Toward a comprehensive explanatory model of reliance on alternatives to the tap: evidence from California's retail water stores

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ABSTRACT

Building on a recent increase in scholarly attention to the problem of tap water mistrust and resulting negative health impacts, we examine the relationship between neighborhood reliance on tap water alternatives and a range of explanatory factors. We model retail water store locations as a proxy for reliance on tap water alternatives in urbanized neighborhoods across California. Our study is unique in its inclusion of variables representing both compliance with primary and secondary water quality standards by publicly regulated drinking water systems serving particular neighborhoods, other water system attributes and the socioeconomic characteristics of neighborhoods. The location of retail water stores in urbanized neighborhoods does not appear strongly related to observed measures of water quality. Secondary contamination shows a weak relationship to tap alternative reliance, and primary contamination was not correlated with higher levels of tap alternative reliance. On the other hand, our research suggests that other socioeconomic factors, particularly country of birth, are associated with the prevalence of more water stores. Increasing reliance on tap water likely requires measuring and addressing secondary contamination found in distributional systems and premise plumbing, and more aggressive public education campaigns.

Key words | perception, Safe Drinking Water Act, secondary contamination, tap water, water vendors

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INTRODUCTION

In the last decade, but especially since the discovery of publicly regulated, health-harming drinking water provided and overlooked by public agencies in Flint, Michigan (Associated Press 2016), there has been heightened scholarly attention to the problem of tap water mistrust in the United States (for instance, see Pierce & Gonzalez 2016; Javidi & Pierce 2018; Levêque & Burns 2018; Rosinger *et al.* 2018). Despite the salience of the Flint water scandal and similar instances, empirical data show that most regulated drinking water systems serving the vast majority of the US population do meet US Safe Drinking Water Act (SDWA) primary contaminant standards as well as international water quality standards (WHO-UNICEF 2017). (This applies to medium and large publicly regulated systems. The case of state small systems and private, unregulated wells is entirely different. For instance, small systems serving mobile home parks (Pierce & Gonzalez 2017) and private wells are much more likely to serve water with levels of contamination which exceed the primary standards of the SDWA (Knobeloch *et al.* 2013).)

The SDWA classifies drinking water contaminants into two groups. The presence of nearly 100 primary contaminants in treated water is subject to testing by all publicly regulated water systems. Maximum contaminant levels (MCLs) for primary contaminants are established to protect the public from both acute and chronic health risks. Systems

doi: 10.2166/wh.2019.289

incur a violation if testing results show an exceedance of MCLs. Secondary contaminants are not officially considered health-threatening chemicals per the SDWA. This regulation also sets non-mandatory secondary maximum contaminant levels (SMCLs) for these 15 contaminants because they may cause noticeable aesthetic effects in drinking water (affecting taste, odor, or color) and cosmetic effects (skin or tooth discoloration). SMCLs are recommended but non-enforceable guidelines for water systems.

A key challenge facing proponents of tap water consumption is that people tend to more strongly associate aesthetic qualities in their drinking water, largely stemming from secondary contamination rather than primary contamination, with health-related risks (Doria Pidgeon & Hunter 2009; McLeod Bharadwaj & Waldner 2015). On the whole, as a growing body of US studies show, mistrust of tap drinking water quality and related reliance on alternative beverage sources adversely impacts household health, affordability, and the environment (Beaumais *et al.* 2010; Johnstone & Serret 2012; Pierce & Gonzalez 2016; Javidi & Pierce 2018; Levêque & Burns 2018; Rosinger *et al.* 2018). With respect to health, reliance on alternatives to tap water is associated with decreased water consumption and increased intake of sugary drinks (Onufrak *et al.* 2012), contributing to obesity as well as decreased oral health (Ogden *et al.* 2012). Even when consumption is shifted to bottled water, oral health often suffers due to inadequate exposure to fluoridation in bottled sources (Hobson *et al.* 2007).

To our knowledge, however, only two published studies have jointly tested the effect of measured health-related water quality contamination and socioeconomic status on household reliance on alternative sources to publicly regulated tap water, only one of which is in the US context. Reynaud & Garcia-Valiñas (2015) modeled interactions between observed water quality, quantity, and prices in France. They found that higher levels of bacteriological pollution in tap water significantly decreased residential tap water consumption. Pesticide contamination of groundwater also reduced tap water consumption. Closer in context to our study, using SDWA and proprietary data from Northern California and Nevada, Zivin *et al.* (2011) found a positive spatial relationship between water quality violations and tap water avoidance behavior. This relationship was measured by the correspondence between water quality violations from microorganisms, elements, and chemicals, and changes in bottled water consumption where these violations were incurred.

Similarly, we are only aware of two studies which have tested the relationship between secondary contaminants and household perception of tap water, again only one of which is in the US context. Kulinkina *et al.* (2017) found, in the context of rural Ghana, an association between the probability of drinking water quality complaints and World Health Organization (WHO) exceedances of pH, turbidity, chloride, iron, and manganese. More narrowly, Piper (2003) found that lower levels of water hardness (mineral content) in the United States led to an increase in the quantity of tap water demanded in the same areas.

By contrast, we rigorously test the relationship between tap alternative reliance, primary water quality standard compliance, secondary water quality standard compliance, socioeconomic status, and water system characteristics. To measure reliance on alternatives to the tap in this study, we focus on a novel source of data: retail water facility locations across California obtained from the California Department of Public Health (CDPH) in 2015. Despite the existence of water stores throughout the US Southwest, only one previous study has examined any aspect of these water suppliers. Russell (2015) found that retail water facilities (retail water stores) in Los Angeles County are located almost exclusively in neighborhoods with high shares of low-income and Hispanic residents, but this study did not simultaneously account for tap water quality characteristics in those same neighborhoods. Based on our review, the only other US state outside of California which appears to monitor any aspect of retail water stores is Texas. While a food manufacturer's license is still required for water stores to operate in Texas, in 2015, it appears that the state discontinued most of its specific regulatory programs for various types of bottled and vended water (including its retail water stores), which might have provided comparable data for analysis (Texas Department of State Health Services 2015).

The most robust literature on alternative water suppliers similar to water stores may be found in studies of water vendors in urban areas of low- and middle-income countries (LMICs), where both stationary and mobile retail water suppliers serve a substantial proportion of urban populations (e.g., Whittington *et al.* 1991; Kimani-Murage & Ngindu 2007). The context for these studies differs, however, in that the presence and endurance of vendors in urban LMIC areas are attributed to the ubiquitous failure of publicly regulated water systems to provide accessible, safe, reliable water to urban residents. The lack of studies in similar contexts and with a similar breadth of explanatory factors underscores the novelty of our research on retail water stores in California.

Using the CDPH data, we model neighborhood retail water store prevalence in urban California as a function of both the observed primary and secondary water quality of the system serving the neighborhood, water system characteristics, and the socioeconomic characteristics of the neighborhood.

DATA AND METHODS

To carry out this study, we constructed a neighborhood-level dataset that includes the geolocation of the 1,200 retail water stores registered with CDPH in 2015 across the 8,000 neighborhoods (census tracts) in California. We merged this dataset with tract-level indicators of socioeconomic status from the 2011–2015 American Community Survey (ACS) 5-Year Estimates. We then included information on primary MCLs and SMCLs incurred by community water systems in California, which were spatially overlaid to the tract level using water system boundary shapefiles in ArcGIS. We also included other water system characteristics – extracted from the California State Drinking Water Information System 3.21 – which we hypothesize may influence dependence on alternatives to the tap.

We aggregated the number of primary contaminant violations reported for each neighborhood's community water system (of which there are about 3,000 in California) from the Annual Compliance Report (ACR) published by the California State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW). The dataset includes the most recent available primary water quality violation data, from 2010 to 2014. We also included the aggregate number of testing result exceedances for different types of secondary contaminants. Based on a review of available literature, we focus on the secondary contaminants which have been found to create noticeable aesthetic effects when an exceedance occurs.

Among the 8,000 census tracts in California, approximately 40 tracts have water stores but no water system boundary data and thus could not be included in the analysis. Additionally, 905 tracts had neither water stores nor water system boundary data. These 905 tracts have far more primary water quality violations than other tracts, but we could not spatially allocate these to tracts due to missing water system boundary information. However, we note that very few water stores were found to be located in water systems without shapefiles.

Unlike for primary contaminants, no readily accessible data source identifies systems with secondary water quality exceedances (SMCLs), as these do not create a violation flag. The lack of ease in working with system-level secondary quality data may help to explain the paucity of studies using this type of data. Accordingly, we use the 2010–2014 data from the DDW's Water Quality Monitoring (WQM) database to identify whether systems incurred SMCLs. The WQM system relies on the reports of certified drinking water laboratory samples submitted by public water systems (California State Water Resources Control Board 2016). (We also considered other potential sources of secondary contamination data, including California's Groundwater Ambient Monitoring and Assessment (GAMA) Program, but opted to use the WQM data because it has greater geographical coverage and includes information on post-treatment quality.) The WQM database includes information such as the primary station code of the sample or the state source number (California State Water Resources Control Board 2015), attributes which were spatially joined with water systems using the public water system number (PWS ID) to identify the name of the quality parameter and the numerical result of the contamination level. After combining the WQM data with public water system boundaries, we then spatially joined system-level data to census tracts (neighborhoods).

New research indicates that SMCL thresholds for certain secondary contaminants may be set too high and thus even drinking water with lower contamination levels which do not have SMCL exceedances may still trigger consumer complaints and may lead to greater reliance on alternatives to the tap (Dietrich & Burlingame 2015; Burlingame Doty & Dietrich 2017). Given the current unchanged regulation and lack of consensus regarding new recommended levels, however, our study uses official SMCL thresholds for contaminants as the best available metrics to identify secondary contamination which may trigger tap quality concerns. To identify secondary exceedances, we first assessed the occurrence of exceedances of selected secondary contaminants which previous studies have demonstrated to produce noticeable aesthetic effects when their concentrations surpass SMCL thresholds. These aesthetic effects could have significant impacts on the perception of drinking water and lead to greater reliance on alternatives to the tap.

Using Stata 14.0 software, we then use multivariate regression models to test our null hypothesis (H_0) that the number of retail water stores per capita across neighborhoods is not associated with water quality, water system, or neighborhood characteristics. Due to the count nature of the outcome variable and the over-dispersed nature of the conditional means, our primary specification is a zero-inflated negative binomial model.

Our preferred model specification passes the *Vuong* test, which compares the zero-inflated negative binomial model with an ordinary negative binomial regression model, and in this case, indicates that the zero-inflated model is preferred. We also ran the *ZIP* test, which compares the zero-inflated negative binomial model versus the zero-inflated Poisson model, and in this case, indicates that the binomial model is preferred to the Poisson model. Finally, we tested the sensitivity of the results by clustering our results at the water system level, but this did not have a notable difference in the robust standard errors.

We test H_0 against four alternative explanations, as follows.

H_1: Neighborhoods served by water systems with primary quality violations have more retail water stores per capita than those that do not.

H_2: Neighborhoods served by water systems with secondary quality exceedances have more retail water stores per capita than those that do not.

H_3: Neighborhoods served by water systems with other important water system characteristics have more retail water stores per capita than those that do not.

H_4: Neighborhoods with higher percentages of Hispanic and foreign-born residents have more retail water stores per capita than those that do not.

RESULTS

Table 1 shows the occurrence of exceedances of prominent SMCLs across publicly regulated water systems in California and the common relationship of these contaminants to customer water quality experience. Exceedances of manganese levels were found to be most common, followed by iron and odor. Fluoride and copper exceedances were relatively uncommon.

Table 2 shows the results of the multivariate zero-inflated negative binomial model for urbanized neighborhoods in California. The outcome of interest in the model is the number of water stores per capita, a proxy for neighborhood reliance on tap water alternatives. Both higher total neighborhood population and population density show a strong positive effect on the likelihood of a neighborhood having a water store within its boundaries. (We considered two population density thresholds (500 and 1,000 persons per square mile in a census tract); however, these do not qualitatively change the results.)

Table 1 | Secondary contaminants: prevalence of SMCL exceedance level and expected effects of exceedances

Contaminant	Secondary MCL	Noticeable effects above the SMCL	Percentage of water systems with exceedance of MCL level for particular contaminant
Manganese	0.05 mg/L = 50 μg/L	Black to brown color; black staining; bitter metallic taste	10.6
Iron	0.3 mg/L	Rusty color; sediment; metallic taste; reddish or orange staining	6.70
Odor	3 ton (threshold odor number)	'Rotten-egg', musty or chemical smell	4.50
Fluoride	2.0 mg/L	Tooth discoloration	0.40
Copper	1.0 mg/L	Metallic taste; blue-green staining	0.04

Source: Tabulated by authors from the Water Resources Control Board, Division of Drinking Water, Water Quality Monitoring database, 2010–2014.

Table 2 | Regression model of number of retail water stores per capita per neighborhood

Independent variables	Coefficient (robust standard error)
Number of primary health violations (H_1)	−0.001 (0.002)
Percent of test exceedance of secondary contaminants (H_2)	
Manganese	−0.031 (0.096)
Odor	−0.208 (0.125)*
Copper	−1.190 (2.260)
Iron	−0.104 (0.136)
Fluoride	−0.575 (0.133)***
Water system characteristics (H_3)	
Private system	−0.049 (0.036)
Municipal system	−0.006 (0.033)
System size	−0.000 (0.000)**
Neighborhood characteristics (H_4)	
Median household income	−0.000 (0.000)
Percent of high school graduates	0.001 (0.002)
Percent of Hispanic	−0.120 (0.118)
Percent of Black	0.019 (0.128)
Foreign-born non-citizen	0.007 (0.002)***
Foreign-born naturalized	0.004 (0.002)
Total population	−0.000 (0.000)***
Total population density per square mile	−0.000 (−0.000)
Constant term	3.975 (0.112)***
Model inflation factors	
Total population	−0.000 (0.000)***
Total population density per square mile	−0.000 (0.000)***
Constant term	2.686 (0.092)***
Model statistics	
Total observations = 7,020; non-zero observations = 925	
Wald $\chi^2 = 772.15$; $p >$ Wald $\chi^2 = 0.000$	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

After accounting for the binary presence or absence of a store in a given neighborhood, we find no relationship between water systems with sub-standard primary water quality (H_1), as measured by health-related violations, and the number of retail water stores per capita. Moreover, secondary contaminants (H_2) show a negative relationship to tap alternative reliance, as measured by the presence of retail water stores. Other measured water system characteristics (H_3) also show a weak and inconsistent relationship to tap alternative reliance.

The only water service factor with a strong correlation to the number of stores per person was system size, with neighborhoods served by larger water systems tending to have fewer water stores per capita. Presence and popularity of retail water stores appear most influenced by neighborhood indicators of disadvantaged socioeconomic status (H_4), most notably foreign-born nativity. Tracts with higher proportions of foreign-born residents have more water stores per capita than those that do not, and this relationship is the most influential explanatory factor across various model types considered. Further research should examine nuances in this relationship, such as how the experiences of immigrants with drinking water quality in their native countries could influence water supply choices in the United States.

DISCUSSION

Across model specifications, we find strong evidence that the presence and popularity of retail water stores are most influenced by neighborhood indicators of disadvantaged socioeconomic status, most notably foreign-born status, and citizenship. This result coheres with the findings of Pierce & Gonzalez (2017). Contrary to Piper (2003) and Zivin *et al.* (2011), our findings do not suggest that reliance on alternative water sources is tied to observed primary or secondary water quality outcomes. In fact, we find a negative correlation between secondary contaminants and alternative reliance. As we discuss below, this lack of observed relationship may be due to limitations in the measurement of secondary contamination which affects perception at the tap via system-reported water quality data sources.

This study's limitations also suggest areas for policy reform and future research. First, as noted above, new research indicates that SMCL thresholds for certain secondary contaminants may be set too high (Dietrich & Burlingame 2015; Burlingame Doty & Dietrich 2017). These studies suggest that regulatory standards should be set lower to better reflect when customers are likely to notice aesthetic quality concerns and consequently choose alternatives to the tap.

Second, water stores represent only part of the landscape of supply alternatives to tap water reliance. Future studies should consider whether the same set of factors influence three other important alternatives to the tap: (1) bottled water bought in grocery or convenience stores, (2) bulk water bought at vending machines (our initial research using bulk water vending machine locations across California shows similar trends to observed as found in the siting of water stores), and (3) bulk water delivered to homes and businesses by private companies.

A third limitation of this study is that existing, system-level data do not allow us to identify contamination which may be introduced via systems' distributional networks or in premise plumbing. Contamination introduced by either of these sources may influence perception at and non-reliance on the tap but occur after an SDWA water test is conducted to determine primary MCLs/SMCLs. For instance, as a consequence of public incidents causing tap water avoidance in several communities in Los Angeles County, the county Department of Public Health is attempting to implement additional requirements for water systems to test for primary or secondary contamination within their distribution networks. Our ongoing research on perception in Los Angeles County suggests that distributional system and premise (on-plot) plumbing issues may explain some instances of tap water mistrust in urbanized areas.

The issue of premise plumbing contamination is a particularly important social equity concern for low-income and multi-family housing tenants. Premise plumbing is the responsibility of the landlord who owns the building (not the water system or the tenant, if different from the landlord), but landlords rarely have the incentive to address such problems without public financing support. Independent testing of quality at the tap would allow households to determine what treatment is necessary to address contamination issues introduced within premise plumbing. For instance, installing appropriate simple point of use filtration devices, which are less costly than bottled or vended water, may solve these issues. In the case of low-income rental housing, potential solutions to address this problem include public finance instruments which provide funds to property owners to upgrade their piping now and either pay later (i.e., deferred special assessments and water well financing programs) or pay less than commercial rates for such infrastructure improvements (e.g., property assessed clean energy programs).

If, as our results suggest, reliance on tap water alternatives is largely explained by particular socioeconomic status factors, how can perception be changed or influenced to improve health?

Generally, public information campaigns led by water systems and local public health departments seek to increase trust in tap water, but to date, these campaigns have had limited success (Doria 2010). The results from our study suggest that addressing reliance on alternatives to the tap, which likely reflects tap water mistrust, may require more aggressive policies and advocacy activities. Such campaigns must address false advertising regarding tap water quality by private, commercially minded water purveyors (Community Health Councils 2017), which continue to propagate misleading narratives regarding the benefits of their (more expensive) products. Indeed, one explanation for the rise in bottled water consumption has been a strong emphasis by bottled water purveyors on marketing messages which promote the health benefits of bottled water (Doria 2010; Saylor *et al.* 2011; Espinosa-García *et al.* 2015; Huang & Liu 2017). However, addressing false advertisement should extend beyond showing the lack of health benefits from bottled water consumption (Gleick 2010) to include the lack of benefits from consumption of water sourced by retail water stores and other mobile water vendors. Given the potentially confrontational nature of this approach, environmental justice organizations may be best suited to play this role. Environmental justice organizations are non-profit groups that specialize in advocating on behalf of and with disadvantaged communities which are disproportionately and unjustly burdened by environmental hazards and pollution.

Further, our study shows that public education campaigns by proponents of high-quality, affordable drinking water consumption – including water systems, county public health agencies, and environmental justice non-profit organizations – should be more targeted than they have been to date. Broadly, primary and secondary MCL exceedances are noticed and understood by customers in different ways which may engender different degrees and types of tap alternative water reliance. While consumers would likely learn both of primary MCL violations and the return to compliance by their water systems from public notifications, news media, or directly from water utilities, secondary MCLs are often directly experienced by consumers as aesthetic properties of tap water and are more likely to persist indefinitely.

Moreover, education about tap water must better address the unique experiences and concerns of immigrants and foreign-born, non-citizens. As noted by Pierce & Gonzalez (2016), more research is needed to trace the relationship between experiences with tap water and alternative sources in the home country of foreign-born US residents and the effects of these experiences on the perception and consumption of tap alternatives in the United States. This learning must inform customized educational and policy solutions relevant to these populations, which are often the most difficult to reach and persuade due to historical and cumulative injustices and a resulting lack of trust.

CONCLUSION

We model retail water store locations as a proxy for reliance on tap water alternatives in urbanized neighborhoods across California. We include controls for primary and secondary water quality standards by publicly regulated drinking water systems serving those neighborhoods, other water system characteristics, and the socioeconomic characteristics of the neighborhoods, to build the most comprehensive model to date which explains tap alternative water reliance. The location of retail water stores in urbanized neighborhoods does not appear strongly related to observed measures of primary or secondary water quality. On the other hand, our research suggests other socioeconomic factors, particularly country of nativity, are associated with the prevalence of more water stores.

We conclude that more persuasive and targeted efforts will be necessary to help alleviate mistrust of tap water quality where it is unmerited, and thus to reduce unnecessary reliance on alternative drinking water sources such as retail water stores. Reliance on safe taps can yield positive health and affordability impacts for drinking water service, particularly for disadvantaged urban communities in the United States.

ACKNOWLEDGEMENTS

The authors thank Silvia Gonzalez, Kyra Gmoser-Daskalakis, Rickey Russell, Rachel Connolly, J.R. DeShazo, and participants at the 2017 University of North Carolina-Chapel Hill Water and Health conference for their constructive feedback which informed this research.

COMPETING FINANCIAL INTERESTS DECLARATION

All authors declare that they have no actual or potential competing financial interests.

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First received 5 December 2018; accepted in revised form 12 February 2019. Available online 14 March 2019