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Exploring Reasons for Variations in Water Quality and Ownership of Community Water Systems across the State of Connecticut

Claire Hadelman

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By

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ABSTRACT

HADELMAN, CLAIRE Exploring Reasons for Variations in Water Quality and Ownership of Community Water Systems across the State of Connecticut.

ADVISOR: PROFESSOR THERESE MCCARTY

The goal of this thesis is to explore reasons for variations in drinking water quality in the state of Connecticut, including differences in community water system (CWS) ownership. Disparities in drinking water quality have come to the forefront as an urgent environmental and public health issue after recent focusing events like the Flint Water Crisis. Using SDWA (1974) violations from 2018, I hypothesize that a CWS will experience more violations if it is publicly owned, serves more people, sources its water from surface water resources, and if it operates within a low-income and minority community. In regards to public vs. private ownership, I hypothesize that private ownership is more likely to occur in Republican-leaning communities, with lower housing densities, lower population densities, and in lower income communities. Regression results suggest that SDWA violations will increase due to increases in population, increases in the number of facilities within a CWS, if the CWS uses surface water, and if it is publicly owned. Logistic regression results suggest that if a majority of a town is Republican-leaning and has a lower housing density then the odds of having a private CWS are higher. These results are important because they suggest reasons for variation in water quality and identify characteristics of underperforming CWSs. They also present a further understanding of why private or public ownership differ among CWSs. These results could target assistance towards CWS and communities that could benefit from improved water distribution technology and compliance.

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Chapter 1: Introduction

Drinking water quality has recently come to the forefront as one of the most urgent environmental issues that challenges the United States. Focusing events, like the Flint Water Crisis, have really emphasized the disparities that people in the U.S. face when it comes to water quality. The purpose of my project is to explore how water quality differs across the State of Connecticut, specifically looking at the effects of ownership (public vs. private), the political leanings of the communities, and the demographics of the communities that are being served by community water systems. The state of Connecticut was selected for this study due to the public availability and quality of the data.

For this project, water quality will be measured by the number of health and management violations of the U.S. Safe Drinking Water Act (SDWA) of 1974. The SDWA established guidelines and regulations to protect public drinking water supplies. Through this act the Environmental Protection Agency (EPA) set standards for certain contaminants and management practices for water treatment facilities that each state must uphold. States differ in their requirements for drinking water standards, but the EPA has a set list that each state must report. Failure to report is reflected in the management violations.

Community water systems (CWS), as defined by the EPA, are government regulated water systems that consistently provide water for the same population year-round (EPA). Ownership of CWSs vary across the nation. The majority of CWSs in the United States are publicly owned, but in some cases they are privately managed. Governments choose to switch to private water services for many reasons. The cost of updating aging water infrastructures places a large financial burden on city resources (e.g., taxes). Some communities have resisted the transition to privatization because they are worried that the prices of water will increase and transparency about water quality will decrease (Jacobs and Howe 2005). The private sector has been understood to be more operationally efficient than the public sector because of profit motivations, but there have been no definitive studies that have determined that the involvement of the private sector has improved/worsened water quality in the United States (Gardner 2000).

Political affiliations of communities can influence the level of government involvement on environmental issues and their willingness to pay for environmental goods (Dupont and Bateman 2012; Switzer 2019). Democratic–leaning communities are likely to pay more for higher quality environmental goods (e.g., water quality) and comply with environmental policy regulations (Dupont and Bateman 2012; Switzer 2019). Contrastingly, Republican-leaning communities are willing to pay more for environmental goods if they are privately provided but these communities are more likely to violate environmental policy regulations (Dupont and Bateman 2012; Switzer 2019).

Disparities in drinking water quality have often been linked to issues of environmental justice. Economic literature supports the idea that lower-income, minority communities are more at risk of experiencing SDWA violations (both health and management violations). Low-income, minority communities are not able to dedicate large portions of their tax revenue to improve their decaying infrastructure because they cannot handle the financial burden that comes with updating these water systems (Allaire et al. 2018). The failure to address water infrastructure concerns increases the risk of public health crises (e.g., lead poisoning) in these low-income, minority communities.

I hypothesize that communities within Connecticut that are being served by a public water system have higher median incomes, larger percentages of non-minority communities, and have a higher share of democratic leanings will experience fewer drinking water quality violations and will, therefore, experience a higher level of water quality. In contrast, communities in Connecticut that are served by private water systems have lower median incomes, larger percentages of minority communities, and have a higher percentage of republican leanings will experience more drinking water violations and will experience a lower level of drinking water quality.

Using data from the EPA's SWDA database, Connecticut DOH drinking water data, MIT election lab data, and demographic data from the U.S. Census and American Community Survey, I aim to explore the reasons for variations in water quality and CWS ownership in Connecticut. Previous studies of this topic have explored the violations of community water systems all over the United States, but there has been no study of water quality in State of Connecticut that explores variables such as political affiliation, ownership characteristics, and demographics.

Chapter 2: Background and Context of Water Provision and Quality

This chapter will provide relevant background information regarding the topic of water quality, the regulation of water quality, and management of community water systems (CWS). This section will begin with a general discussion of the state of water quality in the United States and the regulatory framework that surrounds the enforcement of water quality. Background information will also include why water quality may vary among different communities (e.g., aging infrastructure, origin of water source, demographic disparities, and water distribution systems).

2. 1: Safe Drinking Water Act of 1974

Human activities have seriously altered the state of water quality around the world. Global, rapid population growth has contributed to the increased pace of industrialization and scale of agricultural production. According to the United Nations, the most pressing water quality concern is eutrophication; a phenomenon closely linked to agriculture. Eutrophication is a consequence of high nutrient levels (e.g., phosphorus, nitrogen, etc.) that enter a body of water and decrease the beneficial uses of that water (e.g., ecosystem destruction) (United Nations, Water for Life, 1). Eutrophication has become an increasing concern mainly due to the increased agricultural practices and industrial effluent around the world (United Nations, Water for Life, 1)

Most Americans, and people who live in developed countries, experience the luxury of not having to think twice about the quality of their water. This has not always been the case for water in the United States. Following a series of environmental movements in the 1960s and the early 1970s, President Richard Nixon consolidated multiple government agencies to create the Environmental Protection Agency (EPA) in 1970. In 1974, Congress passed the Safe Drinking Water Act (SDWA) which gave the EPA regulatory power to set uniform drinking water standards for public community water systems the United States. This regulatory framework created water quality standards that are determined by comparing samples to predetermined water standards that are set by the EPA.

Leading up to the passage of this act, there were lots of concerns about the safety of drinking water due to the increased synthetic chemical production that would leach into groundwater and surface water pre- and post-World War II (Weinmeyer et al. 2017). The US Public Health Service conducted a study of drinking water compliance in 1969 and found that 40% of the water systems that were surveyed were not in compliance with federal water regulations (Weinmeyer et al. 2017, 1019). During the 1960s, there was an estimated number of 46,000 cases of diarrheal diseases that were caused by chlorine-resistant pathogens that were found in drinking water (Weinmeyer et al. 2017, 1019). These poor public health conditions were a result of poorly enforced drinking water quality regulations. The SDWA sought to combat these issues and establish a regulatory framework with strict compliance guidelines.

The responsibility of the enforcement of the SDWA exists at both the state and federal level. The EPA sets the maximum contaminant levels (MCLs) for various different analytes that could be in the water (e.g., lead, arsenic, benzene, etc.). Today, there are roughly 90 analytes that the EPA requires testing for at every CWS (EPA SWDA). Every 5 years, the EPA will update their list of contaminants that water systems must test for (Weinmeyer et al. 2017; EPA SDWA). According to a non-profit environmental group, the Environmental Working Group, the EPA has not updated the list of contaminants since the 1990s (EWG, "Fixing Our Nation's Drinking Water Policy"). The states have to enforce that each public water system is testing for these analytes and they report the findings to the EPA (failure to do so will result in a management violation). Some states monitor for more contaminants than the EPA requires, but are not legally accountable to do anything about these contaminants if found in drinking water samples (e.g., analytes that are deemed "emerging contaminants", like PFAs) (EPA SWDA). The EPA can sue individual states and water systems that do not comply with their regulations (Weinmeyer et al. 2017).

2.2: National Drinking Water Quality Trends

Trends of drinking water violations vary across the United States. Allaire et al. (2018) conducted the most recent spatial and temporal trend analysis of drinking water violations between the years of 1982 and 2015. Figure 1 shows the spatial trends of the SDWA violations across America. Figure 1 shows the total violations from 1982 – 2015 by county. Texas, Oklahoma, and Idaho have the most number of violations (as indicated by darker shading). Allaire et al. (2018) and other economic literature note that these violations may be due to the fact that these counties are primarily rural. Rural counties are known to have a higher likelihood SDWA violations due to factors of population density and financial resources (Allaire et al. 2018; Jacobs and Howe 2005; Switzer and Teodoro 2017). Fracking activities in Oklahoma and Texas may lead to increased SDWA

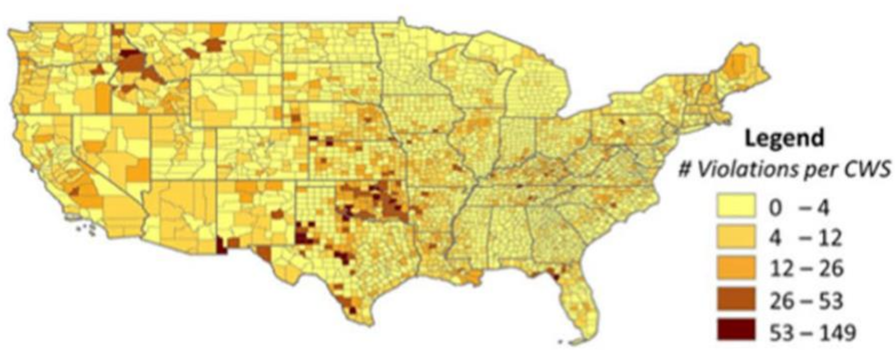

Figure 1: Figure from Allaire et al. (2018) that shows the spatial trend of SDWA violations between 1982 – 2015 across the continental United States.

violations because fracking is not forced to comply with federal drinking water regulations (Tiemann and Vann 2015, 26).

SDWA was effective in increasing the overall drinking water quality in the United States, but still faces challenges in consistently ensuring that all drinking water provided by public systems is keeping up with EPA regulations. There have been recent cases of contaminated drinking water across the United States. Inadequate funding for updating water infrastructure and implementing new water purifying technology has contributed to cases of poor drinking water quality. The American Water Works Association (AWWA) estimates that the federal and state governments will have to pay over $1 trillion in upgrading water infrastructure in the upcoming years (American Water Works Association, 1).

2.3: Water Distribution

United States water distribution systems are extremely complex and are non-uniform in their types of distribution (e.g., pipe vs. well water). For the purpose of my project, I will be focusing on community water systems (CWS). CWS are public water systems that serve the same population year-round and receive water through a pipe network (EPA, Drinking Water Requirements for States and Public Water Systems, 1).

CWS can either be a local/state government or a private firm. There are different levels of privateness depending on the contract between the municipality and the private firm. The most common form of water privatization, and what is observed in Connecticut, is the concession of municipal water services. Concessions are when municipalities delegate complete and total water service responsibilities to private firms.

Regardless of ownership type, the water distribution networks are relatively the same across the state. The water utility gets their water from some source (e.g., groundwater or surface water), the utility owns the water treatment facility and the water main and service pipes that bring the water to various locations (e.g., residential areas). The customer (e.g., the person who pays for the water services) is responsible for the piping from the curb (where their private property begins) to their desired location (e.g., a house). The municipality may oversee the water main, but if the services are contract out, then the private firm is responsible for any repairs or stoppages in the water mains and service pipes.

It is also important to mention the fragmented nature of the U.S. water distribution services. There are 150,000 water distribution systems in the U.S. Of those distribution systems, only 52,000 are CWSs that service a majority of the U.S. population (~286 million people) (Lipton, Water Smart, 2016). 82% of the U.S. population is served by 8% of CWSs (Lipton, Water Smart, 2016). This means that the remaining 18% of population is served by 92% of CWS (Lipton, Water Smart, 2016). This presents a wide range of issues for the CWS serving smaller populations which includes. Smaller CWSs are going to have smaller revenue bases to finance operations (e.g., infrastructure, technology) and most of these smaller CWSs are located in rural areas that have declining demand due to increased migration to urban areas (Lipton, Water Smart, 2016). A memo done by the Brookings Institute in 2014 found that 2/3 of SDWA violations occur within the water systems that serve small populations (Harris et al. 2014, 1). Smaller water systems present a complex regulatory challenge because they lack the resources to address their problems of maintaining adequate water quality standards.

2.4. Water System Infrastructure and a History of Demographic Inequities

Problems of aging infrastructure have been linked to serious health crises in the United States. The most recent and infamous water crisis was Flint, MI. In 2014, the city switched its water supply from Lake Huron to the Flint River which would effectively reduce the water supply costs for the city by $200 million over 25 years (Kennedy 2016). Almost immediately following this switch, E. coli and coliform MCLs were exceeded and residents had to boil their water (Kennedy 2016). A few months following the switch, lead was detected in water samples (Kennedy 2016). Lead began to leach into the water systems because the physical and chemical nature of the water from the Flint River was different than the water from Lake Huron (Kennedy 2016). The change in water types released lead from the aging water pipes (Campbell et al. 2016; Kennedy 2016). Government officials denied that there was a problem with the water quality for months which unfortunately exposed more people to contamination (Campbell et al. 2016; Kennedy 2016). Lead poisoning among children is a major concern because it can have many adverse developmental affects (e.g., decreased intelligence).

Low-income minority communities are the most at risk for water quality violations (Allaire et al. 2018; Switzer and Teodoro 2017). Many analyses of the Flint Water Crisis have commented on the lack of environmental justice demonstrated throughout the crisis. Campbell et al. (2016) noted that the poor, African-American community were hit the hardest by lead contamination; their levels of exposure were higher compared to other minority communities. The African-American community tried to address their complaints with the Flint Water Advisory Task Force and their concerns were consistently ignored (Campbell et al. 2016). Unfortunately, this trend is present in most cases of extreme drinking water violations.

2.5: Sources of Water

Water systems get their water from various different sources. The two biggest sources of drinking water come from surface water and groundwater. Majority of CWS rely on groundwater (371 of the 440 CWS in this study get their water from groundwater aquifers). Surface water sources are bodies of water like rivers, creeks, streams, lakes, and reservoirs (WaterEducation 2019, 1). Groundwater is a result of precipitation that seeps into the earth's crust and settles in spaces between rocks (WaterEducation 2019, 1). Many factors influence the initial quality of water before it is treated. There are very complex chemical and physical changes that water goes through, that is beyond the scope of my thesis, but is important to note because it affects drinking water quality. Both surface water and groundwater are exposed to sediments (e.g., pieces of rocks and soil), naturally occurring organic matter (e.g., plant debris, human and animal waste), nutrients (e.g., carbon, nitrogen, phosphorus, etc.), bacteria (e.g., coliform, E. coli), and toxic substances (e.g., pesticides) (Vandas and Winter 2002).

Different types of contaminants are more likely to show up in different types of water sources. Allaire et al. (2018) found that groundwater was more likely to have coliform bacteria than other types of water sources. Surface water tends to have higher number of SWDA violations than groundwater (Allaire et al. 2018; Switzer 2019). This may be because surface water is exposed to more point and non-point pollution. Air pollution can seriously contribute the quality of surface water because contaminants in the air can precipitate back into the water (Allaire et al. 2018). Where the water is sourced from also determines the type of treatment that each water facility must perform before providing the water to people. Water facilities are limited to where they can get their water from due to geographic location and costs. If a wealthy community is located near a river but it happens to be polluted, they can source their water from a faraway aquifer that has a superior quality of water than the river. Low-income communities may be restricted in their choices of where to get their water because of financial restraints and may have to procure water from a dirtier source.

2.6: Background and Context of Water Provision and Quality Conclusion

Many factors can influence the ownership of water utilities and the quality of water that people drink in the United States. As stated above, not everyone receives the same quality of water. This is dependent on not just geographical factors, but demographic factors. These demographic factors present themselves to be strong determinants for drinking water quality.

Chapter 3: Literature Review

This chapter will discuss the existing literature surrounding water quality and water services. The section will start with a discussion on current literature that explores the overall water quality trends in the United States. The following sections include discussions regarding political affiliations of communities, environmental justice, aging infrastructure, and ownership of community water systems (public vs. private).

3.1: National Drinking Water Quality Trends Literature

Allaire et al. (2018) conducted the most recent national drinking water quality trend analysis in the United States. Their project was motivated by the 2016 water crisis in Flint, MI and the lack of research regarding the status of water quality across the United States. Using Safe Drinking Water Act violations from 1982 – 2015, Allaire et al. (2018) used temporal and spatial analysis and demonstrated that water quality varied across all states for various different reasons. Allaire et al. (2018) argued that variations in water quality can be linked to demographic factors and differences among state regulations/compliance.

Rural counties, specifically in Oklahoma and Texas, had higher prevalences of water quality violations (Allaire et al. 2018). Tiemann and Vann (2015) suggested that there is a link between SDWA violations and hydraulic fracturing activities. Under the Energy Policy Act of 2005, the EPA lacks authority to enforce the SDWA for hydraulic fracturing unless diesel gas is used in the process (Tiemann and Vann 2015). Areas with hydraulic fracking are at a higher risk of having contaminated drinking water sources due to the invasiveness of the fracking process itself (Tiemann and Vann 2015). The lack of regulatory framework surrounding drinking water and fracking prevent proper testing from being conducted (Tiemann and Vann 2015). For the purpose of my project, fracking will not be a concern because there are no known fracking activities in Connecticut, but fracking is important to consider when understanding national trends of drinking water quality violations. Rural communities, even without the presence of fracking, face greater difficulties in regulatory compliance because of their limited financial resources due to typically smaller population bases (Allaire et al. 2018). The limited financial resources (e.g., taxes) makes it harder to update water infrastructure. Aging infrastructure has been linked as a casual factor for poor water quality in the United States (Allaire et al. 2018; VanDerslice 2011; Switzer and Teodoro 2017).

3.2: Population and Housing Density

Population density, housing density, and urban sprawl appear to be important factors when discussing water distribution systems (Masten 2011; Prierto et al. 2014). Prierto et al. 2014 noted that lower population and housing densities experience higher costs of supplying the water because the water network length increases. The more spread out houses are the more piping a water system will need to service each housing unit. Past studies have shown that municipal ownership of water utility services is correlated to population distributions and housing densities (Masten 2011). CWS are more likely to be municipally owned when there are higher numbers of connections per mile of water mains (Masten 2011). Municipalities prefer to own their water systems in areas with higher population and housing densities because excavations for extending the service network are extremely disruptive and less common in denser areas because the area is already developed with a water service network (Masten 2011; Nauges and Thomas 2000). Evidence shows that it is not the size of the urban area or water system, rather it is the density that matters (Masten 2011; Nauges and Thomas 2000; Prierto et al. 2014).

3.3: Connection between Political Affiliations and Environmental Policy

Switzer (2019) explored how political affiliations of communities can influence the level of government involvement on environmental issues. Local municipal governments are responsible for providing water services in their community, either they provide the services or they contract it out to a private firm. These water systems are regulated by the federal SDWA policies which require states to regulate and comply with federal water standards through self-monitoring and self-reporting (with federal oversight). This means that local government involvement will determine the level of compliance for the water treatment process and will shape the quality of water that the community receives (Switzer 2019). Results showed that Democratic-leaning communities are more likely to comply with the SDWA than Republican-leaning communities (Switzer 2019). However, political affiliations were determined by federal election results, not local government elections which allowed Switzer (2019) to conduct an analysis across the 48 continental states. Switzer (2019) acknowledged that federal election votes can serve as a proxy for local government elections although it is unlikely that people choose their presidential candidate based on their water quality policies.

Dupont and Bateman (2012) suggested a link between willingness to pay for environmental goods and political affiliations. Through survey analysis, people who are Democratic-leaning were more likely to pay higher prices for environmental goods (e.g., water quality). In contrast, Republican-leaning individuals were not willing to pay more for environmental goods (Dupont and Bateman 2012). Willingness to pay was also dependent on who was providing the service of the respective environmental good. Republican-leaning people were willing to pay more for their environmental goods if it was privately provided rather than if the government were providing them with the good (Dupont and Bateman 2012).

3.4: Demographics and Environmental Justice

Disparities in drinking water quality have often been linked to issues of environmental justice. Economic literature supports the idea that lower-income, minority communities are more at risk of experiencing both health and management SWDA violations (Switzer and Teodoro 2017; VanDerslice 2017). Switzer and Teodoro (2017) used class, race, and ethnicity as predictors for drinking water quality violations for the years 2010-2013 across 1,000+ community water systems in the United States. They found that Black and Hispanic communities are more likely to experience SDWA violations than white communities (Switzer and Teodoro 2017; Allaire et al. 2018). These variations in water quality were found to be conditional on poverty-level (Switzer and Teodoro 2017). Communities with majority of its population living below the poverty line were more likely to experience higher rates of SDWA violations and, therefore, experience poorer water quality (Switzer and Teodoro 2017).

3.5: Water Infrastructure

Aging water infrastructure is a major problem all over the United States. The American Water Works Association estimated that the federal government will have to spend over $1 trillion to address the aging infrastructure concerns in each state (American Water Works Association, 1). Low-income, minority communities were also more likely to experience poor water quality as a result of aging infrastructure (VanDerslice 2011; Switzer and Teodoro 2017). VanDerslice (2011) aimed to explore the variations in water quality as a function of aging infrastructure. Data regarding the age of infrastructure and problems with the infrastructure was extremely hard to come by, but VanDerslice (2011) used SDWA, American Housing Survey, and specific geo-referenced data to create a proxy for infrastructure and the region that specific water systems served. Switzer and Teodoro (2017) also included age of infrastructure but they created a dummy-variable which indicated if the water system was built before or after 1981.

Low-income and minorities experience poorer water quality as a result of their aging infrastructure or lack of infrastructure in general (VanDerslice 2011). Minority groups, like Native Americans who live on reservations, lack the water infrastructure (e.g., pipes) to get their water from the main community water systems and have to fund and source their own water and construct their own infrastructure (VanDerslice 2011). Low-income, minority communities that have decaying water infrastructure are not able to dedicate large portions of their tax revenue to improving their infrastructure because these communities cannot handle the financial burden that would be required to fix their old water systems (Allaire et al. 2018; VanDerslice 2011). Problems with aging water infrastructure plague rural communities because they lack the customer base to increase revenues to go towards maintenance and updates (Allaire et al. 2018).

3.6: Public v. Private Water Utility Provision

Municipalities will choose to either provide their communities with water or contract the service out to private firms. Economic literature tends to focus on the differences in operational efficiencies among public and private water services (Beecher 2001; Gardner 2000; Hall and Lobina 2005; Jacobs and Howe 2005; Shih 2004). It is generally understood that private firms are operationally more efficient because they are motivated by profits (Gardner 2000). Municipalities that are financially stressed (e.g., lack the resources to address water infrastructure and updating technology) are more likely turn to privatization to address their water quality problems (Allaire et al. 2018; Bel and Fageda 2008; Gonzalez-Gomez et al. 2011). Petrova (2005) explored the reasoning for water privatization in developing countries around the world. Problems like inadequate sanitation technology and expanding access to potable water in rural countries forced governments to consider contracting out their water services (Petrova 2005). Developing countries lack the resources to address problems of aging infrastructure, expanding infrastructure, and investment in water quality technology which makes privatization a more attractive option to try to better water quality and water access in general (Petrova 2005).

Explanations for differences in ownership types in developed countries vary. The United Kingdom and France have undergone almost complete privatization of their water utilities. Nauges and Thomas (2000) conducted a study on privately operated water utilities in France. They found that municipalities were more likely to concede their water services to private utilities because their, “lack of technical know-how” and financial limitations (Nauges and Thomas 2000). More and more contaminants are being added to regulatory standards so these water systems either have to expand their treatment capacities or invest in new technology that will meet the growing list of standards (Nauges and Thomas 2000; Gonzalez-Gomez et al. 2011).

Wallsten and Kosac (2008) explored water quality disparities among private and public ownership of community water systems. Regression analysis, using data from SDWA database, indicated a small difference among the private and publicly owned water systems (Wallsten and Kosac 2008). Private systems did report fewer SDWA violations than publicly owned water systems (Wallsten and Kosac 2008). Wallsten and Kosac (2008) suggested that private firms have fewer violations because they are subjected to a higher level of scrutiny by state regulators than publicly owned systems that self-regulate. Another reason for fewer reported violations is that these private operators are not reporting all of their violations (Gonzalez-Gomez et al. 2011; Niskanen 1974; Wallsten and Kosac 2008).

There are many reasons that municipalities transfer their water provision responsibilities to the private sector (e.g., financial cost of updating infrastructure, expanding water networks, increasing compliance standards) but some communities strongly oppose the introduction of the private sector. Jacobs and Howe (2005) note that communities oppose private water services because they believe transparency about water quality will decrease because these private firms are motivated by profits rather than the welfare of the tax-payers. Communities that were surveyed argued that private firms will withhold important water information (Demsetz 1968; Jacobs and Howe 2005). The contract bidding process is lengthy and expensive and a municipality could pull-out of negotiations at any moment which could cause the private firm to lose thousands of dollars in investments (Jacobs and Howe 2005). Jacobs and Howe (2005) also highlight the importance that the contracting introduces competition into a typically monopolistic dominated utility service. The contract bidding would put pressure on water utilities to increase their performance and provide consistent water quality or threatened to be contracted out (Demsetz 1968; Jacobs and Howe 2005).

3.7: Literature Review Conclusion

There is extensive economic literature on the topic of water quality and water services. Although, the literature lacks studies on individual states. As suggested above, state variation contributes to the level of water quality that consumers experience. My research will aim to add to the above literature and will emphasize factors like demographics and ownership and how they affect water quality in the state of Connecticut.

Chapter 4: Economic Theory

This chapter addresses the underlying economic theory behind my project. Basic economic concepts influence interactions among the variables I am exploring within my project. This section discusses demand curves (including normal goods and income elasticities of demand), willingness to pay, economies of scale, natural monopolies, and a discussion of public v. private provision of utilities.

4.1: Demand Theory

Demand illustrates how much of a good or service people are willing to buy under specific conditions (Karlan and Morduch 2018, 52). These conditions can either be the perceived benefits of purchasing a good or the opportunity cost they face for buying the good (e.g., what people are giving up to buy the good) (Karlan and Moduch 2018). There are also non-price determinants like consumer preferences, prices of related goods, income, expectations, and number of buyers that can affect demand for a good (Karlan and Moduch 2018, 54). The non-price conditions encompass either the benefit of buying this good or demonstrate the opportunity costs of buying a good or service (Karlan and Moduch 2018). The good in question for this project is water quality. Water quality is considered to be an environmental good. An environmental good is typically a non-market good (e.g., clean air, clean water, etc.) which is a good that exists outside of the marketplace (cannot necessarily buy water quality) but is influenced by market factors (e.g., price).

Figure 2 depicts a demand curve with price on the y-axis and water quality on the x-axis. As price decreases the quantity demanded for water quality will increase. The rational person's preferences, we can assume, would be to have better water quality. There are many factors that can hinder this preferences, like income (if someone has more income to spend they can invest in goods and services to further improve their water quality). As income increases, the demand for more water quality will also increase (income elasticity of demand). People who have higher incomes may be willing to dedicate more of their income towards environmental goods because they are not as concerned with meeting their basic everyday needs that someone who has a lower level of income would be concerned with (e.g., food, etc.). The demand curve also motivates questions about demographics. Low-income, minority communities may not be able to afford higher levels of water quality given income restrictions. Nevertheless, these communities should still have access to water quality that is at a healthy, drinkable level. Levels of education may influence the demand for better water quality. Education and income are linked together (people with higher education levels typically have higher incomes) which means that higher levels of education may lead to better water quality.

Empirical evidence has shown that areas with higher median incomes experience higher levels of drinking water quality (Allaire et al. 2018; Switzer and Teodoro 2017).

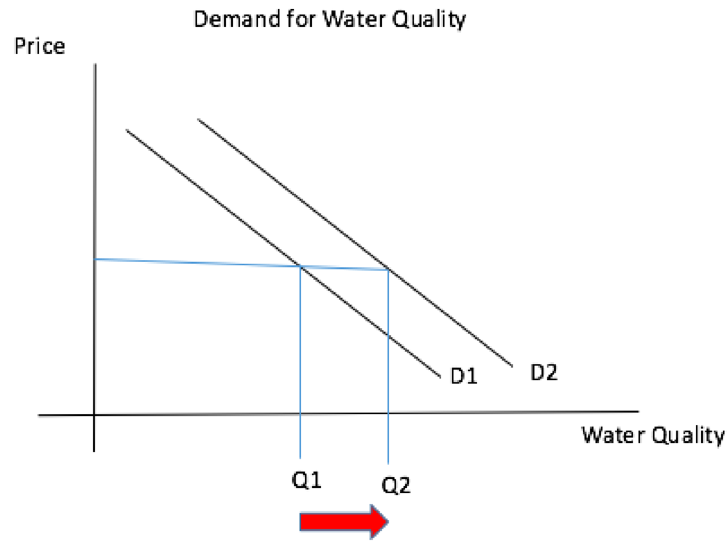

Figure 2: Demand curve depicting the relationship between price and water quality. Also showing how a shift in the demand curve (e.g., increase in income) increases the quantity of better water quality.

Typically, there are substitute and complementary goods that would affect the demand for certain goods. There are no known substitutes for water because we all need it to survive and to use it for daily activities (e.g., cooking and bathing). There are some complementary goods that can come with buying water services like sewer and waste water treatment services and those are sometimes bundled together when purchasing water from firms or municipalities.

Price elasticity of demand could be an influential factor on the demand for water. Price elasticity of demand is, "[…] the change in quantity demanded of a good or service when its price changes." (Karlan and Morduch 2018, 86). If the price of water drastically increased from events like drought, reduced streamflow, groundwater pollution, etc., the quantity demanded will ultimately change. Prices would increase, and therefore, according to demand theory, the amount of water demanded would decrease. Various studies on price elasticity of water consumption argue the opposite. Water consumption is price inelastic. This means that if the price of water quality changed, then the change in demand would be smaller than that of the change in price (Metaxas and Charalambous 2005; Clark and Goddard 1977; Karlan and Morduch 2018).

4.2: Willingness to Pay

Willingness to pay is the, "[…] maximum price that a buyer would be willing to pay for a good or service." (Karlan and Murdoch 2018, 105). How much people are willing to pay for better water quality is an important question to ask. A lot of factors influence willingness to pay (e.g., income, political affiliation, context of situation that they are paying in, private v. public provision of water, etc.). Willingness to pay is the point where the benefit that a person will get from purchasing a good is equal to the benefit of spending the money on another good (e.g., opportunity cost) (Karlan and Murdoch 2018, 106).

Water quality has diminishing marginal utility and this demonstrated through the willingness to pay curve (Figure 3). This means that people are going to pay more initially to improve their water quality. As water quality starts to improve, people are not going to pay a lot more for one more unit increase in improved water quality. According to the graph depicting willingness to pay, as water quality increases, willingness to pay will also increases (Figure 3). This rate of willingness to pay will eventually taper off at the point where benefit of water quality is equal to the opportunity cost of the consumer (Karlan and Morduch 2018, 106).

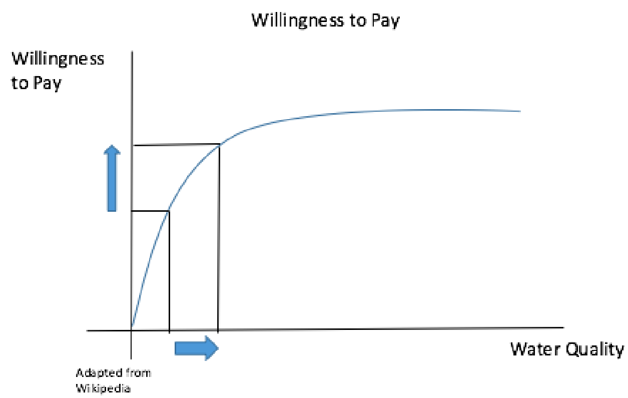

Figure 3: Shows willingness to pay curve with water quality. Demonstrates diminishing marginal utility. As water quality increases the rate of willingness to pay is slowing down.

4.3: Economies of Scale

Economies of scale occur when, "The percentage increase in output exceeds the percentage increase in all inputs. Equivalently, average cost falls as output expands." (Tietenberg and Lewis 2012, 626). Economic literature suggests that economies of scale exist in fragmented water industries, utilities provided by governments and private firms (González-Gómez 2011; Prierto et al. 2014). The U.S. is considered to have a fragmented water industry because water utilities are provided either through municipalities or private firms.

Economies of scale in the water industry would suggest that if water treatment facilities expanded their operations, then the cost of treating the water and supplying it to customers goes down (Figure 4). In this case, a larger water operation is more efficient than a smaller one because it is cheaper to filter and distribute water to a larger population. Most research on economies of scale in the water industry has focused primarily on operation costs and not water quality. For my project, economies of scale would not be presented in the classic relationship between average cost and output. Rather, water quality would serve as a proxy for average cost (assuming there is a link between these two variables) and population would be used as a proxy for output (the number of people who receive the water treated by a CWS). I included a quadratic term for population in my model because if economies of scale are present, the regression would take on a non-linear shape. This would be interesting to explore because as water systems expand the number of people it serves because the effects of scale of water treatment on the water quality is unknown.

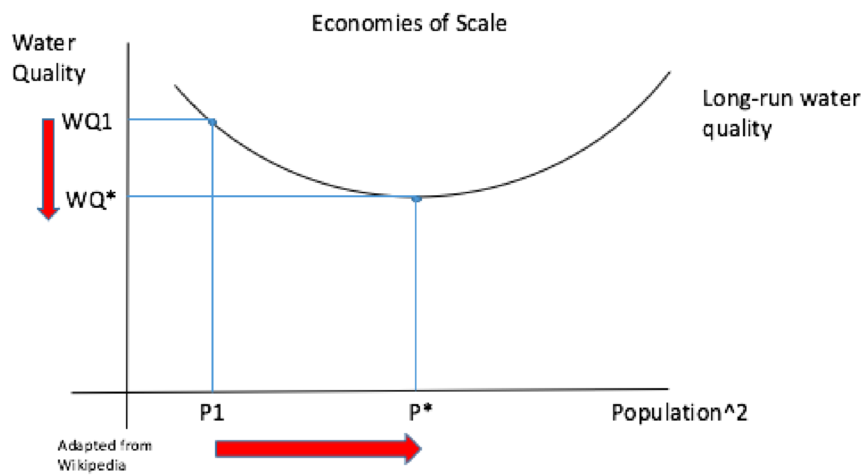

Figure 4: This figure shows economies of scale. This is not a traditional representation. Water quality is a proxy for average cost and population squared is a proxy for output.

4.4: Natural Monopoly

Natural monopolies typically occur when industries have high infrastructure costs and barriers to entry (Karlan and Murdoch 2018).

> Water service is highly monopolistic and demonstrates many of the classic economic features of monopoly: barriers to entry (economic and legal), capital intensity, high fixed costs, economies of scale (declining unit costs), inefficiency in redundancy (more than one pipe), the obligation to provide service on demand, and opportunities for substitution or choices. (Beecher 17)

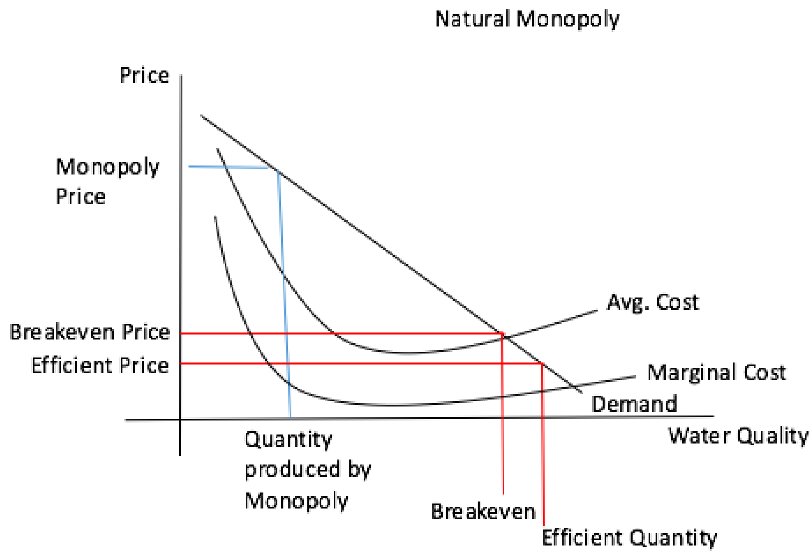

Figure 5: Adapted from Natural Monopolies, Wikipedia. This figure shows the inefficiencies of having multiple suppliers of water and why one monopolistic firm is more efficient.

According to the figure 5, it is more efficient for a monopoly to exist because the cost of operations is cheaper for that one monopolistic firm than if there were multiple firms operating in the market. Despite this efficiency, a monopolistic firm would not be ideal for the water industry because it would not produce inadequate quantities of water services, at a much higher price, compared to those demanded by the customer (efficient quantity vs. quantity produced by monopoly).

The government plays a crucial role in regulating water resources and water quality. Water services are heavily regulated through legislation like the Clean Water Act (1972) and the Safe Drinking Water Act (1974). Large public water utilities in the United States are typically operated by governments. Some regulatory inefficiencies arise because it is the government regulating the government. Konisky (2015) found that publicly owned water treatment facilities are more likely to violate the SDWA and are less likely to be penalized for those violations.

Although it is inefficient to have more than one firm supplying water services in a given community, governments try to add some aspects of competition to avoid private firms from setting their prices at monopoly prices. This is typically done through the competitive bidding process (Demsetz 1968). If the process is successful, the private firm will charge somewhere between the breakeven price and the efficient price (Figure 5).

4.5: Private v. Public Provision of Utilities

There are ongoing debates across communities regarding private sector involvement in the provision of water utilities. Community resistance largely stems from the belief that private firms will be less transparent about true water quality levels and that prices will increase (Jacobs and Howe 2005). Do private firms promote the public interest of safe and clean drinking water? Are governments better because they are solely responsible for protecting and maintaining the public good and promoting public health?

Utility regulation is a complex topic. Some utilities require multiple producers and some require only one. Demsetz (1968) argued that there will be only one producer of a specific utility, if we assume economies of scale are present. Economic literature suggests that there are economies of scale present in community water systems (Shih et al. 2004). Because of these scale economies, it is more cost efficient for one firm to provide water to the community rather than two firms providing water to the rest of the community (Demsetz 1968). Water utilities require vast networks of underground piping to households and buildings; it would be inefficient to have multiple networks rather than one large one (e.g., like transmission lines for the electricity sector). If these utilities were left unregulated by their respective municipal government, the singular firm would be left to set the price at monopoly levels (Demsetz 1968). This is why people worry about private firms providing water because they think they will be paying the monopoly price, but Demsetz (1968) showed that through a competitive contract bidding process, monopoly prices will be avoided. The price that customers will pay for their utilities is determined by the bidding process, typically the firm that offers the lowest-price (considering other factors like efficiency and quality) will win the contract (Demsetz 1968). Demsetz (1968) concluded that if private firms are going to provide utilities they need to be regulated through the competitive bidding process.

Bel and Fageda (2008) argued that there are four main reasons for local governments choosing to privatize their utility services. The four reasons are: economic efficiency, financial stress, political influence, and ideological perspectives (Bel and Fageda 2008; Gonzalez-Gomez et al. 2011). Economic literature has not been able to distinctly determine whether or not private firms are more operationally efficient than the public sector in regards to water services. Private firms are considered to be more efficient because they are subjected to market-forces (e.g., contract bidding) which promote productivity and efficiency which will thus enhance social well-being, or water quality (Gonzalez-Gomez et al. 2011). Gonzalez-Gomez et al. (2011) noted that the fiscal stress that a specific municipality is under will influence the decision to privatize their water services. A private contract will provide municipalities will additional revenue which would alleviate some financial stress among the community (Gonzalez-Gomez et al. 2011).

Political interests and ideologies of certain municipalities will also influence whether local governments will choose to privatize their water (Gonzalez-Gomez et al.

2011). Politically conservative towns are more likely to privatize because that will reduce the presence of the public sector in the economy (Dupont and Bateman 2012; Switzer 2019; Bel and Fageda 2008; Gonzalez-Gomez et al. 2011). Gonzalez-Gomez et al. (2011) mentioned the influence of Public Choice Theory on the decision to privatize. This theory states that politicians aim to maximize their well-being over the social well-being of the community (Gonzalez-Gomez et al. 2011; Niskanen 1974). Gonzalez-Gomez et al. (2011) conducted their survey of water services in Southern Spain and they noted that some politicians were motivated by bribes or funding for their re-election campaigns from private firms. When politicians decide to prioritize their well-being over the municipality that is when we start to see the underperformance of the utilities (e.g., poor water quality) (Gonzalez-Gomez et al. 2011; Morgan et al. 1988). On the other hand, if public employment or being a civil servant is of importance in a community, a government will be more likely to keep the water services within the public sector (Gonzalez-Gomez et al. 2011; Morgan et al. 1988). Figure 6 shows the preferences of government officials that demonstrate the Public Choice Theory (I2) and the preferences of public (I1). The government official that does not keep the interests in mind of the overall social well-being will decide to forego better quality to increase the amount of other goods (e.g., bribes from private water firms to limit regulation oversight).

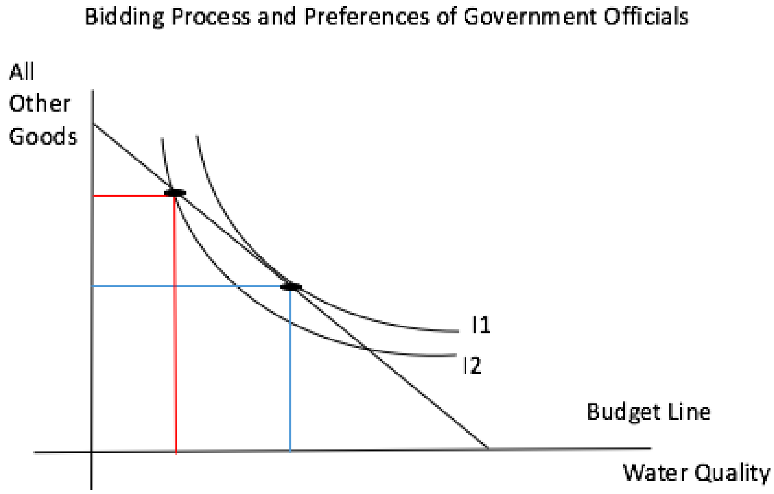

Figure 6: This figure shows the trade-offs between water quality and other goods and how governments determine how much to spend based off preferences.

Bennett and Johnson (1979) explored the public v. private provision of garbage services in Fairfax County, Virginia. Although garbage services are different than water services, this literature provides good insights into the differences among public v. private services. People who are provided their garbage services through the municipality pay a price that covers all the costs associated with the service, but private firms have to face costs that the government is not subjected to (e.g., taxes) (Bennett and Johnson 1979). Private firms have to charge lower fees than the municipality or they not going to be awarded the contract to serve the community (Bennett and Johnson 1979; Demsetz 1968). For a private firm to operate they have to provide cheaper services while facing higher costs than the public firms which allows us to conclude that the private firm is more operationally efficient because it can provide the services at a lower cost than the public firm (Bennett and Johnson 1979).

Chapter 5: Model and Data

For my project, I used linear and logistic regression analyses on drinking water quality (represented through the number of SDWA violations per CWS) and for ownership (private v. public). Access to high quality water differs across the United States. The quality of water has always been an issue for the U.S., but more recently events like the Flint Water Crisis have been getting lots of media attention. Although the EPA created a regulatory framework for drinking water (SDWA of 1974), how water is provided and treated differs across the country by state. Water is provided through states/municipalities or these services can be provided through private firms. I specifically analyze the water quality and ownership of utilities in the state of Connecticut in the year 2018.

There is an overwhelming amount data on water quality. A majority of these data include water before it was treated (e.g., groundwater samples, river samples, lakes, etc.), but for my project I am only focusing on treated water in community water systems. A few pollution advocacy groups (like Environmental Working Group) have done studies across the country that include data from both the EPA's Safe Drinking Water Database and treated water data from state's Department of Health. For my project, I will use the same methodology of combing EPA data along with data from the Connecticut Department of Health. The EPA has data on the community water system level (e.g., town served, county served, population served, violation type, MCL, date of violation, etc.). This data set includes valuable information on not only for the characteristics of the community water system, but the EPA data includes ownership and management type of the individual community water system which is essential for my analysis of how ownership/management affects water quality. The presence of violations would indicate poor water quality and no violations may indicate better water quality or poor management practices (e.g., failure to report violations).

I was able to obtain drinking water quality data from the State of Connecticut from 2002 – 2019. I requested time series data with variables regarding the specific water system (e.g., water system ID, origin of water source, population) and all of the analytes (biological and chemical variables) they test for (e.g., nitrates, chloroform, e coli, etc.).

5.1: Linear Regression Model

The dependent variable for the linear regression model will be number of Safe Drinking Water Act violations per CWS. This data was obtained from the Department of Health from the State of Connecticut. There are multiple independent variables that I want to explore. The preliminary independent variables are: population density (e.g., rural, suburban, and urban classifications), housing density, population served, population squared, median income, education level, ethnicity (e.g., minority communities), political environment, ownership, measure of financial strain, water type, and the number of facilities in a CWS.

The regional and geographic variable refers to the population density and will reflect whether the water service operates in rural, suburban, or urban communities. Population density data on the county level was taken from the 2010 U.S. Census. "Utilities in more rural, less urbanized areas tend to have less capacity to comply with quality regulations and face financial strain due to declining populations and lower incomes." (Allaire et al. 2018). Rural areas have a higher chance of violating regulations compared to urban and suburban communities (Allaire et al. 2018). Therefore, counties with lower population densities would expect to have more violations than counties with higher population densities.

Housing density is the number of housing units within a square mile. A housing unit, as defined by the U.S. Census, is a house, an apartment, a group of rooms, or a single room that is intended for occupancy as separate living quarters (Housing Unit, U.S. Census Definitions). This definition counts each apartment in an apartment building (Housing Unit, U.S. Census Definitions). Housing density data was taken from the 2010 U.S. Census. The housing density would indicate extensiveness of the water networks. In more urban areas, the housing density would be higher and in rural areas the housing density would be lower. It is more expensive for municipalities to have extensive water networks in rural areas because they have less people connected to a single water system (Prierto et al. 2014). In urban areas the water networks are more centralized and more people are connected to one system. Urban areas, with higher housing densities tend to have less SDWA violations than rural, less dense areas (Allaire et al. 2018). Nationally, rural communities experience more SDWA violations than urban communities (Allaire et al. 2018). I wanted to explore the idea of housing density and if that has a similar impact as population density.

The population variable is the number of people served by a given water system. Would a water system that serves a lot of people be monitored more closely because if there was a problem it would affect more people? Would it be updated with newer water cleaning technologies? Allaire et al. (2018) notes that shrinking populations put financial strains on the local/state government that provides the water services. There are not as many people to tax when the population shrinks so updating the water utilities would be difficult to fund. Private water utilities may be optimal in areas with smaller populations because they can better secure the funding for infrastructure projects than municipalities can (Masten 2011). The population served data can also be found through the EPA SDWA database.

The population squared variable is intended to explore the presence of economies of scale in water quality. Economic literature suggests that there are economies of scale present in water services (Shih et al. 2004). There is no literature that suggests if economies of scale are present in terms of water quality. Would it be cheaper to provide a higher level of water quality to more densely populated areas because they are served by one piping network that may be easier to test? I aim to explore this idea in my project.

The median income variable would measure the median level of income for a community that a water service serves. Town level median household income data is used from the American Community Survey (ACS) of 2013 – 2017. Does a higher income community have better water quality? I would assume that water quality acts as a normal good so when income level rises, then the demand for higher quality water would also increase. As median household income increases, the number of SDWA violations would be expected to decrease. This variable can also lead to questions about environmental justice (e.g., cases like Flint, MI). Water quality has also been thought of to be dependent on poverty level, so if a community has a higher percentage of its people living in poverty, they have poorer water quality (Switzer and Teodoro 2017).

The education level variable would measure the average amount of education that a community has attained. Educational attainment is measured by the percentage of a population in a town in Connecticut that holds a bachelor's degree from a 4 -year university. This data comes from the 2013 – 2017 ACS. Income and education are related to each other. More education typically leads to higher income. Higher levels of education could lead to more public awareness of certain environmental issues (e.g., water contamination) and people would demand better quality water utilities (Switzer and Teodoro 2017).

The ethnicity variable would show the proportion of different ethnicities within a town in Connecticut. Percentages of ethnicities within a town are available through the 2013 – 2017 ACS. Low-income, minority communities are more likely to experience poorer water quality (Allaire et al. 2018; Switzer 2019; Switzer and Teodoro 2017). Black and Hispanic communities are the most at risk for an SDWA violation (Switzer and Teodoro 2017). Are minority communities, in the state of Connecticut, more vulnerable to drinking water violations than other communities?

The ownership variable would represent the ownership and management type of the community water system. This variable will most likely be a dummy variable indicating whether the water is provided by the government (state or local) or it has been contracted out to a private firm. The state of Connecticut is a unique situation in regards to water utility ownership because 80% of CWS are privately owned and operated. This is a far larger percentage than the rest of the United States which only has 12% of CWS being privately owned (Kopaskie 2016). The effect of water privatization on water quality is unknown. Some sources have said that water quality improves when it is privately contracted out and other sources have disagreed. Allaire et al. (2018) found that privately provided water is less vulnerable to quality violations. Ownership type is available through the EPA SDWA database for each CWS.

I included a measure of financial strain for the municipality that is serviced by a given water system. If they are running a budget deficit, then they are most likely not going to be prioritizing updating their water infrastructure. Municipal debt per capita for the state fiscal year 2017 – 2018 was available through the CT data collaborative. Each state has a comptroller website with budget data.

Water type is also extremely important when considering what impacts water quality. The water type indicates what kind of source the CWS gets their water from, either surface water or groundwater resources. These two are connected through the hydrological cycle, but can produce different water quality results. Surface water has a higher chance of exposure to contaminants (e.g., higher rates of run-off, air pollution, etc.) because it not as concealed as underground aquafers that hold groundwater. Groundwater can still be exposure to natural (and unnatural) contaminants that are harmful to humans (e.g., arsenic, sulfur, runoff, etc.) but surface water is typically exposed to more contaminants that are not naturally occurring. Because of this exposure, we can expect CWS that use surface water to have more violations than CWS that use groundwater. The EPA includes a water source variable that indicates what kind of water type each CWS is using.

I have also decided to include the number of facilities that are in each CWS. This is to help control for size. There is a lack of literature on how the number of facilities may impact SDWA violations or water quality in general. The minimum number of facilities in a CWS is 2 and the maximum number is 167. It may be easier to have a violation if there are more facilities than if there are fewer facilities; this may be simply because there are more places to conduct testing so the likelihood of having a violation would increase with the number of facilities within a CWS.

5.2: Logistic Regression Model

I want to explore what effects ownership of community water systems. For most of the United States, municipalities own their community water systems. In Connecticut, however, 80% of the community water systems are privately owned and operated. Various literature has pointed to factors of population density, housing density, and political affiliations of communities as indicators of ownership types of community water systems. The dependent variable is ownership, which is a binary variable (1 meaning private ownership and 0 indicating government ownership, either state or local).

State and local governments will contract out their water utilities for various reasons. These reasons include inadequate funding to update infrastructure or adding to the existing infrastructure to give more homes access to piped water. Private firms have an easier time securing investments to expand water networks than municipal governments (Masten 2011). This may mean that if housing densities and population densities are lower, it is more likely that a private firm will take over water operations.

I decided to include median household income in the logistic regression model. This variable will provide further understanding of what types of communities have privately owned water systems. Are towns with higher median household incomes more likely to have their water services provided by public or private CWS? Are lower income towns more vulnerable to municipalities contracting out their water resources because they may be more financially strained than the higher income towns?

Political affiliation has a known influence on adoption and implementation of environmental policy and public health legislation (Dupont and Bateman 2012). Are more progressive/liberal counties prioritizing public health and making water quality a top issue than conservative counties? People who affiliate with the political right have a lower willingness to pay for a publicly provided goods, but will pay more a privately provided good (Dupont and Bateman 2012). This would be an interesting variable to explore in conjunction with privatization of water services. I will also be using federal election data which can serve as a proxy for local political preferences (Switzer 2019). Although it is not likely that people's preferences for water quality is reflected in their vote for a federal election, but it will allow us to explore the political preferences of the community in question (Switzer 2019).

5.3: Model Conclusion

Using all the variables mentioned above, I aim to perform both regression analyses. The linear regression analysis will provide more understanding of what effects water quality and by how much. The logistic regression model will tell us under what conditions is private ownership will be more likely than public ownership of community water systems.

Chapter 6: Analysis of Results

This chapter contains a discussion of the initial exploratory analysis of the data and the results from the linear and logistic regression models and their respective implications. The first section begins with the results of the linear regression model. The second section addresses the logistic regression model.

6.1 : General Exploratory Analysis of the Data

For this project, I am explicitly using observations from the year 2018 in Connecticut. The unit of analysis for this project is on the CWS. There are 440 CWS included in this study and the number of CWS varies per town. The minimum population served by a CWS is 25 people and the maximum population served by a CWS is 418,900 (Table 1). The average number of facilities within a certain CWS is 12.8, the minimum is 2 and the maximum is 167 (Table 1). 356 of the 440 CWS are privately owned and operated (Table 2). The average number of violations is 598.91, the minimum number of violations is 20 and the maximum is 19, 654 (Table 1). 371 of the CWS get their water from groundwater resources and 66 get their water resources from another source (e.g., surface water or purchased water) (Table 3). There is a wide variety of community water systems within the state of Connecticut.

Table 4 shows the top 5 CWS by SDWA violations in the year 2018. The populations of these respective CWS are well over 50,000 people (Table 4). All of their water comes from surface water resources (Table 4). The important story to look at are the demographics presented in Table 4 and compare them to the averages of the demographic variables (Table 1 and Table 4). The average percentage of white populations within

Connecticut towns is 84.7% (Table 1). but the highest percentage of white population within these CWS is 77% and the lowest is 15% (Table 4). The majority of the percentages presented in the table have population percentages of the Black and Hispanic communities that are far larger than the White population (Table 4). The average municipal debt per capita with in the data set is $1,643.79; 4 out of the 5 CWS are well over this value (Table 4). The CWS that has lower municipal debt per capita is the CWS with the 77% of the population being white (Table 4). The average percentage of the population within a given town in Connecticut that has a college degree is 40.7% and all of these CWS are below that mark (Table 4). The average median household income in Connecticut for 2018 was $87,669.20 which is well above the median household incomes within these respective CWS (Table 1 and Table 4). The CWS with the highest median income out of the 5 CWS shown in the table is $75,056 which happens to be the CWS with the highest percentage of white population (Table 4).

The table with the top 5 CWS in terms of SDWA violations (Table 4) suggests that lower-income and minority communities experience the most SDWA violations. These results raise concerns of environmental injustice because the most violations occur within predominantly minority communities that lack the resources to address these kinds of problems of poor water quality. If a community is financially strained (expressed through municipal debt per capita) they are not going to fund infrastructure updates because that requires a huge amounts of capital. These communities also have lower annual incomes compared to the rest of the state, so to get products like water filters and to have to be changing them constantly is a large cost to endure when you only make $30,000 a year. The results in Table 4 are consistent with the literature on water quality, income, and racial disparities (Switzer 2019; Switzer and Teodoro 2017; Allaire et al. 2018; VanDerslice 2017).

6.2 : Linear Regression Model

The number of violations per CWS in 2018 was used as the dependent variable for the linear regression models. The number of violations, both managerial and MCL violations, were calculated by adding all the violations per CWS. The dependent variables are: the population served by each CWS, population squared (quadratic term), population density, number of facilities within each CWS, water type (dummy variable; 1 if groundwater), percentage of ethnicity within a town's population in CT (Asian, Black, Hispanic, and other nonwhite), median household income, municipal debt per capita, and percentage of population within a town that has a bachelor's degree (Table 5).

The CWS population served variable was positive and statistically significant (Table 5). If the population served by a specific CWS increased by 1, the number of violations would increase by 0.085. This is a relatively small increase in number of violations per one person served increased. Hypothetically, if a water utility increased their service network to a new neighborhood which would increase the number of people served by the thousands, then the number of violations would increase by the hundreds. Most of the literature that I have read suggested that more violations occur when water utilities have to service smaller populations. This result may suggest a lower violations per capita because this variable is not adjusted for size, but may be capturing the size of the CWS. Alternatively, larger CWS have to process more water to serve more people. The larger volume of water to be processed means that there is more water to test and a higher likelihood of getting a SDWA violation.

The quadratic term, population squared, was negative and statistically significant (Table 5). Although the coefficient of population squared is essentially equivalent to zero, it is still important to explore its implications. The non-linear shape of the regression is determined by the values of the population and population squared terms. The CWS population served variable is positive and the population squared variable is negative. The values of the two respective population variables suggest a concave downward parabola shape. Initially, as population increases the number of violations will increase and then it will hit a certain point and as population continues to increase the number of violations will decrease. The relationship between population and number of violations appears to be one of diminishing marginal returns. These results suggest that once a CWS reaches a certain population, that there is something causing the number of violations to decrease. This may be that once the water system becomes big enough the firm or municipality is able to dedicate more funding to water quality compliance or hire more personnel to monitor the water treatment plant to ensure water quality. Given these regression results and the linear shape of concave downward, the relationship between water quality and population do not exhibit characteristics of economies of scale (as suggested in section 4.3).

Number of facilities within a CWS was positive and statistically significant (Table 5). As the number of facilities increases by 1, the number of violations will increase by 21.8 (Table 5). This variable may be capturing the size of the water distribution system similar to the CWS population served variable. If there are more places to test for water quality violations, it may be harder to comply with SDWA standards because there are so many testing sites that have to comply with the water quality standards. The larger CWSs may have more personnel reporting and therefore more violations to report than smaller CWS simply because they are able to do more monitoring.

The water type variable was negative and statistically significant (Table 5). This suggests that if the water source comes from groundwater, it reduces the number of SDWA violations by 122.9 (Table 5). This is a large amount of violations and clearly demonstrates the differences between sourcing water from groundwater sources vs. surface water sources. 371 of the 440 CWS in this study source their water from groundwater sources (Table 3). The nature of surface water, being above ground and exposure to higher frequencies of being contaminated (e.g., air pollution, run-off, etc.) will make it harder to and more complex to treat compared to groundwater resources. While groundwater is not immune from contamination, it presents less treatment challenges than surface water and therefore may be less likely to violation the SDWA standards.

The private ownership variable was negative and statistically significant (Table 5). The private variable indicates whether a CWS is privately operated or publicly operated. A private CWS, according to the regression results, will experience 205 less SDWA violations than a publicly owned CWS (Table 5). There are many explanations for private firms having less SDWA violations than public water utilities (sections 3.6 and 4.5). Connecticut presents a unique case study because 356 of the 440 CWS in this study are privately owned and operated (Table 2). This is unique to the rest of the U.S. because the majority of CWS are publicly owned (Kopaskie 2016). The majority of the larger CWS

(10,000+ people served) are publicly owned. As suggested by the population and facility variables, the larger the water system and population served, the more SDWA violations a CWS is going to have (Table 5). The ownership variable may not accurately capture reasons for less violations among private CWS because the larger CWS account for the majority of the violations and they happen to be publicly owned and operated.

The ethnicity variables (Asian, Black, Hispanic, and other nonwhite races) were all statistically insignificant (Table 5). This may be attributed to the low level of diversity within Connecticut. The average percentage of white population within a Connecticut town between 2013 – 2017 was 84% (Table 1). The minimum percentage of white population within a town in CT is 14%, but the other minimums for the racial category are 0% (Table 1). The homogenous characteristics of the state may not allow it to clearly demonstrate the racial disparities in drinking water quality that other economic literature has presented (Switzer and Teodoro 2017; Switzer 2019; VanDerslice 2017).

Given the significance placed on race within various economic literature regarding water quality, I ran a separate regression with number of violations per CWS in 2018 as the dependent variable and the ethnicities as the independent variables (Table 5). This regression analysis cannot provide strong conclusions because other independent control variables were not included (e.g., income, education, population served, number of facilities, etc.). The statistically significant results included Hispanic and other non-white race variables (Table 5). The Asian and Black/African American variable appeared to be statistically insignificant (Table 5). Economic literature has placed an emphasis on the connection between poor water quality and minority communities (Switzer and Teodoro 2017; VanDerslice 2017). This disparity in water quality faced by low-income, minority communities is demonstrated by recent current events (e.g., Flint Water Crisis and the Compton Water District, Los Angeles). There is a perception that race influences water quality and that perception is weakly supported by the regression in Table 5. It is possible that if this study were done across the U.S. and for a longer period of time, that there could have been stronger and more conclusive results that demonstrate the racial disparity in drinking water quality (Switzer and Teodoro 2017; VanDerslice).

Unexpectedly, the median household income and education variables were statistically insignificant in the regression (Table 5). Other studies done with SDWA violations have suggested that income is a strong determinant for water quality (Allaire et al. 2018). Again, if this study was done on a larger scale and over a longer period of time, then income and other income related variables would probably have an effect on drinking water quality outcomes.

6.3: Linear Regression Output

Number of Violations	Model 1 b/se	Model 2 b/se
CWS Population Served	0.085***	
	(0.01)	
Population Squared	-1.29e-7***	
	(0.00)	
Population Density	-0.672	
	(0.68)	
Number of Facilities	21.808***	
	(7.11)	
Water Type	-122.916*	
	(70.33)	
Private	-205.123*	
	(78.89)	
Asian alone	10.590	-5.498
	(10.10)	(38.42)
Black or African American Alone	-2.383	68.776
	(2.46)	(63.85)
Hispanic Alone	-1.541	119.070*
	(4.67)	(60.06)
Other Non-White Races	-3.112	-183.883**
	(12.55)	(68.26)
Housing Density	1.747	
	(1.68)	
Median Household Income	-0.002	
	(0.00)	
Municipal Debt Per Capita	-0.004	
	(0.01)	
Percent College Degree	0.974	
	(1.50)	
_cons	347.809*	87.047*
	(155.60)	(253.56)
R-sqr	0.9634	0.3174
Dfres	434	437
Std. Error adjusted for 119 clusters by town		

* p<0.05, ** p<0.01, *** p<0.001

Table 5: This table includes two linear regression models with number of SDWA violations per CWS in 2018 as the dependent variable. Model 2 includes only race independent variables. Statistically significant independent variables in the first model include: population served, population squared, number of facilities in a CWS, and private. The statistically significant variables in the second model are: Hispanic and other non-white races.

6.4: Logistic Regression Analysis

For the logistic regression model, the private ownership variable is the dependent variable (Table 7). This is a binary variable (1 indicates private ownership, and 0 indicates public ownership of the CWS) so a logistic regression is necessary for analysis. The independent variables indicate if the majority of the town voted for the Republican party in the 2016 election, population density by county, housing density by county, and median household income (Table 7).

The political affiliation variable indicates whether the percent majority (>0.50) of the town in Connecticut voted for the Republican party in the 2016 presidential election (Table 7). Republican-leaning communities are willing to pay more for environmental goods (water quality) if they are privately provided (Dupont and Bateman 2012). The results from the logistic regression were unusually large for the Republican variable. The odds ratio is 3.10 which is not the typically outcome for a logistic regression (between 0 and 1 are typical results) (Table 7). This result suggests that the odds of having a private water utility supply water for a community is 3 times higher if the majority of the community voted for the Republican party in the 2016 presidential election (Table 7). This would be interesting to explore further to see how compliance varies across CWS with majority of the community being Republican. Switzer 2019 claims that Republican communities experience higher frequencies of SDWA violations than Democratic-leaning communities.

Population density has an odds ratio of 1.01 and is statistically significant (Table 7). The odds ratio is so close to 1 which means that population density may not have an effect on CWS ownership. Because it is slightly over 1 we can interpret it but it has little to no effect on ownership likelihoods for a given CWS. The odds ratio is over 1, it means that privatization is more likely occur for denser populations. Economic literature tends not to focus on population densities rather more on housing densities because it is really where people are geographically distributed that determines water distribution rather than the number of people.

Housing density has an odds ratio of 0.976 and is statistically significant (Table 7). An odds ratio less than 1 indicates that housing density would make privatization less likely to happen. This is consistent with the various economic literature on housing density and water distribution (Prierto et al. 2014: Masten 2011; Nauges and Thomas 2000; Allaire et al. 2018). As housing density increases, it is less likely for the CWS to be privately owned and operated. If housing distribution is more spread out, the more expensive the water distribution system becomes because it requires more piping but less customer connections so there are not as many people connected and therefore less profit to be generated (Masten 2011). CWS are more likely to be municipally owned the more connections per mile there are (Masten 2011).

The median household income has an odds ratio of 1.00 and is statistically significant (Table 7). This means that median household income does not affect the odds of a CWS being private or public. Initially, I thought that income may have had an impact on whether or not a CWS would be private or not, but median household income does not determine public or private ownership of a CWS. The results from the logistic regression suggests that the spatial patterns of houses and the political tendencies of communities are strong determinants of private ownership of CWSs private (Table 7).

6.5: Logistic Regression Output

Private	Model 1 Odds Ratio/se
Majority Republican	3.103*
	(1.227)
Housing Density	0.976*
	(0.009)
Population Density	1.009*
	(0.004)
Median Household Income	1.000*
	(6.58e-6)
_cons	1.053*
	(0.628)
Pseudo R-sqr	0.05
Dfres	437

* p<0.05, ** p<0.01, *** p<0.001

Table 7: This table contains the output from the logistic regression. Private ownership is the dependent variable and town majority republican, population density, housing density, and median household income are the independent variables. All independent variables are statistically significant.

Chapter 7: Conclusion

The purpose of this thesis was to analyze reasons for variations in water quality while also exploring differences in CWS ownership. The results from this project present interesting conclusions on what influences variations in water quality and what determines ownership type among CWS in the state of Connecticut. Regression analysis was motived by various economic literature on water quality, water services, utility services, and environmental justice These conclusions can be used to target underperforming CWS and identify communities that are most at risk of experiencing SDWA violations.

The linear regression model suggests that there is a strong relationship among the dependent variable, number of SDWA violations, and various independent variables. The statistically significant variables are: the population served by a specific CWS, population squared (quadratic term), number of facilities within a CWS, water type, and private ownership (Table 5). The linear regression model also included demographic variables of various races, housing density, median household income, municipal debt per capita, and percentage of the population with a college degree. Although economic literature suggested the influence of these types of demographic variables on water quality, they were not statistically significant in the linear regression model.

The logistic regression model suggests that there is a strong relationship with private ownership of CWS within low housing density and Republican-leaning communities (Table 6). If a town in Connecticut had a majority of the people who voted for the Republican party in the 2016 Presidential election, then the odds of having a private CWS is 3 times higher than having a public CWS. The housing density variable is also a statistically significant indicator for private CWS ownership. If housing density goes up the likelihood of privatization goes down. According to the regression model, private CWSs also experience lower SDWA violations than public CWS (Table 5). This project did not set out to explore operational differences among private versus public CWS ownership. However, the results of the linear regression suggest that there is a difference between the two types of ownership concerning water quality (Table 5). The population density and median household income odds ratios were statistically significant but have little to no effect on the likelihood of a CWS being privately owned or publicly owned.

As suggested in the exploratory analysis section of this paper and the regression analysis, there may be racial and income inequalities when it comes to drinking water quality (section 6.1). While the regression analysis could not provide any conclusive evidence, it does suggest that there may be a connection among race and number of SDWA violations (Table 5). The top 5 CWS with the most number of SDWA violations serve low-income, minority communities compared to state averages within the data sample (section 6.1, 6.2). Additional studies on a national scale would provide more insight on the connection between race and water quality (Switzer and Teodoro 2017).

This project also highlights some weaknesses within the Safe Drinking Water Act (1974). The SDWA is considered to be an effective piece of legislation because it was able to decrease the overall number of drinking water related illnesses, however, there are still large amounts of drinking water violations occurring since the enactment of the law (Weinmeyer et al. 2017). As scientific knowledge surrounding emerging drinking water contaminants grows, there are naturally going to be more violations because there are more contaminants to test for (Weinmeyer et al. 2017). The Regional Water Authority that operates in New Haven has 19,654 SDWA act violations (Table 4). This is an extraordinary amount of drinking water violations given that the state average for SDWA violations in 2018 is 598 violations (Table 1). There are clearly CWS that need more regulatory oversight to increase compliance with drinking water policies. Given that the SDWA establishes funding for CWSs across the country to put towards water compliance, the act should be able to maintain the public's confidence that these water utilities can provide safe and clean drinking water (Weinmeyer et al. 2017). Lack of funding or misuse of funding will only contribute to the worsening of water quality as problems such as infrastructure and outdated technology are left unaddressed (Allaire et al. 2018; Weinmeyer et al. 2017).

Safe and clean water is essential for all humans. While most people think problems with drinking water quality are exclusive to developing nations, these problems are present within the United States. This project has presented reasons for water quality variation within the state of Connecticut. Policies should be made to further target underperforming CWS to support increased drinking water compliance. While safe drinking water should be guaranteed in the United States, access and reliability of water resources are not. Moving forward, states and the EPA should adjust how they address compliance for drinking water standards.

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APPENDIX A

Variable	Obs.	Mean	Std. Error	Min	Max
CWS pop_ served	440	5742.98	33619.61	25	418900
Number of facilities	440	12.82	15.95	2	167
Number of violations	440	598.91	1743.38	20	19654
White Alone	438	84.70	13.09	14.8	97
Debt per Capita	438	1643.79	1019.70	0	5735
Median Hsld Income	438	87669.2	21516.63	33841	208848
Pct. College Degree	438	40.74	13.27	14.14	81

Table 1: This table contains the descriptive statistics of population served, number of facilities, number of SDWA violations in 2018, water type, percentage of white population, municipal debt per capita, median household income, and percentage of population with a college degree.

Ownership	Frequency
Public	84
Private	356

Table 2: This table depicts the number of CWS that are private owned (1) vs. publicly owned (0). 84 of the CWS in this data set are publicly owned and operated and 356 of the CWS are privately owned and operated.

Water Type	Frequency
Surface Water	66
Groundwater	371

Table 3: This table shows the frequency of CWS that get their water from surface water (0) or groundwater (1) resources. 371 of the CWS within this data set get their water from groundwater resources and 66 of the CWS get their water from surface water resources.

Description of CWS with the most SDWA violations in 2018.

CWS Name	CWS Pop Served	Num Viol..	Black or African ..	Asian Alone	Hispanic or Latin..	White Alone	Private	Watert..	Debtpe..	Pct College ..	Median Hsld Inc..
REGIONAL WATER AUTHO..	418,900	19,654	32	5	30	30	0	0	4,452	34	39,191
METROPOLITAN DISTRICT..	390,887	13,968	35	3	44	15	0	0	5,035	17	33,841
AQUARION WATER CO OF ..	351,756	13,413	33	3	39	21	1	0	4,425	18	44,841
CTWC - NORTHERN REG-..	98,390	8,939	10	5	7	77	1	0	1,022	35	75,056
NEW BRITAIN WATER DE..	73,534	8,048	12	3	41	42	0	0	3,861	18	43,611

Table 4: This table, created using Tableau, includes information regarding the top 5 CWS with the most SDWA violations in 2018. Variables included are: CWS name, number of people served by the CWS, the number of SDWA violations, percentage of races within the town where it operates: Black, Asian, Hispanic, and White, private ownership variable (1 indicates privately operated), water type (0 indicates surface water and 1 indicates groundwater), municipal debt per capita for SFY 2017 – 2018, percentage of the town with a college degree, and the median household income for the town where the CWS operates.

APPENDIX B

March 13, 2020

Dear Ms. Jennifer Squires and Mr. Sachin Patel,

I am Claire Hadelman, a senior Environmental Policy major and Economics minor at Union College in Schenectady, NY. Back in October 2019, I requested drinking water data from the state of Connecticut to conduct my senior thesis on exploring variations in water quality and ownership of community water systems for the year 2018 in Connecticut. Thanks to your help, I was able to complete this research project.

The results from my project present some interesting conclusions regarding water quality and CWS (community water system) performance in the state of Connecticut. Regression results indicate that public CWSs that serve larger populations and source their water from surface water resources experience much higher levels of Safe Drinking Water Act (SDWA) violations. I also found that private CWSs experience over 100 less SDWA violations than public CWSs – this may suggest operational inefficiencies within publicly owned and operated CWSs. I ran another regression analysis on ownership type within the state and found that private CWS are more likely to occur in rural areas with low housing density and in communities that are Republican-leaning.

Additionally, I was able to combine the CWS data with 2013-2017 American Community Survey data to look at the demographics of the communities that are served by these CWS. General exploratory analysis of the top 5 CWS with the most SDWA violations showed that they predominantly service low-income and minority communities (in comparison to the rest of the state). Regression analysis was unable to confirm this result as a strong determinant for water quality, but various economic literature has made the connection between poor drinking water quality and low-income, minority communities across the United States.

I hope that what I have found could be of any interest and use to the Connecticut Department of Health as you work to address violations in the future. As I am sure you may know, these violations can be avoided through increased early intervention at water treatment facilities and better, more frequent reporting. Drinking water violations should be actively addressed so that the state can avoid public health risks in the future.

Again, I extend my appreciation to both of you for your help in organizing the data. I am happy to further discuss my results with you or answer any questions regarding my study. This project would not be possible without the help from the Connecticut Department of Health.

Sincerely,

Claire Hadelman