hope to incorporate some of this analysis in the May version of this draft for my Second Year Paper. All analysis of the data will be my own. However, I must include my USDA collaborator as a co-author of the work per my data access contract. Since the Second Year Paper must be single-authored work, I will eventually separate my analyses of the Nielsen and Circana data into two distinct papers.

Circana Data

I am pursuing a collaboration with colleagues at the USDA Economic Research Service that would allow us to access Circana weekly retail data from participating stores with longitude and latitude coordinates. With more precise store location information, I plan to match stores to nearby domestic wells within a specified distance.

Store-level Circana data would have several advantages over aggregated Nielsen data. With large geographic areas, I combine data from stores far from shocks into our response variable, which lowers the power of our tests. Although potentially sparse store coverage may limit the number of well shocks that fall close enough to a store to detect an effect, I will have better temporal coverage. Circana data are available through 2023, which includes the historic drought period in 2021 and 2022, when most of the reported failures in our sample occurred. Precise location data also addresses the potential issues arising from spillovers. I can determine the distance between the store and each dry well to compute the number and share of total wells within a reasonable driving distance that experience problems each week. Circana data also include bulk shopping and convenience stores that are likely to experience water bottle demand shocks.

Circana data will also allow us to identify stores that fall within public water system boundaries[4]. I plan to interact an indicator for the existence of public water infrastructure with the treatment to see how the effect varies with alternative water source availability. Finally, with our specification (discussed below), I will directly

[4]Public water system data come from California Drinking Water System Locations, a combination of three datasets that provides best-available location information for public California drinking water systems and state small drinking water systems. The data are combined into a GIS feature layer and can be accessed here

identify a store-level effect that is more interpretable than the aggregate effect over a larger geographic area.

C Appendix II: Data

This appendix contains a detailed description of the data cleaning process. I document the process I used to evaluate options when I reached a fork in the road.

C.1 Nielsen

C.2 Well Reports

To do: add Brief discussion of how I constructed F and distribute work across this section and data appendix:

While preparing the sample data, I drop failure reports missing the issue start date, with start dates that occur after the report was filed, and reports filed more than one year after the issue start date. Well failures that occurred but are not captured in our sample would bias our estimates downward.

For the reports marked as resolved, I mark the beginning of the outage as the approximate issue start date (given in the data), and I designate the date the report was filed as the date the dry well was resolved. Using this assumption, I calculated that 54% of the resolved reports were filed within two months of the approximate issue start date. For reports marked unresolved, I added two months to the date the well report was filed and interpolated

For resolved reports, the time between the issue start date and the report creation can be used to infer the median duration of reported well outages.