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The Price on Our Tap: A Policy and Quantitative Analysis of County-Level Water Affordability in Alabama

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The Price on Our Tap: A Policy and Quantitative Analysis of County-Level Water Affordability in Alabama

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Dedication

I dedicate this work to my parents, Mrs. Chinmoyee Datta and Mr. Mihir Kumar Datta, my most important teachers. Their work, love, and unconditional support drives my own creativity and work ethic. Their exemplary careers as public-school teachers in the poorest county in America has inspired my own career in public service.

I also dedicate this work to all those who are suffering from a lack of access to water, energy, and food. Let this thesis solidify my passion and commitment to advocate for those who continue to suffer through these injustices.

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I want to take this opportunity and thank my mentors Dr. David Hoffman from Mississippi State University and Professor Ashleen Williams of the University of Mississippi, both of whom have spent countless hours making sure that I am able to do the things that I am passionate about. I want to thank my best friends, Braeden Foldenauer and Ryan Hopson, whose tireless friendship has gotten me through the past five years. Finally, I want to thank my parents, Mrs. Chinmoyee and Mihir Datta, to whom I dedicate this thesis.

Abstract

This thesis examines disparities in water affordability in Alabama by exploring the relationship between water expenditure and other variables based on a quantitative analysis of a four-year water provider-level, panel data set. I utilize ordinary least squares to answer the following research question: “After controlling for income, what variables affect water expenditure in Alabama, and particularly, what impact does race have on water affordability and expenditure in Alabama?” This analysis is motivated by the on-going water and sewer affordability crisis that currently affects nonwhite households in the broader United States. Given that there are very few policies addressing water affordability, possible affordability disparities mean that households, particularly those in majority-nonwhite communities, are at risk of losing access to water. Based on my analysis, I find that counties with high Latinx population tend to also have households that face high water expenditure. Furthermore, I also find that rural counties and counties with a high number of Safe Drinking Water Act violations face high water expenditures.

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Chapter One – Introduction

1.1. Chapter Introduction:

Access to clean and affordable water and sewer services is essential to the health and well-being of communities. Forty countries and the United Nations have deemed access to clean water as a human right; however, the United States does not formally recognize access to water as an inalienable right for Americans (*Palmer, 2016*). Due to outdated water infrastructure within the US, the price of water is rising rapidly and disproportionately affects low-income communities (Teodoro, 2019). Between 2000 and 2016, the price of water increased by nearly 300% and represented the largest price increase of any other household utilities, and this increase was attributed to a range of variables, such as outdated infrastructure within water utilities to aging housing stock (Broaddus and Kane, 2016). This increase in the price of water has meant that millions of Americans face water bills that are more than 4% of median household income within the census tract, a threshold past which water expenditure is considered unaffordable by the US Environmental Protection Agency (Lakhani, 2020).

1.2. Water Affordability in the United States

Federal funding for water utilities has fallen by nearly 54% in the past two decades (Morton, 2021). Much of this funding goes toward water infrastructure upgrades and repairs. However, according to the US Environmental Protection Agency, water utilities around the US require nearly $800 billion in infrastructure investments to ensure that they can provide safe, reliable, and affordable water to their residents (EPA, 2019). To ensure the cost of infrastructure maintenance and repairs, water utilities incrementally increase their customer's water prices. This increase in water prices is not only the result of decreasing funding from the federal government, but also an increase in the sticker price of raw materials, caused largely due to inflation (Walton, 2022). For low-income households, these incremental increases typically make up a greater share of their monthly income and create unaffordability challenges (Mack & Wrase, 2017). Water unaffordability disproportionately affects Black, Latinx[1], or other non-white households, which are also more likely to face higher water affordability challenges when compared to white households after controlling for income; Mack and Wrase, 2017). High water affordability challenges lead to customers being unable to pay their bills, and these bill delinquencies result in large number of water shutoffs, which are predominantly faced by nonwhite households (Ashman & Neumuller, 2020).

1.3. Direction of Research and Hypothesis:

In this thesis, I explain the current policy and historical landscape of water affordability and water infrastructure financing in the United States. Through this process, I intend to show how broader historical events have created a financing system in which water utilities, particularly in predominantly Black and Latinx communities, are unable to provide affordable access to water for their customers. Then, I conduct a county-level analysis to measure the water, wastewater, and combined water-and-wastewater affordability in Alabama.

I hypothesize that water bill cost in Alabama will increase as the percentage of non-white residents, particularly Black and Latinx, population increases, while holding income constant. Black and Latinx households are more likely to live in areas with lower-quality infrastructure than white households due to historical trends of both environmental racism and economic injustices that are correlated with systematic racism (Jones and Armanios, 2020; Logan and

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[1] The United States Census Bureau defines Hispanic as an ethnicity, and for the purposes of this research study, all Hispanic ethnicities are grouped into the term "Latinx."

Parman, 2017; Gasteyer et al., 2016; Mirosa, 2015; Carrera, 2014; Logan and Stults, 2011; Carrera and Gasteyer, 2008; Wilson et al., 2008; Pulido, 2000). One reason proposed for the discrepancy in water burden across race is the fact that the added cost of repairing water infrastructure are passed down to the households themselves. This problem is especially prevalent in nonwhite communities (Logal & Parman, 2017; Gasteyer et al., 2016). In predominantly white communities, research has suggested that households do not incur the added cost of infrastructure repairs because water utilities located in predominantly white communities have historically received more federal funding for infrastructure repairs and upgrades than non-white communities (Hansen et al., 2021). Furthermore, due to systematic racism and segregationist practices, Black and Latinx households in Alabama have a lower median household income than white households, as shown in **Table 1.1** (Ashman & Neumuller, 2020).

Table 1.1: Median Household Income for Black, Latinx, and White Households in Alabama

Median Income (in US Dollars)	
White	$49,465
Black	$30,383
Latinx	$34,373

Data Source: US Census Bureau (2020)

Therefore, equal increases in water bills are more financially burdensome for Black and Latinx households as they make up a greater share of their overall income than that of white households.

1.5. Organization of Thesis

In this work, I first discuss the historical and policy background of water affordability and infrastructure in the United States. Because water usage and expenditure is related to climate-induced policies, I also discuss the relationship between water affordability and climate change, and the disproportionate impact of the water affordability crisis on nonwhite households. Then, I explore if there is a relationship between water expenditure and other socioeconomic variables, particularly the percentage of non-white households within a county, in Alabama. This thesis is organized as follows: Chapter two examines the historical context of water infrastructure financing and its relationship to the water affordability crisis in the United States. This chapter then discusses related research on climate change and environmental racism, and the disproportionate impacts of water affordability challenges. Furthermore, it identifies opportunities to add to this research. Chapter three details a literature review that provides the methodological basis and the policy context of measuring water affordability in the Alabama. Chapter four explains the data and methods, describing the key variables and their construction, data sources, and the models utilized. Chapter five describes the main findings, including the primary variable relationships and differential impacts of minority populations on water and wastewater bills. Chapter six concludes with a discussion of the validity of my initial hypothesis, limitations and generalizability of my findings, alternative hypotheses, and recommendations for both policy and future research based on my findings.

1.5.1. Policy Significance:

Currently, water and wastewater in the United States is regulated by the Safe Drinking Water Act (1974) and the Clean Water Act (1972). However, these federal regulations do not protect consumers from facing high water bills and shutoffs (Levine, 2020). Recently, legislators have implemented the Low-Income Water Assistance Program as part of the American Rescue Plan Act of 2021 (H.R. 1319 – American Rescue Plan Act of 2021, 2021). Furthermore, the US Environmental Protection Agency defines a household to face a “high” water affordability burden if the households water expenditure is more than 4.5% of the median household income within the census tract (US EPA, 2021a). Researchers have criticized this metric to be inaccurate as it does not measure the water affordability challenges faced in either extreme of the income distribution (Mack and Wrase, 2017; Cardoso and Wichman, 2020). the US EPA has suggested revising the affordability metrics used to measure water affordability in low-income communities; however, the EPA has implemented no such program to this date (EPA, 2021a). This work is aimed to bolster the efforts of activists and other researchers to persuade the EPA to implement these proposed changes to water affordability standards. Furthermore, this research could also bolster existing programs such as the American Low-Income Water Assistance Programs. The thesis examines the relationship between county-level household water expenditures and other factors, such as median income and percent-nonwhite households, may shed a better light on the state of water affordability in Alabama. Alabama-specific findings of inequitable water affordability may inform state water affordability policy to compliment future federal laws, meeting needs that may be underserved by federal regulations, as well as extending water affordability protections set forth during the COVID-19 pandemic.

Chapter Two – Historical Background on Water Affordability

2.1. Chapter Introduction:

Before assessing the existence of water affordability challenges in Alabama, it is prudent to first examine the current situation and underlying causes of water affordability in the United States. In this chapter, I use research published by water policy experts and advocates to draw a connection between the current water affordability crisis within the United States and the underlying causes of water affordability: federal and state funding for water infrastructure, the relationship between climate change and water affordability, and the systematic nature environmental racism in the United States. I argue that historical austerity trends of water financing, along with health and climate change impacts, have placed the burden of water unaffordability onto historically disadvantaged communities within the United States.

2.2. Landscape of the Water Affordability in the United States:

The Environmental Protection Agency considers a household's water bill to be unaffordable if it is above 4.5% of the median household income (MHI) within their census track (Mack and Wrase, 2017; Mirosa, 2015). However, because median-income measurements do not consider households at the extreme ends of the income distribution, researchers have criticized the EPA's affordability metric to be an inaccurate representation of water affordability in low-income or disadvantaged households (Baird, 2020; Cardoso & Wichman, 2020; Mack and Wrase, 2017). Furthermore, the current 4.5% affordability metric incorrectly views water affordability, which is more of a spectral issue, through a binary lens of being "affordable" or "unaffordable". For instance, a household with a water affordability rate of 5.0% and 15% are both considered simply "unaffordable" and, consequently, receive similar policy considerations (Baird, 2020). For example, according to the water affordability advocate Catherine Flowers, utility managers across the state of Alabama often use the 4.5% of median household income within the county standard as an excuse not to address high water burden in their communities, even if those in the community are unable to pay their water bills (Personal interview with Mrs. Catherine Flowers, 2022). While there are clear flaws in the way that governments measure water affordability, the causes of water poverty depend on the age of the housing stock as the newer homes have fewer leaks and lower water consumption, age of meters, and state/local/federal funding of water infrastructure.

2.3. History of Water Infrastructure Financing in the US:

Federal funding of water infrastructure has decreased by nearly 75% (from $20 billion in 1975 to $5 billion in 2019) since the early 1970s (Greer, 2020). According to the Environmental Protection Agency's most recent infrastructure needs assessment, Congress needs to invest an estimated $470 billion to upgrade the country's water and wastewater infrastructure (EPA 2015). However, without federal support, the cost of upgrading water infrastructure has been passed to state and local governments, save in cases of some water associations, water districts, and private utilities. While some municipalities have been able to make necessary upgrades to their water and wastewater infrastructure, many cash-strapped communities continue to rely on aging water and wastewater delivery systems – e.g. meters, pumps, pipes, etc. Furthermore, the type of water utility also has a significant impact on water expenditure and consumption. Only close to 3% of the water utilities in Alabama are for-profit, and the remaining water utilities are either municipality-owned or are nonprofit organizations (EFC, 2019). The cost of repairing this outdated infrastructure falls directly on low-income households, particularly those located in predominantly non-white communities (Teodoro, 2019). Therefore, to understand the state of water poverty throughout

Alabama, it is imperative to understand the history of water infrastructure financing in the United States.

2.3.1. 1960s to 1970s: Johnson Administration and the Importance of Clean Water

While the federal government's involvement in financing local water infrastructure goes as far back as the New-Deal era, the federal government did not begin to regulate and finance local water infrastructure until the 1960s (Gerlak, 2006). Concerned with worsening water quality standards, the Johnson administration passed a series of laws to strengthen the nation's water quality standards. Recognizing that the financial burden of meeting national standards would disproportionately affect small water utilities, Congress passed the Water Resources Research Act of 1964, charging a college or university of each state to conduct research on water resources (Gerlak, 2006). In 1965, the Johnson administration signed into law the Water Quality Act of 1965, requiring water utilities throughout the country to meet certain water quality standards (Ramseur and Tiemann, 2019; Gerlak, 2006). While these standards were not as stringent as the ones in the Clean Water Act (1972) or in the Safe Drinking Water Act (1974), the Water Quality Act of 1965 was an unfunded mandate that left states and municipalities with no way of paying for the construction required to meet the water quality standards set forth in the law (Gerlak 2006; Ramseur and Tieman, 2019). This meant that states that were regularly reporting data on water and wastewater affordability (Alabama, Minnesota, Oregon, etc.) were better prepared to enforce the standards set forth by the Water Quality Act of 1965. For states that opted out of the 1964 Water Resources Research Act, the lack of data on affordability in Mississippi has meant that water utilities, especially those in low-income and minority communities, continue to provide unaffordable services to their customers while failing to meet national regulatory standards (Cardoso & Wichman, 2020; Teodoro 2022).

2.3.2. 1970s to 1980s:The Clean Water Act and the Safe Drinking Water Act

Environmental reports on high levels of pollution in the Hudson River and Chesapeake Bays during the late 1960's and the infamous 1969 fire caused by an oil spill on the Cuyahoga River caused Congress to build upon the Johnson administration's efforts to reduce pollution in America's water system. In the following years, Congress passed the Clean Water Act (1972) and the Safe Drinking Water Act (1974) to provide clean water to Americans. After the passage of CWA and SDWA, the federal government financed local/regional water infrastructure through special project grants through an established program within the Environmental Protection Agency (Title II of P.L. 92-500). P.L. 92-500 allowed the federal government to directly allot money to states and cities that then used the funds to build their water infrastructure to meet federal pollution standards set within the CWA and SDWA (Ramseur and Tiemann, 2019). However, in the next decade as the early water treatment systems began to break down, Congress realized that it would need to make a substantial investment into CWA and SDWA construction grants program to upgrade the nation's water treatment infrastructure and came up with a solution that has left its marks to this day.

2.3.3. 1980s to Present Day: The Reagan Administration, Austerity, and State Revolving Fund

During the 1980s, the federal financing of local water infrastructure has also been subject to trends of austerity. Around this time, industries that relied heavily on water systems called on the Reagan administration to roll back environmental regulations (Gerlak, 2006). Sympathetic to these calls and to reduce federal spending, the Regan Administration passed the 1987 amendments to the Clean Water Act to phase out construction grants and instead authorized the EPA to create a revolving loan fund known as the State Revolving Loan Fund, or SRLF (Greer, 2020; Gerlak, 2006; Ramseur and Tiemann, 2019). Under the new program, in CWA Title VI, federal loans would be provided as seed money for state-administered loans to build sewage treatment plants and, eventually, other water quality projects. Utilities, in turn, would repay loans to the state, enabling a phaseout of federal involvement while the state built up a source of capital for future investments (Ramseur and Tiemann, 2019).

More critically, however, the introduction of the SRLF reduced the federal government's contribution to water-infrastructure financing from 75% before the Reagan Administration to less than 50% after the grant to loan change in the policy (Ramseur and Tiemann, 2019). Given the lack of federal support of water infrastructure, states and municipalities have turned toward the private sector and the financial market. Today, more than 90% of public water utilities in the country rely on financial markets, such as the bond market, or have sought to privatize their water utilities (Greer, 2020). There are also concerns that existing federal funding of water infrastructure through the state revolving funds is not equitably distributed to the water utilities that need them the most. In Alabama, only 15% of eligible water utilities apply for funding through the state revolving fund, and only 20% of these utilities receive any funding through the state revolving fund program (Hansen et al., 2021). Hansen et al. (2021) have also found that predominantly Black and Latinx counties and small, rural counties are half as less likely to receive funding through the state revolving funds, compared to predominantly white communities or communities in more urban areas. The decrease and inequitable distribution of in federal support, along with states and cities having to finance their own water infrastructure to meet pollution standards, meant that low-income and disadvantaged communities often did not have sufficient funds to upgrade their water infrastructure and were often incapable of repaying their loans (Mirosa, 2015; Gerlak, 2006; Ramseur and Tiemann, 2019). This lack of water infrastructure has meant that low-income and disadvantaged communities often face higher rates of shutoffs, higher rates of water pollution, and higher rates of water, ground, and air pollution (Flowers, 2020).

2.4. The Impacts of Water Unaffordability on Non-White Households:

Research has shown that nonwhite households have a higher likelihood of facing higher water bills than white households, even after controlling for income (Cardoso and Wichman, 2020; Mack and Warse, 2017; Teodoro, 2019). Unaffordable access to water and wastewater services also leads to inequitable health outcomes. Furthermore, the looming threat of climate change exacerbates existing inequities and water affordability challenges faced by low-income and minority households.

2.4.1 Water Affordability and Health

The lack of water infrastructure, and the subsequent water poverty, has led to severe health impacts, particularly in low-income or minority communities. The most notable example of this in the United States is Flint, MI. The debt faced by Flint's local water utility to the State of Michigan led not only to massiv9e shutoffs but also to austerity measures that caused mass lead poisoning due to the presence of lead pipes within older homes located in the city's predominantly low-income and minority communities (Raganathan, 2016; Clark, 2021; Murthy, 2016). Today, thousands of households throughout the city continue to suffer high rates of lead pollution and water shutoffs. In Alabama, the most notable example of a community facing detrimental health impacts is in Lowndes County, a predominantly Black county in Alabama whose median income is nearly half of the state-wide median income (US Census Bureau, 2020). Residents of Lowndes County have reported paying thousands on water and wastewater expenditure. Alabama requires every resident to have access to a septic system, and due to the high cost of septic infrastructure, Lowndes county's residents regularly dump raw sewage in their backyards (Flowers, 2021; Maxcy-Brown, 2020). The infiltration of raw sewage in drinking water systems has led to higher than average infection rates of hookworm within the community (Ranganathan, 2021).

2.4.2. Water Unaffordability and Climate Change

In addition to age-related wear, costs water providers incur due to the growing pressures of climate change present challenges for water affordability. Wastewater systems endure an increased frequency and intensity of weather events because of climate change, which causes costly strain to these systems (Mack and Wrase, 2017; Jones and Moulton, 2016; Christian Smith, Gleick, & Cooley, 2012). While providers cannot postpone costs incurred through federal mandate compliance, those incurred via climate change-related damage may not be as highly prioritized and deferred in favor of keeping costs low to both providers and consumers. The effects of climate change and water unaffordability are not experienced equally but are instead exacerbated by existing societal inequalities such that marginalized communities experience disproportionate effects of both climate change and rising water bills (Schmeltz, 2021; Kaiisera and Kronsellb, 2014).

Different communities are differentially affected by climate change due to social and economic factors, rather than simply different levels of exposure to climate hazards. For example, income and resultant access to resources affects groups' ability to prepare for, protect themselves from, and recover from the hazards of climate change, such as hurricanes, tornados, and droughts, as those with greater resources can secure higher quality housing that is less exposed to climate hazards, is more durable in the event of storms, and can recover lost housing and other resources more quickly (Thomas, Hardy, Lazrus, et al., 2019). Further, resource access influences social groups' ability to adapt to a changing climate. The unequal distribution of economic, institutional, and political resources enables highly resourced individuals and groups to adapt more readily to changing climatic conditions than those who are less highly resourced (Thomas, Hardy, Lazrus, et al., 2019). In the U.S., structural racism and the inequities that result increase the vulnerability of non-white individuals to the effects of climate change (Tuana, 2019).

Alabama and the broader Southeast are under increased pressure to become resilient to climate change but often lack the funding to do so. The coastal population in Alabama is especially vulnerable due to threats from sea level rise and increased frequency of hurricanes. During 2005, Hurricane Katrina caused more than 1,800 deaths and eroded more than 200 square miles of coastal land in Louisiana and Mississippi. Natural disasters such as droughts can also affect water systems in the Southeast. In 2007, drought caused such water shortage in Georgia that the state's agricultural industry saw nearly $340 million in crop failures (R. M. Adams et al., 1999). Water utilities can also come under significant pressure as climate-induced disasters affects the Southeast. For instance, the 2021 winter storm in Jackson, Mississippi, caused the city's water treatment plant to shutdown water services to thousands of residents within the city, and many of these residents remained without water for several weeks after the storm (Lazrus, et al., 2021).

2.5: Chapter Summary and Context:

The root causes of water poverty pertain to the measurement of water affordability and the mechanisms of financing of water infrastructure in the United States. According to the affordability metric set forth by the US Environmental Protection Agency, a household's water bill is considered unaffordable if it is above a threshold of 4.5% of the household's median income (Mack and Wrase, 2017; Mirosa, 2015). Researchers have criticized this threshold as it depends on median income of the county and does not give an accurate picture of the water affordability challenges faced by households at either extreme of a county's income distribution (Baird, 2020; Cardoso & Wichman, 2020; Mack and Wrase, 2017). This inaccuracy in measuring water affordability in the United States has particularly exacerbated water poverty in predominantly minority and lower-income communities in the United States (Teodoro, 2020; Cardoso and Wichman, 2020). In Alabama, utility managers and policy makers have regularly used the 4.5% county MHI affordability metric as an excuse not to address water affordability concerns for households facing high water bills (Personal Interview with Mrs. Catherine Flowers, 2022).

In addition to the flaws in measuring water affordability, the root causes of water poverty also pertains to the way that water infrastructure is funded in the US. While water prices have risen by nearly 300%, federal and state-level funding for water systems has fallen by 75%. Today, US water infrastructure is funded through a variety of means, but the main funding sources that has faced the biggest cut in federal funding is the state revolving fund (Ramseur and Tiemann, 2019). Researchers have raised concerns that these funds are not equitably distributed to the utilities that need them the most. The lack of federal funding for water infrastructure has meant that water utilities, particularly in low-income and nonwhite communities, in Alabama face an unfunded mandate of complying with water treatment regulations. The cost of these repairs are often passed on to customers, many of whom are unable to afford their water expenditure (Cardoso and Wichman, 2020; Teodoro, 2020; Hansen et al., 2021).

Resulting from their water affordability challenges, low-income and nonwhite households often face adverse health effects due to a lack of access to clean water and sanitation. Most notably, residents in Lowndes County, one of the poorest counties and predominantly Black county in Alabama, regularly dump raw sewage in their own backyards because they are often unable to afford their high water and sewage bills (Flowers, 2021; Maxy-Brown, 2020). The resulting infiltration of raw sewage with the residents' drinking water system has led to a high infection rate of hookworm within the community (Rangnathan, 2021).

These impacts are exacerbated by the existing inequities of environmental racism and climate change. Black and brown communities throughout the United States and particularly in Alabama are more susceptible to climate-related hazards than predominantly white communities (Hardy et al., 2017). Alabama and the broader Southeast are under increased pressure to become resilient to climate change but often lack the funding to do so. The unequal distribution of economic, institutional, and political resources enables highly resourced individuals and groups to adapt more readily to changing climatic conditions than those who are less highly resourced (Thomas, Hardy, Lazrus, et al., 2019). In the U.S., structural racism and the inequities that result increase the vulnerability of non-white individuals to the effects of climate change.

Ultimately, low-income and nonwhite communities are often excluded from federal funding of water infrastructure, and the climate and health-related effects of water and sewer affordability in the United States. Given this historical significance of race as a predictor of water affordability and its outcomes, the ensuring examination of water affordability in Alabama shows the relationship between water expenditure and a variety of regional and demographic variables, and much of the analysis focuses how water affordability affects nonwhite households.

Chapter Three – Literature Review and Contribution

3.1. Chapter Introduction:

The water unaffordability crisis in the United States is driven by the cost of outdated water-treatment infrastructure being passed down particularly to consumers. Austerity-based policies on water-infrastructure financing have historically put disadvantaged and minority communities in a debt-cycle, leading these communities to pass down the cost of repairing outdated water-treatment infrastructure due to providers' compliance with non-funded federal mandates. Furthermore, climate change, along with the associated health impacts of inadequate access to clean and affordable water, only exacerbates the water unaffordability challenges in nonwhite communities. Water affordability literature documents the widespread nature of the affordability crisis, and its disproportionate impact on non-white communities. This literature also shows us the shortcomings and strengths of previous research methods and provides the primary methodology of calculating water affordability in Alabama.

3.2. Mack and Wrase (2017): Water Unaffordability as a Percentage of Median Household Income

In their 2017 study, Mack and Wrase published one of the first generalizable studies on water affordability. Mack and Wrase examined the characteristics of U.S. counties that make them "vulnerable" to unaffordable water bills. The authors define affordability using the affordability criteria set forth by the US EPA – that is water expenditures being more than 4.5% of median household income. The authors sought to convey the importance and urgency of the water affordability crisis to protect vulnerable populations from shutoffs, as low-income individuals will be more greatly impacted from even incremental increases in their water bills due to climate change and infrastructure updates. Assuming recent upward trends in water bills remains constant, the researchers estimated that over a third of American households could face unaffordable water bills, per EPA standards, by 2022.

Mack and Wrase (2017) compare the average annual water bill of a census tract to its MHI to assess affordability, and find that "at-risk" households, those whose tract's average water bill is greater than 4.5% of its MHI, are clustered in "pockets of water poverty" throughout the nation. They identify these "pockets" by computing which census tracts are facing "unaffordable" water bills, and modeling that such tracts are clustered together. The authors identify that disabled individuals, Black, and/or Hispanic households are more likely to experience unaffordable water bills. Mack and Wrase (2017) attribute the disproportionate impact these communities are facing to what they call "compounding economic factors," such as lower rates of health insurance coverage, and higher rates of unemployment relative to nondisabled and/or white households, as these factors negatively affect their ability to pay rising water bills. In addition to evidencing the disproportionate impact of water unaffordability on marginalized populations in the U.S., Mack and Wrase (2017) also highlight that non-essential water use, such as swimming pools and lawn watering, make it difficult to measure water affordability. They note that such water uses may inflate a household's water bill, deeming it "unaffordable," despite the family facing no economic burden to pay for their essential water use.

However, the researchers' utilization of median household income measures and the Environmental Protection Agency affordability threshold disguise important features of the affordability crisis and leave room for future research. The researchers calculate water affordability by examining if the average water bill of a census tract exceeds 4.5% of the tract's median household income. However, this measure does not account for the ability of low-income households to pay their water bills, and therefore their projections of future water unaffordability are likely underestimates. By utilizing only Alabama data, I hope to limit the challenge of measuring what may be non-essential water use, as climate, weather, and possibly even lifestyle factors that influence non-essential water use and, consequently, water bill costs, may vary less within a state as compared to nation-wide comparisons such as that which Mack and Wrase (2017) conducted. Additionally, my thesis will examine affordability in a more complete manner, as my regression analyses will examine the relationship between minority presence and water bill cost, rather than using the binary threshold of the EPA affordability measure that may underestimate unaffordability and does not accurately reflect the ability of low-income consumers to pay their water bill.

3.3. Cardoso & Wichman, 2020: Analyzing Water Affordability in the United States:

Cardoso and Wichman (2020) improve upon Mack and Wrase's (2017) model by noting the limitations of the EPA's affordability metric and by examining water affordability across the full income distribution of the county, rather than evaluating affordability at the 4.5% of the median household income threshold. They found that the number of households in a Census-block group "facing affordability concerns is positively associated with water and sewer prices, impoverished residents, and the proportion of Black residents, even after conditioning for poverty" (Cardoso and Wichman, 2020). These findings are particularly important given the methodological strengths of the paper, and Cardoso and Wichman's work provides a strong basis for my own methodology. The researchers' outcome variable was proportion of households paying more than 4.5% of their income, rather than MHI. They then applied this metric to sixteen different income distributions within Census block groups. This methodology enabled the authors to demonstrate affordability challenges that would not be captured by median income measurements. Although the researchers use 4.5% of a household’s income as an arbitrary measure of “affordable” water bills, they explicitly note that their work is not meant to prove nor disprove the efficacy of the EPA measure, and that their model could be applied to any threshold of household-level affordability. Improving upon Mack and Wrase’s (2017) methodology, Cardoso and Wichman (2020) examined affordability at the county level, and approximate rate structures. While Mack and Wrase (2017) conducted a nation-wide examination to draw attention to geographic aspects of the water affordability crisis, Cardoso and Wichman (2020) note that this survey did not account for “differences in water prices and consumption levels,” instead evaluating water prices and consumption at a constant rate across the nation. This study demonstrates the benefits of examining affordability using a full income distribution, rather than the EPA measure of affordability.

3.4. Summary and Literature Contributions

Black and brown communities bear the disproportionate burden of water unaffordability in the United States due to inequitable funding policies and climate and health impacts (Cardoso and Wichman, 2020; Jones and Armanios, 2020; Wright, 2018; Mack and Wrase, 2017; Mirosa, 2015; Carrera, 2014; Logan, 2014; Christian-Smith, Gleick, & Cooley, 2012; Logan and Stults, 2011; Foltz-Diaz, Kelleher-Calnan, and Moodliar, 2010; Carrera and Gasteyer, 2008; Baird, 2010; Gerlak, 2006; Pulido, 2000). Given the lack of federal protections against water shutoffs, minority populations are more vulnerable than their white counterparts to lose access to water (Gasteyer et. al, 2016; Mack and Wrase, 2017; Mirosa, 2015; Baird, 2010).

My thesis furthers previous water affordability literature by matching utility-level water and wastewater rate data with county-level sociodemographic data to examine the relationship between water expenditure and other variables in Alabama, particularly race and income. While studies on water affordability have focused on understanding the national landscape of water burden in the US, I closely follow the methodology in Cardoso and Wichman (2020) to conduct the first comprehensive study on water unaffordability in Alabama. Rather than limiting my analysis to established affordability metrics, such as the EPA 4.5% MHI metric, I examine the direct relationship between water expenditure and other explanatory variables, such as race and median income.

Chapter Four – Data and Methodology

4.1: Chapter Introduction:

This chapter details the quantitative methodology, the models, and the data utilized to examine the landscape of water affordability in Alabama. First, I list the sources from which I collect my data. Then, I describe my methodology and the explanatory, dependent, and control variables that I used for the county-level analysis. After the methodological section, I present the three models that I used to find the relationship between water expenditures and my explanatory variables in Alabama. Finally, I present a chapter summary in which I list and summarize the steps in my methodology.

I use pooled, cross-sectional data to conduct an observational study of water affordability. To protect against endogeneity, I control for county-level median income, population density, climate zone, year-effect, and other variables provided in **Table 4.3**. For this analysis, I construct three models to find the relationship between the explanatory variables and water, wastewater, and combined water and wastewater expenditure, respectively, within four different income nodes: poverty level, twice poverty level, three-times the poverty level, and four-times the poverty level. The dependent variables are water, wastewater, and combined water and wastewater expenditure, and their summary statistics being provided in **Figure 4.2a, Figure 4.2b,** and **Figure 4.2c**. The explanatory variables include the percentage of the Black and Latinx population within the primary county which the utility serves, an urbanicity indicator, median income, percent of rent relative to income, and other variables. The full list of the explanatory variables, its description, and summary statistics are provided in **Table 4.1** and **Table 4.2**, respectively.

4.2: Data Sources

I utilize data from Environmental Finance Center (EFC), American Community Survey (ACS), Economic Research Service (ERS), the International Energy Conservation Code (IECC) Climate Zone Map, and the Safe Drinking Water Information System (SDWIS).

4.2.1. Environmental Finance Center

The Environmental Finance Center is a program within the University of North Carolina at Chapel Hill. The group conducts a variety of projects, such as promoting efficient management of drinking and wastewater by partnering with utilities across the nation and designing energy finance systems to promote clean energy (EFC, 2021b). Each year, the EFC collects rate and customer data by conducting a survey of water and wastewater utilities in select states throughout the country. I utilize the Alabama-specific data that is available for download on the EFC website. For each water utility within the dataset, I collect data on water and wastewater charges at different consumption levels (3000 gallons per month (gpm), 4000 gpm, 5000 gpm, 7000 gpm, 10000 gpm, and 15000 gpm) and the base-charge for the water and wastewater service. Here the base-charge is a flat fee for consuming some base amount of water and wastewater; for the purposes of this study, I assume that the base-charge is for 0 gallons per month of consumption. This dataset also contains information on the number of accounts served, the total population served by the utility, and the county that the utility predominantly serves. The EFC has Alabama-specific water and wastewater rate data dating for the years 2014, 2016, and 2019. Over these years, the number of respondents remain constant, and I limit my analysis to these three time periods and assume that any changes in water rates between the data collection years is reflected in these datasets.

4.2.2. American Community Survey (ACS)

The American Community Survey (ACS) is an ongoing survey conducted by the US Census Bureau. It is sent to a smaller sample of the American population than the Census, and collects data not captured by the Census, such as employment, transportation access, and education (U.S. Census Bureau, 2020). From the ACS, I collect the following variables for each county in Alabama: percent of the total county population that identifies as Black, percent of the total county population that identifies as Latinx, median age of a household within the county, the land-area and population of the county, the percentage of gross rent relative to income, percentage of rented units relative to occupied, and average household size within the county. Although the ACS does not list counties' population breakdowns by racial and/or ethnic groups, the survey does collect data on the number of residents that are Black or Latinx, as well as the county's total population. I use the ACS database to collect this data for the 2014, 2016, and 2019.

4.2.3. Economic Research Service (ERS)

The ERS is a division of the U.S. Department of Agriculture. It conducts research that aims to inform public and private decision makers about issues related to food, agriculture, and the environment (ERS, 2019). Their Rural-Urban Continuum Codes were developed in 1974 to classify counties across the nation as metropolitan or non-metropolitan for this research (ERS, 2020). These codes classify "urban" counties by the size of the county's metropolitan area, and "rural" counties by the county's degree of urbanization and adjacency to a metropolitan area. These metro/non-metro categories are then further divided into three "metro" and six "non-metro" categories (ERS, 2020). "Metro" counties in categories 1-3 are those in metro areas with a population of less than 250,000 people to 1 million or more. Nonmetropolitan counties include those that are adjacent and non-adjacent to metro areas, and have urban population of 2,500 to 20,000 or more, or are completely rural with an urban population of less than 2,500. I utilized the ERS's 2013 data, the most recent dataset available.

4.2.4. International Energy Conservation Code Climate Zone Map

The International Energy Conservation Code (IECC) is a model code that regulates building heating, cooling, and water supply requirements. The IECC database divides the United States into seven different zones (1-7) and two different moisture regions (A and B). Water rates vary by climate zones (Dyer, 2016; Cardoso and Wichman, 2017). I collected the climate zone data for each county in Alabama, which are placed into either of the two climate zones: 3A or 2A.

4.2.5. Safe Drinking Water Information System (SDWIS)

The SDWIS tracks information on drinking water contamination levels and drinking water violations as required by the 1974 Safe Drinking Water Act for every utility and service provider within the United States. The Safe Drinking Water Act (SDWA) and accompanying regulations establish Maximum Contaminant Levels (MCLs), treatment techniques, and monitoring and reporting requirements to ensure that water provided to customers is safe for human consumption.

4.3. Methodology:

4.3.1 Combining Datasets

For this county-level analysis of water and wastewater affordability in Alabama, I followed the methodology discussed by Cardoso and Wichman (2020). My first step was to combine the 2014, 2016, and 2019 data sets and to create three year-effect dummy variables: ye_2014 (1 if the data point is taken from the 2014 dataset and 0 if not); ye_2016 (1 if the data was taken from the 2016 dataset, 0 if not); ye_2019 (1 if the data point is taken from the 2014 dataset and 0 if not). The EFC data provided information on the county that is “primarily” served by the water utility. Typically, water utilities serve more than one county, and more than one water utility can also serve within a single county. Because the EFC data indicated which county was primarily served by each water utility, I was able to match the county-specific demographic data that I compiled from ACS, along with the urbanicity indicator and the climate zone, for each of the primary counties.

4.3.2. Calculating the County-Level Weighted-Average of the Rates and Consumption

After I combined the datasets, I converted the utility-level dataset into a county-level dataset and found the consumption for each utility. The EFC dataset presented the total bills at different consumption levels: 3000-15000 gallons per month. First, I linearly interpolated to find the total bills at 5 ccf (3740 gallons), 10 ccf (7480 gallons), and 15 ccf (12500 gallons) for both water and wastewater. This was done to find the “rate05c” and “rate10c” in **Equation 4.1**. Then, I took the weighted average of these bills for each utility in a county based on the number of accounts that each utility had within each county. Next, to find the “basecharge” variable in **Equation 4.1**, I first calculated a weighted marginal rate for water between the water base charge and the water total bill for the 5 ccf consumption level, and I repeated the same process to find the sewer base rate (defined as the weighted marginal rate between the sewer base charge and the sewer bill at 5 ccf of consumption). Then, I found the “rate05c” and “rate10c” variables. “Rate05c” is defined as the weighted marginal rate between the combined water and wastewater charge at 5 ccf and 10 ccf. Similarly, “rate10c” is the weighted marginal rate between the water or wastewater weighted charge at 10 ccf and 15 ccf.

After this step, I calculated the average individual daily consumption (w_c) for each utility in Alabama based on Equation 4.1, which was provided by Cardoso and Wichman (2020). In Equation 4.1, med_inc represents the median income of each county in Alabama for 2014, 2016, and 2019. The variable "popc" represents the total population of each county in Alabama for 2014, 2016, and 2019.

Equation 4.1: $$\boldsymbol{log(w_c) = \alpha_0 + \alpha_1 \log(med\_inc) + \alpha_2 \log(popc) - \alpha_3 * baserate - \alpha_4 \log(rate5c) + \alpha_5 \log(rate10c) - \alpha_6 CZ2a + \alpha_7 CZ3a}$$

Cardoso and Wichman (2020) combine water utility rate data from the American Water Works Association (AWWA) and the Environmental Finance Center.[2] The rates within the AWWA dataset were provided at different consumption levels: 0, 5, 10, 15, and 30 ccf (cubic hundred feet) per month. However, for the EFC data, the total charges are provided at levels from 0 to 15000 gallons per month. Therefore, Cardoso and Wichman (2020) linearly regressed the AWWA rates against the EFC rates and used Equation 4.1 to predict the consumption within the EFC data.[3] The values for α in Equation 4.1 were provided to me by Professor Casey Wichman and are listed in **Table D.1** in **Appendix D**.

Before I could predict the average individual consumption for every utility, I created two dummy variables: cz2a (1 if the county was located within the Climate Zone 2A and 0 if not); and cz3a (1 if the county was located within the climate zone 3A and 0 if not). Then, I calculated the values for rate5c and rate10cn. In order to calculate the values for rate5c and rate10c, I first linearly

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[2] The initial plan for me was also utilize a combination of AWWA data, which was provided to Dr. Matthew Interis, and EFC data. However, because the AWWA data listed a very small sample size for Alabama, I quickly abandoned this plan.

[3] Equation 4.1 is listed as Model S5 in Cardoso and Wichman (2020).

interpolated the total water and sewer bills for 3740 gallons (5 ccf), 7480 gallons (10ccf), and 12500 gallons (15 ccf). Then, I used a loop-code in R to take the weighted average of all the water rates and sewer rates for all utilities within a county based on the number of the accounts that the utility had within each county. I finally calculate the rate10c and rate5c as the per ccf marginal rates between the total water and wastewater bills at 10 ccf and 5 ccf and between 15 ccf and 10 ccf respectively. After calculating the accurate rate5c and rate10c variables for both water and wastewater, I found the w_c, the average water consumption within a county in Alabama. I assumed that all water that came into the house also went out through the home's wastewater system. Thereby, I assumed that the wastewater consumption for an average individual in each county was equal to the individual's water consumption (w_c). While this is likely not true for many households, this step was done because I did not have the exact estimate of a household's wastewater usage in Alabama.

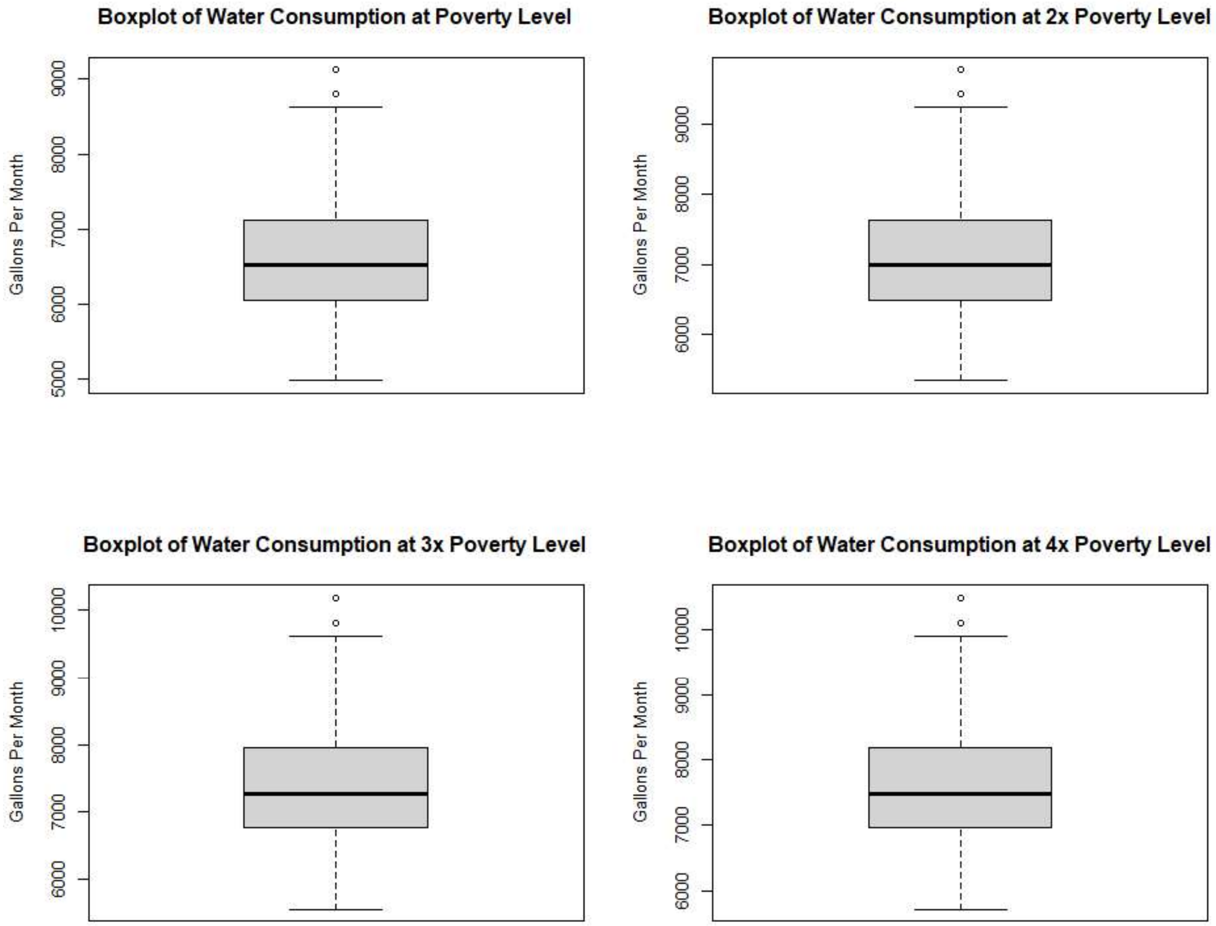
4.3.3. Calculating Consumption Based on Income

After predicting the average individual consumption for each county in Alabama using equation 4.1, I followed Cardoso and Wichman's (2020) assumption that an individual's water demand is dependent on their income, and researchers have found the income elasticity of water consumption to be somewhere between 0.1 and 0.7 (Havranek et al., 2018; Allen et al., 2014). Adjusting consumption based on income allows me to control for any exogenous impacts that income may have on water expenditure in Alabama. Flowing the methodology in Cardoso and Wichman (2020), I use Equation 4.2 to calculate the consumption based on the following income nodes: poverty level, twice-poverty level, three times poverty level, and four-times poverty level. In Equation 4.2, w_{ci} is the individual daily consumption for each county; and y_{ci} is the income at the chosen income node. ϵ is the income elasticity of water consumption, assumed to be 0.1. w_{ch} is represented as the average monthly household water consumption as a function h_{ci}, the average household size within each county.

$$\textbf{Equation 4.2: } \boldsymbol{w_{ch} = 30w_c\left(\frac{y_{ci}}{med\_inc}\right)^{\epsilon} h_{ci}}$$

I calculated the specific income value for each income node in each county by first finding the poverty-level income for each county based on average household size (See **Appendix E**). Then, I used **Equation 4.2** to calculate the average monthly household consumption for each of the three income nodes for each county. The descriptive statistics of the consumption at each of the income node are given in **Figures 4.1, 4.2, and 4.3.**

Figure 4.1: Descriptive Statistics of Consumption at Poverty, 2x, 3x, and 4x poverty levels.



4.4 Dependent Variable: Calculating Expenditure Based on Income-Specific Consumption

After calculating the monthly household water – by extension, wastewater – consumption, I calculated the monthly water, wastewater, and combined water and wastewater expenditure for each of the four income nodes. To calculate the monthly water expenditure for each of the three income nodes, I assumed that most utilities in Alabama followed an increasing block-rate structure for their water and wastewater rates. According to the EFC data, more than 80% of the utilities in Alabama, including the ten largest utilities, used an increasing block rate structure. I calculated the total water, wastewater, and combined water and wastewater bills at different income-specific consumption levels by linearly interpolating between the corresponding county-average water and wastewater charges presented in the EFC data (0, 3000, 4000, 5000, 7000, 10000, and 15000 gallons per month consumption levels). The descriptive statistics of the water, wastewater, and the combined water and wastewater expenditure at the poverty-level income node are provided in **Figure 4.2a, b, and c.**

Figure 4.2a: Water Expenditure at Poverty, 2x, 3x, and 4x Poverty Levels

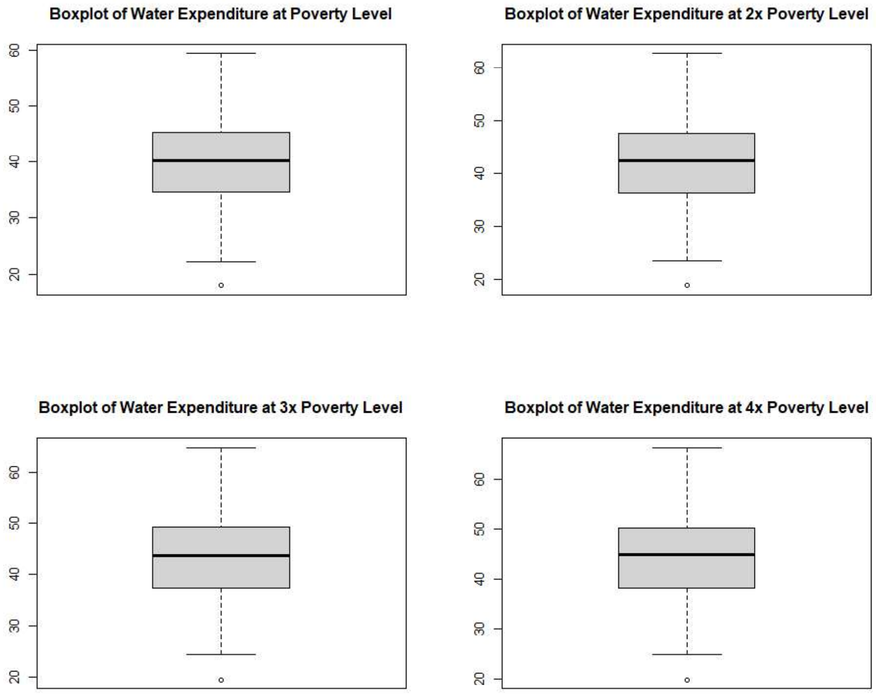


Figure 4.2b: Expenditure of Sewer Expenditure at Poverty, 2x, 3x, and 4x Poverty Levels

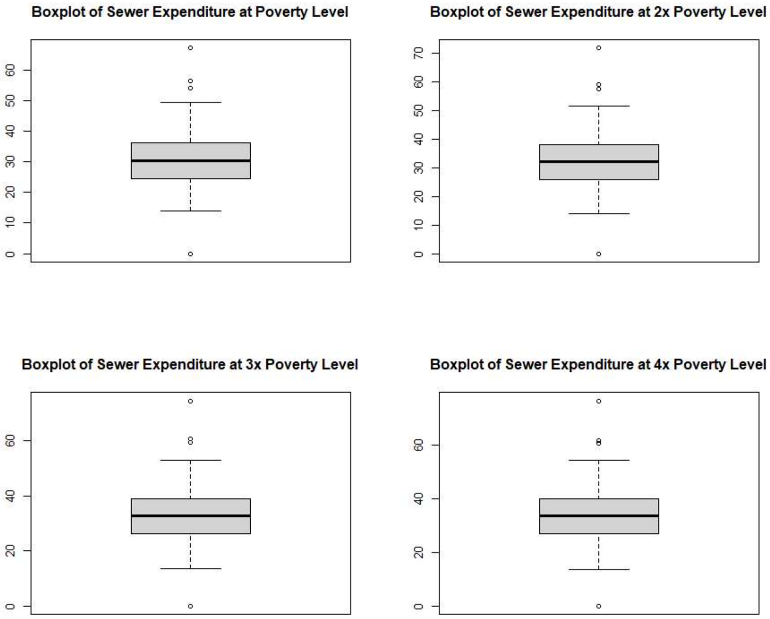
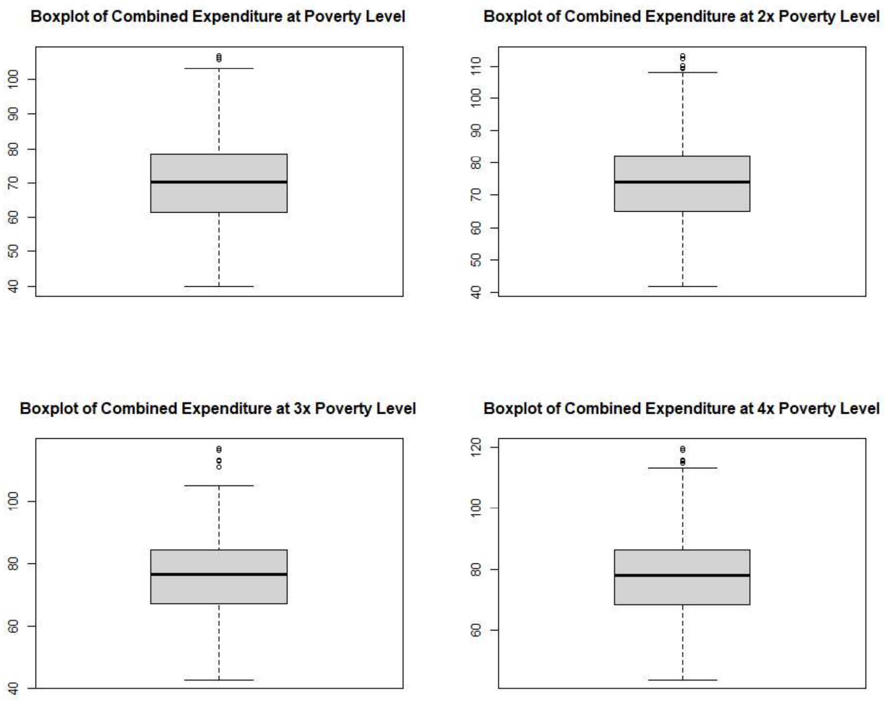


Figure 4.2c: Combined Expenditure at Poverty, 2x, 3x, and 4x Poverty Levels



At the different income nodes (poverty level, 2x poverty level, 3x poverty level, and 4x poverty level), the mean value of water expenditure is between \$40 and \$50. At the different income nodes, the mean value of wastewater bills is \$25 and \$40, and the combined water and wastewater mean expenditure is \$65 and \$90.

4.4: Model Presentation

I used ordinary least squares (OLS) regression to find the relationship between water, wastewater, and combined water and wastewater expenditure and explanatory variables such as race and income. Below, I present the models that I constructed for my OLS regression. The dependent variables in my model below are Y_{ci}, the expenditure for the income node, i (poverty level, 2x poverty level, 3x poverty level, and 4x poverty level). This model was estimated separately for each of three different dependent variables: water expenditure, wastewater expenditure, and combined water/wastewater expenditure. The explanatory variables are described in the succeeding sections.

Model: $Y_c = \beta_o + \beta_1(perblack_c) + \beta_2(perlatin_c) + \beta_3(UrbanIndicator_c) + \beta_4(YearEffect_{ct}) + \beta_5 \log(PopDen_c) + \beta_6(perRentInc_c) + \beta_7(WaterBaseCharge_c) + \beta_8(perRent_c) + \beta_9(MedInc) + \beta_{10}(MedAge_c) + \beta_{11}(violations) + \beta_{12}(PovHouse) + \beta_{13}(Pov2xHouse) + \beta_{14}(med\_inc) + \beta_{16}(yeareffect_{2014}) + \beta_{17}(yeareffect_{2016}) + \beta_{18}(cz2a) + \beta_{19}(cz3a)$

4.5. Explanatory Variables

The following table shows the explanatory variables used in the linear regression models above.

Table 4.1 – Description and Source of Explanatory Variable Data

Description and Source of Data		
Variable	Description	Source
$perblack_c$ (%)	The percentage of people who identify as Black in every county, c, in Alabama.	American Community Survey
$perlatin_c$ (%)	The percentage of people who identify as Latinx in every county, c, in Alabama.	American Community Survey
$UrbanIndicator_c$	Designated as 1 if the ERS score is less than 2, 0 if not.	Economic Research Service
$PopDen_c$ (Number of People per square mile)	The population density within each county, c, in Alabama.	American Community Survey
$BaseCharge_c$ ($)	The weighted average base charge rate for water, wastewater, and combined scenarios.	Environmental Finance Center
$PerRentInc_c$ (%)	Average household gross rent as a percentage of median household income.	American Community Survey
$PerRent_c$ (%)	Percentage of households in a county that are rented.	American Community Survey
$violations_c$	The total number of drinking water violations in a county in 2014, 2016, and 2019.	Safe Drinking Water Information System
$PovHouse_c$ (%)	Percentage of homes at or below the poverty level for the county, c	American Community Survey
$Pov2xHouse$ (%)	Percentage of homes at or below 2x the poverty level for a county, c	American Community Survey
$medage$ (years)	The median age of the house in a county	American Community Survey
med_inc ($)	The median income of the county	American Community Survey
Year Effect (2014, 2016, & 2019))	Year effect dummy variable for 2014, 2016, and 2019	Environmental Finance Center

Climate Zone (2a and 3a)	Climate zone dummy variable for zones 2A and 3A	International Energy Conservation Code Map

I chose to use these variables as the explanatory variables because Cardoso and Wichman (2020) and Mack and Wrase (2017) had used similar variables in their regression analyses and because they would sufficiently explain how water affordability might affect households in Alabama. To examine how water affordability affects different racial minorities, I decided to use the percentage of the county population that identifies as Black and the percentage of the county population that identifies as Latinx. While it is true that other nonwhite groups also experience water affordability challenges, I decided to focus particularly on these two groups because they are more likely than other nonwhite minorities to face environmental and climate racism (Brown, 2019; Mack and Wrase, 2017; Christian Smith, Gleick, & Cooley, 2012). In addition, of particular note in my work is $UrbanIndicator_c$, the variable that indicates whether a county is considered to be rural or urban. Because I was interested in whether rurality affected water affordability, I wanted to include this variable into my model. Because the Alabama Department of Environmental Management considers any county with an ERS code of above 2 to be rural, I used the ERS database to create the urban indicator variable by creating the dummy variable $UrbanIndicator_c$, which equals 1 if the ERS code is 2 or below and 0 if it is above 2. In other words, rural counties are coded with the $UrbanIndicator_c$ being 0, and urban counties are coded with the $UrbanIndicator_c$ being 1.

4.5.1 Descriptive Statistics of Independent Variables

This table shows the descriptive statistics of the explanatory variables. Here, n is three times the number of counties in Alabama because there are three years of data – 2014, 2016, and 2019.

Table 4.2 – Descriptive Statistics of Explanatory Variables

County-Level Analysis – Descriptive Statistics of Explanatory Variables

	n	Mean	Min	Median	Max
$perblack_c$	202	28.07	0.41	23.07	83.17
$perlatin_c$	202	3.37	0.03	2.50	17.16
$UrbanIndicator_c$	202	0.5941	0	1	1
$PopDen_c$	202	72.80	4.20	37.858	593.01
$BaseCharge_c$	202	32.42	27.11	32.43	53.90
$PerRentInc_c$	202	17.04	9.64	16.64	29.82
$PerRent_c$	202	24.60	12.63	24.50	41.80
$violations_c$	202	125	9.0	94	810
$PovHouse_c$	202	27.68	6.80	29.83	50.04
$Pov2xHouse$	202	55.74	25.05	60.08	88.07
$medage$	202	45	3	48	125

Of particular note, the mean value of percentage black population within a county is 28.07%; the mean value for the percentage Latinx population Is 3.37%.

4.6. Control Variables

Median Household Income:

I control for the median household income (in US Dollars) for each county for the associated years between 2014-2019. Median income can be correlated with other explanatory variables, such as race, housing characteristics, etc, and median income by itself can be related to expenditure at different income nodes. Therefore, to protect against any cases of such endogeneity, I incorporated median income into my model, even though this measure does not demonstrate the water affordability challenges faced by households in Alabama. Higher county MHIs may be associated with increased water use and consequent increases to household water and wastewater bills. Higher county MHIs may also be correlated with higher-quality infrastructure that is in less need of repair than a lower-income county, lowering the average residential water and/or wastewater bill.

Year-Effect

Additionally, my models also control for year fixed effects. Because the rates and the number of respondents change between year to year within the EFC dataset, I included two year-fixed effect dummy variable to ensure that change across years is captured within my model. These year-fixed effect variables were for years 2014 and 2016.

Climate Zone

Water access and affordability depends on climate zone (Dyer, 2016; Cardoso and Wichman, 2017). To rule out any possibilities of water use, and thus expenditure, varying strictly due to variations within climate zones, I included two dummy variables cz2a (1 if the county is located in the climate zone 2A, and 0 if not) and cz3a (1 if the county is located in the climate zone 3A, and 0 if not).

Population Density

Finally, I also control for population density (persons per square mile) in my models. It is possible that the water and wastewater prices in a county depends on how many people live in a certain area within the county. For instance, a rural county might experience different water and wastewater prices due to due a sparse population density and water utilities having to distribute water over longer distances. Conversely, urban counties are more likely to have higher population densities and might experience different water and wastewater prices than rural counties. The correlation between urbanicity and population density might introduce some endogeneity to this model. To control for this endogeneity, I included the population density within my model.

4.6.1. Descriptive Statistics of Control Variables

Table 4.3 gives the descriptive statistics of each of my control variables except for year-effect and climate zone. The descriptive statistics for each of the year-effect variables and climate zones are not included due to them being dummy variables.

Table 4.3 – Descriptive Statistics of Control Variables

	n	**Mean**	**Min**	**Median**	**Max**
Population Density	202	72.796	4.204	37.858	593.096
Median Income	202	$46,087	$22,170	$44,736	$95,848

4.7. Limitations of Data and Methodology:

There are limitations to my data and methodology. First, the EFC data is an unbalanced pool since the number of utility providers across 2014, 2016, and 2019 vary between 482 and 575 utility providers. Not all utilities participate in EFC's survey, and if there are systematic differences between those which participated and those that did not, these differences may bias my results. For instance, if factors such as lack of training and capacity led to non- participation, these providers may vary systematically from other providers in the sample in size, age, or other relevant features that affect the provider's ability to deliver affordable water services to their consumers. Finally, many utilities in Alabama have service areas that span both inter-and-intra county lines. While the EFC data for Alabama listed the "majority-county" served, it is possible that my county-level analysis excludes some of the water affordability challenges faced within counties themselves.

4.6. Chapter Summary and Methodological Steps:

I pool data from five different sources: the Environmental Finance Center, the Economic Research Services Database, American Community Survey, International Energy Conservation Code Climate Zone Maps, and the Safe Drinking Water Information System.

Methodological Steps

1. Pool county-level and utility level data using the data sources listed above.
2. Interpolate rates at 5, 10, and 15 ccfs.
3. Take the weighted average of water and wastewater charges based on the number of water and wastewater accounts within a county.

4. Find the marginal rates for 5 and 10 ccf consumption for water, wastewater, and combined water and wastewater consumption.
5. Find the water consumption based on **Equation 4.1** and assume a 1:1 ratio between water and wastewater consumption.
6. Calculate different income nodes based poverty-level income, which is calculated based on the average household size of a county.
7. Calculate water consumption based on different income nodes using **Equation 4.2** and **Equation 4.2a**.
8. Calculate water, wastewater, and combined water and wastewater expenditures for different income nodes.
9. Use Models 1, 2, and 3 to find the relationship between water, wastewater, and combined water and wastewater expenditures and my explanatory and control variables.

Chapter Five – Results and Discussion

The goal of this chapter is to present the results of my OLS regression to explain the relationship between water, wastewater, and combined water & wastewater expenditure and my explanatory variables. Section 5.1 and Table 5.1 details the coefficients, robust standard errors, and p-values for my OLS regression models for 1x and 2x poverty income levels. The OLS regression results for 3x and 4x poverty income levels and the OLS regression results for all the year-effect values are included in **Tables A.1 and A.2**, respectively. Then, in section 5.1.1, I check whether assumptions for OLS regression model hold true to ensure the validity of my models. Finally, I conclude this chapter with a discussion of my results and the broader policy context of water and wastewater affordability in Alabama.

Section 5.1: Checking the Assumption of OLS Regression

There are five main assumptions for ordinary least squares regression. These assumptions are fulfilled by examining the plots generated in **Figures B.1.1** to **Figures B.4.3** in **Appendix B** and in **Figures C.1.1** to **Figures C.4.3** in **Appendix C**. First, the dependent variable (in this case, water, wastewater, and combined water & wastewater expenditure at different income nodes) must be a linear function of all the explanatory variables and the error term (Stock and Watson, 2017). I examined this relationship by plotting the residuals of my model against the fitted values, as shown in the top left panel within the figures mentioned above. The linearity assumption held for the model with water expenditure as the dependent variable and model with combined expenditure as the dependent variable for all income levels as the residuals were evenly spread for both models. However, for the model with wastewater expenditure as the dependent variable, the linearity assumption seemed to be slightly off as the residuals followed a curved pattern.

The second assumption for OLS regression is that all samples for the explanatory variables must be randomly collected, and thus, the residuals of the model must follow a random distribution (Stock and Watson, 2017). This second assumption is fulfilled by examining the Q-Q plot, as shown in the top right panel of **Figures B.1.1** to **Figures B.4.3** in **Appendix B** and in **Figures C.1.1** to **Figures C.4.3** in **Appendix C**. The normality assumption for all three of the models at all four of the income levels is fulfilled since the residuals in the Q-Q plot mostly follow a straight line pattern, indicating a normal distribution.

The third assumption I checked for was the homoscedasticity of the residuals. This means that all error/residual terms for the OLS regression must have the same variance (Stock and Watson, 2017). This assumption can be checked by examining the Scaled Location and Residuals vs. Fitted plots, as shown in the bottom half of **Figures B.1.1** to **Figures B.4.3** in **Appendix B** and in **Figures C.1.1** to **Figures C.4.3** in **Appendix C**. Since the residuals in both lines are relatively horizontal, the homoscedasticity assumption held for all three of the models at the four income nodes.

The fourth assumption for OLS regression is to have little or no multicollinearity between the explanatory variables within the dataset. To check for this assumption, I created a correlation matrix, as shown in **Table 5.2** between all the different explanatory variables. The correlation between the different variables remained close to 0 (between -0.5 and 0.5), except for the correlation between median income and the number of percentage of households at 1x and 2x poverty levels. The correlation factor between these two variables and median income was -0.75 and -0.86. However, this result was to be expected since the percentage of households at 1x and 2x poverty level should go *down* as the median income increases.

Figure 5.2: Correlation Matrix for all Explanatory Variables

	MedInc	PerRent	PerBlack	PerLatin	PerRentInc	UrbanIndicator	violations	BaseCharge	MedAge	PovHouse	PovHouse2x	PopDen
MedInc	1.00	0.02	-0.40	0.27	-0.68	-0.50	0.20	0.13	0.58	-0.86	-0.75	0.27
PerRent	0.02	1.00	0.30	0.02	0.22	-0.09	0.03	-0.17	0.34	-0.20	-0.29	0.03
PerBlack	-0.40	0.30	1.00	-0.48	0.47	0.37	-0.11	-0.07	-0.03	0.16	-0.02	-0.12
PerLatin	0.27	0.02	-0.48	1.00	-0.21	-0.39	0.08	-0.18	0.08	-0.16	-0.05	0.20
PerRentInc	-0.68	0.22	0.47	-0.21	1.00	0.10	0.07	-0.16	-0.57	0.68	0.58	0.09
UrbanIndicator	-0.50	-0.09	0.37	-0.39	0.10	1.00	-0.27	-0.01	0.00	0.29	0.17	-0.61
violations	0.20	0.03	-0.11	0.08	0.07	-0.27	1.00	0.01	-0.02	-0.15	-0.12	0.18
BaseCharge	0.13	-0.17	-0.07	-0.18	-0.16	-0.01	0.01	1.00	0.18	-0.14	-0.12	-0.17
MedAge	0.58	0.34	-0.03	0.08	-0.57	0.00	-0.02	0.18	1.00	-0.82	-0.86	-0.29
PovHouse	-0.86	-0.20	0.16	-0.16	0.68	0.29	-0.15	-0.14	-0.82	1.00	0.96	-0.05
PovHouse2x	-0.75	-0.29	-0.02	-0.05	0.58	0.17	-0.12	-0.12	-0.86	0.96	1.00	0.04
PopDen	0.27	0.03	-0.12	0.20	0.09	-0.61	0.18	-0.17	-0.29	-0.05	0.04	1.00

The fifth and final assumption for OLS regression is that the residuals must be independent of one another – i.e. no autocorrelation (Stock and Watson, 2017). Autocorrelation is especially prevalent in datasets that have a time component to it. Therefore, I plotted the ACF vs LAG, as shown in **Figures C.1.1 to C.4.3**. The ACF is the autocorrelation function between expenditures in each time period, and the LAG is the time gap being considered here (2014, 2016, and 2019). I found that the spread of LAG vs. ACF distribution was evenly distributed for water and combined water and wastewater model at all income nodes. However, for wastewater expenditure model, there seemed to be some autocorrelation in the wastewater regression results, and this may affect the robustness of my conclusions.

5.2: Discussion of Results

To simplify the discussion, I split this section into four categories and its relationship to water/wastewater expenditure: race, income, urbanicity, and environmental and housing characteristics. The discussion within this section refers to **Tables 5.1** in **Section 5.1**, and **Table A.1** in **Appendix A.**

Table 5.1: Regression Results for Models 1, 2, and 3 at 1 and 2x Poverty Levels

	Poverty-level			2x Poverty-Level		
	Model 1: Water	Model 2: Wastewater	Model 3: Combined	Model 1: Water	Model 2: Wastewater	Model 3: Combined
Constant	0.4352***	3.36***	46.88**	0.452***	3.82**	0.482***
	(0.171)	(0.207)	(0.152)	(0.132)	(0.122)	(0.161)
$perblack_c$	-0.312	-0.0232	0.122*	-0.026	-0.024	-5.88
	(0.0033)	(0.0399)	(0.0521)	(0.034)	(0.042)	(4.531)
$perlatin_c$	0.635***	0.486***	1.121***	0.605***	0.513**	1.171***
	(0.176)	(0.213)	(0.228)	(0.182)	(0.225)	(2.418)
$UrbanIndicar_c$	-0.188**	-0.169**	-2.05**	-2.01**	-0.208	-2.200**
	(1.774)	(0.149)	(0.230)	(1.821)	(2.27)	(2.44)
Log($PopDen_c$)	-0.204**	-3.088	-1.766**	-2.00**	4.105**	2.014***
	(1.171)	(1.418)	(0.518)	(1.04)	(1.503)	(1.510)
$perRentInc_c$	0.0822	0.202	0.284	-0.1057	0.252	0.320
	(0.255)	(0.309)	(0.285)	(0.12242)	(0.327)	(0.341)
$BaseCharge_c$	0.553***	0.673*	1.22**	0.555***	0.690**	1.27***
	(0.0069)	(0.081)	(0.086)	(0.069)	(0.085)	(9.2e-02)
$perRent_c$	-0.215**	-0.067	-0.282	-0.885	-0.003	(-0.822)
	(0.122)	(0.148)	(0.332)	(0.157)	(0.157)	1.64e-01
$MedInc_c$	0.00321	-0.0013	0.0012	-0.0067	-0.0068	-5.1e-02
	(1.7e-3)	(1.0e-4)	(1.6e-2)	(0.033)	(0.210)	(2.2e-01)
$MedAge_c$	0.0653***	0.0029	-0.0036	0.0320	0.003	-3.7e-03
	(3.98e-3)	(4.0e-3)	(0.475)	(5.5e-4)	(5.0e-3)	(5.5e-03)
$violations_c$	-0.073***	-0.034	-0.028	-0. 0330*	-0.0033	-0.153***
	(3.73e-3)	(5.0e-2)	(5.5e-3)	(0.023)	(5.0e-3)	(5.1e-03)
$PovHouse_c$	0.183	-0.283	0.216*	-0.325	-0.073	-1.8e-01
	(0.1641)	(0.293)	(0.175)	(4.8e-2)	(0.314)	(3.8e-01)
$Pov2xHouse$	0.00395	-0.0234	0.0083	-0.0059	-0.0001	-1.6e-04
	(0.243)	(0.198)	(0.112)	(0.0131)	(1.3e-4)	(1.3e-04)
$YearEffect\_2014$	-4.909	-2.095	-2.54	-4.832	-2.123	-2.459
	(4.621)	(6.98)	(8.85)	(4.621)	(6.98)	(8.85)
$YearEffect\_2016$	-4.875	-1.371	-4.55	-4.445	-1.876	-4.559
	(4.585)	(6.93)	(8.78)	(4.585)	(6.93)	(8.78)

Robust standard errors are provided in parenthesis

"***" p-value < 0.01, "**" p-value < 0.05, " " p-value > 0.05

Table 5.1 Continued: Regression Results for Models 1, 2, and 3 at 1 and 2x Poverty Levels

cz2a	-7.423	-4.332	-8.74	-4.832	-7.234	-1.459
	(4.621)	(6.98)	(8.85)	(4.621)	(6.98)	(8.85)
cz3a	-4.104	-2.095	-2.847	-4.082	-2.358	-2.974
	(4.621)	(6.98)	(8.85)	(4.621)	(6.98)	(8.85)
Adjusted R-Squared	0.448	0.423	0.629	0.448	0.41	0.627

Robust standard errors are provided in parenthesis
"***" p-value < 0.01, "**" p-value < 0.05, " " p-value > 0.05
See **Appendix A.1** for OLS Results for 3x and 4x Poverty Income Levels

5.2.1: Effect of Race on Water Affordability

Two of the most interesting explanatory variables within my models were "perblack" and "perlatin". All the models showed that the effect of the percentage of Black population on the county's household water expenditure was statistically insignificant for all income levels, except for Model 3 at the poverty income level. This model, which examined the relationship between combined water/wastewater expenditure and my explanatory variables, showed that – holding all else constant – a one percent increase in the county's Black population leads to a 12-cent increase in combined water/wastewater expenditure at the 5% significance level.

The effect of race on water expenditures in Alabama for the Latinx population showed much different results. The results for all three models at all three income nodes were statistically significant at the 5% significance level. At the poverty level, a one percentage point increase in the Latinx population across counties would result in a 60 cent increase in water expenditure; a 49 cent increase in wastewater expenditure; and a $1.21 increase in combined water/wastewater expenditure, holding all else constant. For all other income nodes, an increase in the Latinx population showed an increase in water expenditure to a similar order of magnitude as the poverty-level consumption; the values of the other income nodes are presented in **Table 5.1** and **Table A.1.** My findings on the water affordability crisis affecting the Latinx population in Alabama is especially significant as it parallels the findings from Cardoso and Wichman (2020). For the

Southeastern United States, they find that a one-percent increase in the Latinx population leads to a 0.18 cent increase in water prices. The results found by Cardoso and Wichman (2020) were lower than mine, but this could be explained by the fact that their analysis is at the national and regional levels, and mine is at a more granular, state level.

5.2.2: Effect of Income and Rates on Water Affordability

I also use my three models to find the relationship between expenditure and median income and between expenditure and water rates, specifically the water base charge. All three models at all four income nodes showed that median income had virtually no effect on water expenditure. Furthermore, the effect of median income on water expenditure was statistically insignificant. This could be because median income might not have any effect on water expenditure and affordability. However, a much more reasonable assumption and explanation is I already controlled for the median income when adjusting consumption based on income, and that is replicated in the results of my model.

On the other hand, the effect of the basecharge, the amount charged for some base consumption of water, had a statistically significant impact on the water/wastewater expenditure for all three models at all three income nodes. For all the income nodes, an increase in the base charge led to an increase in the water expenditure. The values for the other income nodes are presented in **Table 5.1** and **Table A.1.** This result follows logic since a higher base charge would lead to a higher expenditure, regardless of the household consumption. Ultimately, both of these results were expected not only due to the very low income elasticity of water demand, but also by the very nature of the base charge.

5.2.3: Effect of Urbanicity on Water Affordability

Both the population density and urban indicator variable gave statistically significant results, except for sewer expenditure at the poverty level. Furthermore, both variables highlighted that a higher density, or more urban area, faced a lower water expenditure and water burden than rural areas. For instance, a 1% increase in population density leads to a $1.76 decrease in water expenditure, holding all else constant. By the same token, poverty-level households in an urban county, with an UrbanIndicator value of 1, faces a combined water/wastewater expenditure that is almost $2 less than rural counties, holding all else constant. Urban centers tend to be located closer together, and utilities serving urban counties might be able to take advantage of economies of scale more thoroughly compared to rural counties. While it may cost more to provide water to rural communities, my thesis works within the foundational framework that access to affordable and clean water is a human right. Furthermore, this finding follows previous Alabama-specific literature that showcases case studies of certain rural communities facing a higher water affordability burden than urban areas (Flowers, 2020; Maxcy-Brown, 2020).

5.2.4: Effect of Environmental Violation and Housing Characteristics on Water Affordability

Finally, my three models test for the relationship between expenditure and different housing characteristics, such as percentage of gross rent relative to income and median age of home. The effect of housing characteristics on expenditure were varied across different models and income nodes. These results are summarized in **Table 5.1** and **Table A.1**. Of particular note is the effect that the percentage of rented units within a county had on water expenditure in Model 1 of the poverty-level income node. In this level, a 1% increase in rented units resulted in a 20 cent decrease in water expenditure for households at the poverty-line.

However, the effect that environmental violations had on expenditure was statistically significant for Model 1 in the poverty-level income node and Models 1 and 3 within the other three income nodes. For instance at the poverty-level income, an increase in SDWIS violation within a county led a 7 cent decrease in water expenditure. At twice the poverty level, a marginal increase in Safe Drinking Water Act violation resulted in a 3 cent decrease and a 15 cent decrease in water and combined water/wastewater rates, respectively. The values for the other income nodes are presented in **Table 5.1** and **Table A.1.**

5.3 Chapter Summary

Within this chapter, I presented the results for the OLS regression and discussed the validity of my models by checking the assumptions of a standard linear regression. I found that all five of the assumptions for linear regression (linearity, no autocorrelation, homoscedasticity, no multicollinearity, and normality of residuals) held for Models 1 and 3. Model 2 seemed to be slightly autocorrelated based on the LAG vs. ACF plot presented in **Figures C.1.1** to **C.4.3.** Model 2 also seemed to break the linearity assumption since the values of the Fitted vs. Residual plots in **Figures B.1.1** to **B.4.3** were skewed slighting to right.

In addition to presenting and checking the validity of my OLS regression results, I also discussed my findings by splitting them into four categories. First, I find that race had largely a statistically insignificant effect for the Black population in Alabama, with only the combined water/wastewater model at the poverty level showing statistically significant results. However, for the Latinx population, the overall trend was that a marginal increase in percentage of the Latinx population in Alabama led to an increase in water expenditure across counties, even after controlling for income.

In addition to race, I found that urbanicity and population density also had an impact on expenditure. Namely, I found that counties with a higher population density and those in urban areas had a lower water expenditure than rural counties. Finally, I found that household characteristics had little and varied impact on water expenditure across the four income nodes and that counties that had higher Safe Drinking Water Act violations tend have higher water and combined water/wastewater expenditures.

Chapter Six – Conclusions, Policy Ramifications, and Recommendations

I have carried out a policy-focused and quantitative analysis of water affordability in Alabama. My research question for this study was to understand how different explanatory variables – such as race, income, and environmental and housing characteristics – affect county-level household water expenditure, and by extension affordability, in Alabama. First, I conducted a qualitative and policy focused analysis of the historical root causes of the water affordability burden in the United States. Then, I conducted a quantitative analysis based on methodology from Cardoso and Wichman (2020) to understand the county-level water affordability landscape in Alabama.

In this chapter, I conclude my findings and detail the limitations of my study. Then, I describe my findings within the larger historical and policy context of water affordability in the United States, and finally, I conclude this chapter with a few policy and future research recommendations.

6.1 – Hypothesis

I hypothesized that nonwhite residents in Alabama, the Black and Latinx population, would face a higher affordability burden than white residents. According to my analysis, the impact that a percentage change in Black households has on household water expenditure within a county is inconclusive. The statistical significance of the "pertblack" variable varies across the four different income nodes. However, for the Latinx population in Alabama, my models consistently returned statistically significant results and showcased that a percentage change in the Latinx population within Alabama led to a higher household water expenditure, holding all else constant, within all the different income nodes. Additionally, other variables also impacted water expenditure in

Alabama. Namely, households in rural counties and those in counties that saw more Safe Drinking Water Act Violations also faced higher water and combined water/wastewater expenditures. However, the urbanicity and the number of violations had varied impacts on the stand-alone water and wastewater expenditure.

6.2 – Limitations

My models had several assumptions that limited the robustness of this analysis. First, because I utilized the EFC data, the estimates were likely inefficient into my analysis due to the fact that there were different number of water providers between the years. Additionally, the estimates of my OLS model could also be inefficient due to any measurement errors in counties served by a utility and how many accounts each utility has within the majority county. Incomplete reporting of water/wastewater rates at the utility level might also bias my results. For instance, it is possible that utilities within Alabama reported varied rates for different consumption levels, and this may under/overstate the estimates of my OLS model. Finally, the EFC data gave the "majority" county for each utility. However, since most water providers work according to their individual service areas that span both intra-and-inter-county lines, a county-level analysis might understate the water affordability challenge compared to a utility-level analysis of water affordability.

6.3 – Policy Recommendation

The root causes of water poverty pertain to the measurement of water affordability and the mechanisms of financing of water infrastructure in the United States. The current metric to measure water affordability (4.5% of median household income) is widely criticized for not capturing the full extent of water affordability in the United States, in particular the water affordability burden faced at either extreme of the income distribution (Teodoro, 2019; Mack and Wrase, 2017; Cardoso and Wichman, 2020). This inaccuracy in measuring water affordability in the United States has particularly exacerbated water poverty in predominantly minority and lower-income communities in the United States (Teodoro, 2020; Cardoso and Wichman, 2020). In Alabama, utility managers and policy makers have regularly used the 4.5% county MHI affordability metric as an excuse not to address water affordability concerns for households facing high water bills (Personal Interview with Mrs. Catherine Flowers, 2022).

In addition to the flaws in measuring water affordability, the root causes of water poverty also pertain to the way that water infrastructure is funded in the US. While water prices have risen by nearly 300%, federal and state-level funding for water systems has fallen by 75%. The lack of federal funding for water infrastructure has meant that water utilities, particularly in low-income and nonwhite communities, in Alabama face an unfunded mandate of complying with water treatment regulations (Cardoso and Wichman, 2020; Teodoro, 2020; Hansen et al., 2021). Furthermore, resulting from this water affordability crisis, nonwhite households in the United States are facing health impacts – such as the cases of lead-poisoning in Flint, MI, and hookworm infection in Lowndes County, Al (Flowers, 2021; Maxy-Brown, 2020). These impacts are only exacerbated by climate change as nonwhite communities are more likely to face environmental and climate racism.

My analysis of water affordability in Alabama finds similar results in light of the larger, historical context of water affordability in the United States. While my results show that Black households face varied and largely statistically insignificant effects of water affordability, my analysis showed that the water expenditure increases with increasing percentage of Latinx population, holding all else constant. Furthermore, my analysis also showed that rural counties and counties that face high rates Safe Drinking Water Act violations also face high water expenditures, strengthening the claim that households face detrimental health impacts as a result of water affordability burden. Therefore, I propose three policy recommendations that can alleviate water affordability in Alabama.

6.3.1 – Equity in Low-Income Water Assistance Program (LIWAP) Distribution

One way to alleviate high water expenditure in Alabama is to directly provide bill assistance to low-income customers within the state. Within the past year, Alabama has received nearly $15.5 million through the American Rescue Plan Act for the sole purpose of providing bill assistance programs for low-income families in the state (Alabama ARPA Summary, 2022). The Alabama Department of Economic and Community Affairs has utilized these funds to start the Low-Income Household Water Assistance Program (LIHWAP). However, advocates throughout the state are worried that the funds will not be distributed equitably, with urban communities receiving a large portion of the funds (Mayfield, 2022). My analysis indicates that special attention should be given instead to low-income households particularly in rural counties. Furthermore, I also recommend that Latinx households, in particular, receive attention when distributing LIWAP funds.

6.3.2 Reform the State Revolving Fund Program

In addition to equitably distributing LIWAP funds, policy makers should also focus on reform current policies and practices around the State Revolving Fund (SRF) program. The SRF is a loan system and is the primary method through which public water providers receive state and federal funding for infrastructure upgrades. Researchers have found that only a small number of water utilities apply for SRF funding every year; in Alabama, only 15% of eligible water providers applied for SRF funding, of which only 20% received the funding (Hansen et al., 2021). Furthermore, Hansen et al. (2021) also found that water providers that operated in predominantly white counties were more likely to receive funding than water providers in predominantly nonwhite counties. Therefore, I recommend that policy makers reform the existing mechanisms through which the SRF funds are distributed in Alabama. For instance, counties that face higher risks from climate change and those that are located in high-minority areas should receive more consideration. Furthermore, more work should be done to increase the outreach efforts of the SRF loan program, which would ensure that a greater percentage of water utilities apply for SRF funding.

6.4 – Recommendations for Further Research

While my research methodology follows the methodology in Cardoso and Wichman (2020), it does have its limitations. First, the county-level analysis likely underreports the water affordability burden faced households in different water-utility service areas. Therefore, future research should consider conducting analysis a more granular level. Furthermore, future research should expand upon how both water quality and water cost vary across Alabama and should focus on more than just Safe Drinking Water Act violations for a county or utility. Finally, future studies must compare water affordability and cost analysis with analysis of SRF funding distribution to understand the demand and supply-side aspects of the water affordability landscape in Alabama.

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Appendix

Appendix A: Table of OLS Results for Models 1, 2, and 3 at 3x and 4x Poverty Income-Nodes

	3x Poverty-level			4x Poverty-Level		
	Model 1: Water	Model 2: Wastewater	Model 3: Combined	Model 1: Water	Model 2: Wastewater	Model 3: Combined
Constant	4.612**	3.46*	4.95	5.312**	3.46*	4.95
	(1.271)	(.585)	(1.67)	(0.433)	(.585)	(1.67)
$perblack_c$	-0.359	-0.025	-6.1e-02	-0.833	-0.088	-8.1e-03
	(0.0035)	(0.043)	(4.6e-02)	(0.0035)	(0.032)	(4.5e-03)
$perlatin_c$	0.673**	0.528*	1.202	0.822**	0.528*	1.202
	(0.198)	0.233	(205e-01)	(0.198)	0.233	(205e-01)
$UrbanIndicar_c$	-0.209	-0.208	-2.30	-0.883	-0.467	-2.588
	(1.774)	(2.358)	(2.52)	(1.774)	(3.44)	(2.50)
Log($PopDen_c$)	-0.216*	4.309**	2.193	-0.216*	4.412**	2.330*
	(1.269)	(1.55)	(1.68)	(1.269)	(1.55)	(1.80)
$perRentInc_c$	0.105	0.282	3.8e-01	0.105	0.282	3.8e-01
	(0.277)	(0.339)	(3.6e-01)	(0.277)	(0.339)	(3.6e-01)
$BaseCharge_c$	0.599**	0.701**	1.301	0.599**	0.701**	1.301
	(0.072)	(0.088)	(9.5e-02)	(0.072)	(0.088)	(9.5e-02)
$perRent_c$	-2.36e-01	-0.079	-3.131*	-2.36e-01	-0.079	-3.131*
	(1.3e-01)	(0.162)	(1.74e-01)	(1.3e-01)	(0.162)	(1.74e-01)
$MedInc_c$	3.80e-06	1.9e-4	-1.3e-04	3.80e-06	1.9e-4	-1.3e-04
	(1.6e-04)	(1.4e-8)	(1.5e-04)	(1.6e-04)	(1.4e-8)	(1.5e-04)
$MedAge_c$	-6.7e-03	3.5e-3	-3.19e-03	-6.7e-03	3.5e-3	-3.19e-03
	(3.9e-3)	(5.3e-4)	(5.6e-03)	(3.9e-3)	(5.3e-4)	(5.6e-03)
$violations_c$	1.867**	3.2e-3	1.541*	1.867**	3.2e-3	1.541*
	(3.73e-3)	(5.6e-3)	(6.8e-03)	(3.73e-3)	(5.6e-3)	(6.8e-03)
$PovHouse_c$	1.82e-01	-0.349	-1.65e-01	1.82e-01	-0.349	-1.65e-01
	(0.1641)	(0.325)	(3.49e-01)	(0.1641)	(0.325)	(3.49e-01)
$Pov2xHouse$	-4.02e-02	1.9e-4	-4.1e-02	-4.02e-02	1.9e-4	-4.1e-02
	(0.243)	(0.163)	(2.4e-01)	(0.243)	(0.163)	(2.4e-01)
YearEffect_2014	-4.245	-3.75	-2.54	-4.785	-1.123	-2.459
	(4.324)	(6.74)	(8.85)	(6.621)	(8.98)	(8.85)
YearEffect_2016	-4.985	-1.123	-4.55	-4.126	-1.876	-4.559
	(4.678)	(6.93)	(8.78)	(9.585)	(2.93)	(8.78)
cz2a	-7.423	-4.332	-8.74	-4.832	-7.234	-1.459
	(4.621)	(6.98)	(8.85)	(4.621)	(6.98)	(8.85)

cz3a	-4.104 (4.621)	-2.095 (6.98)	-2.847 (8.85)	-4.082 (4.621)	-2.358 (6.98)	-2.974 (8.85)

Robust standard errors are provided in parenthesis
"**" p-value < 0.01, "*" p-value < 0.05, " " p-value > 0.05

Appendix B: Residual Plots for Models 1, 2, and 3

Appendix B.1: Poverty Level

Figure B.1.1: Model 1

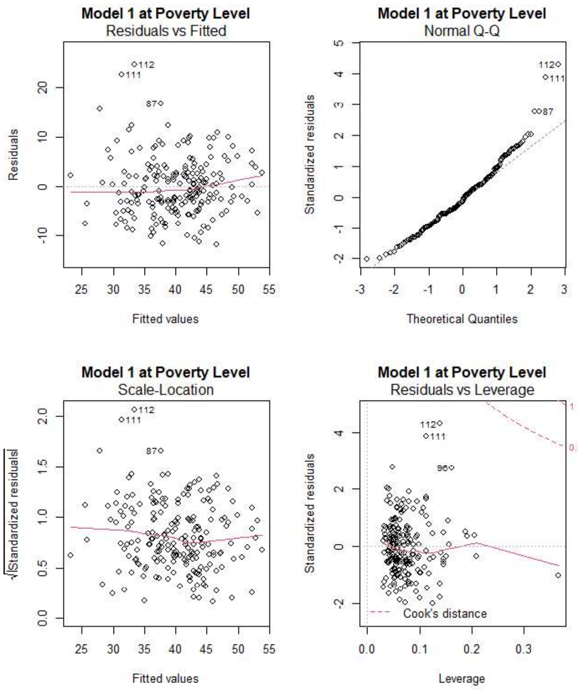


Figure B.1.2: Model 2

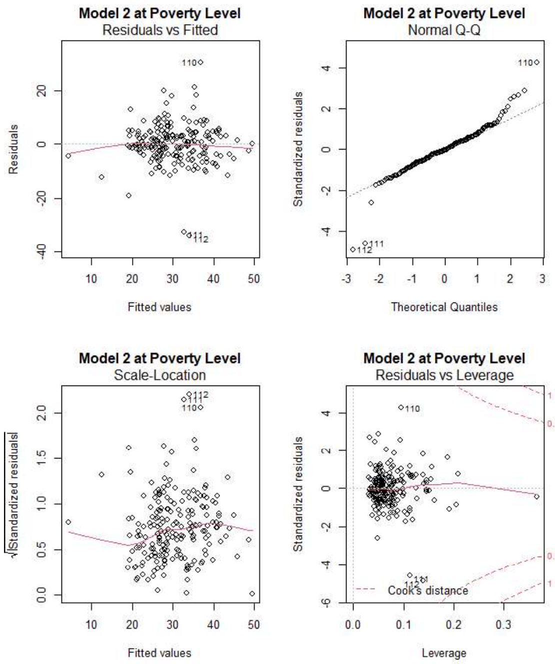
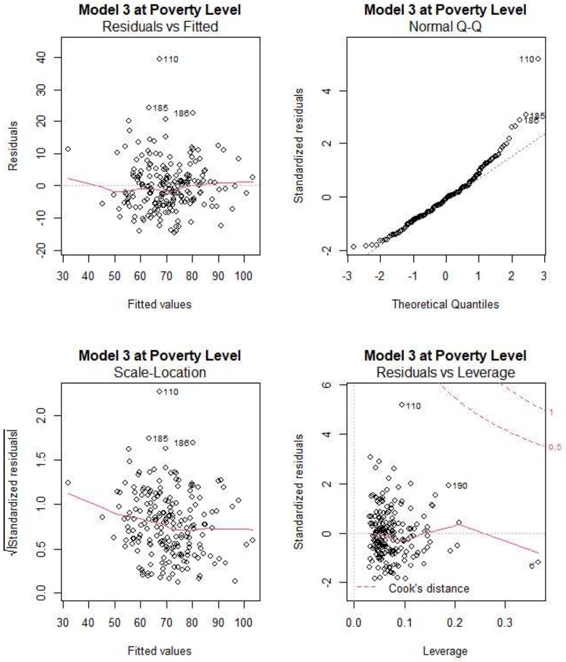


Figure B.1.3: Model 3



Appendix B.2: 2x Poverty Level

Figure B.2.1: Model 1

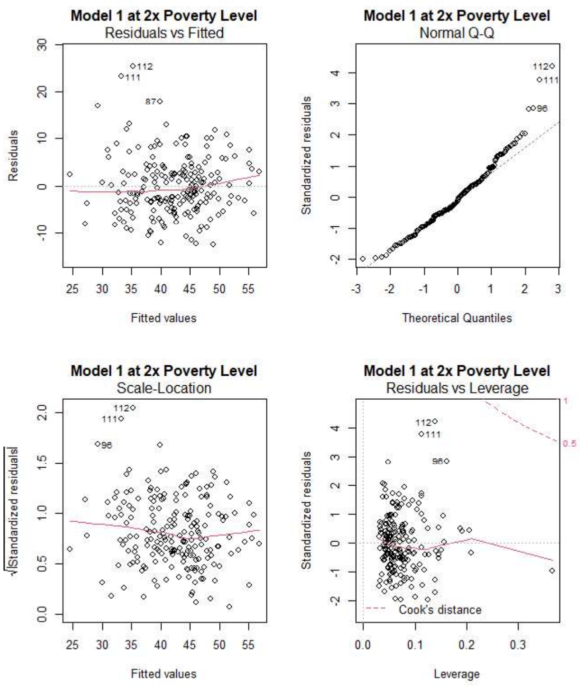


Figure B.2.2: Model 2

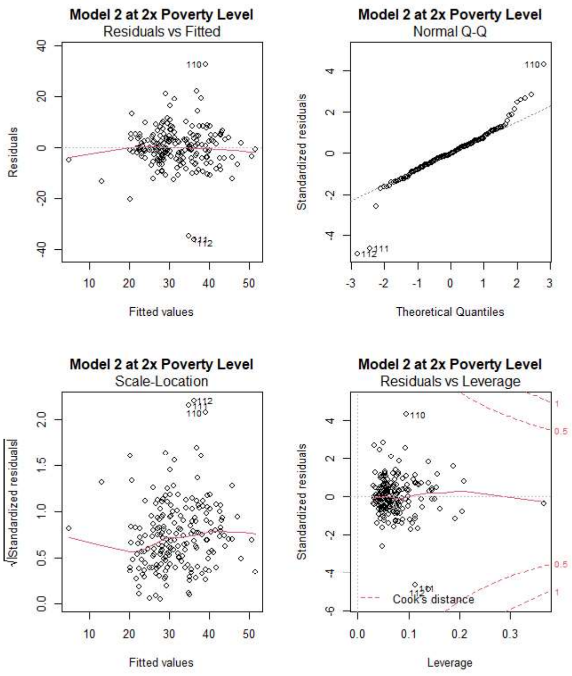
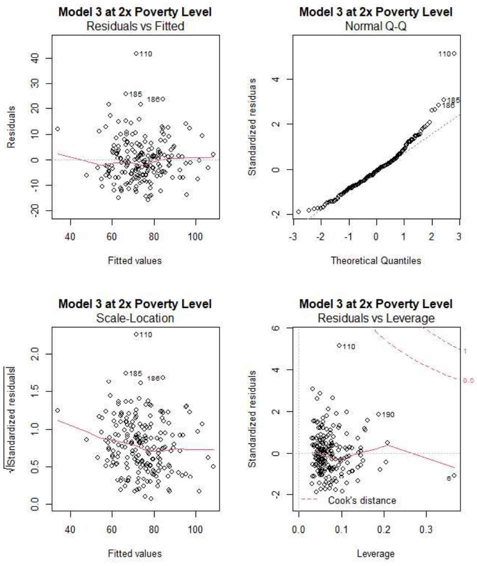


Figure B.2.3: Model 3



Appendix B.3: 3x Poverty Level

Figure B.3.1: Model 1

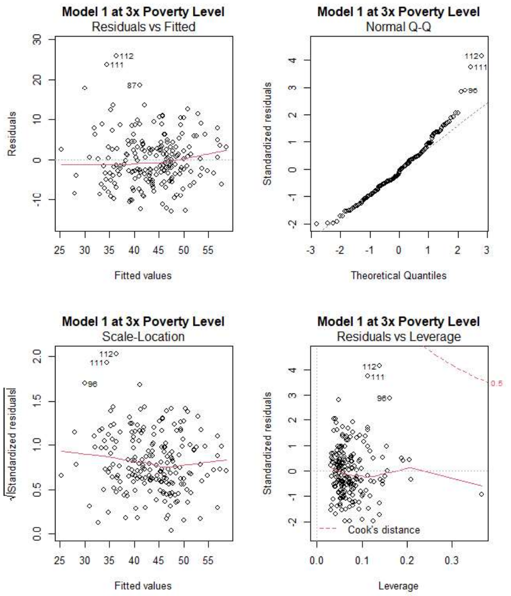


Figure B.3.2: Model 2

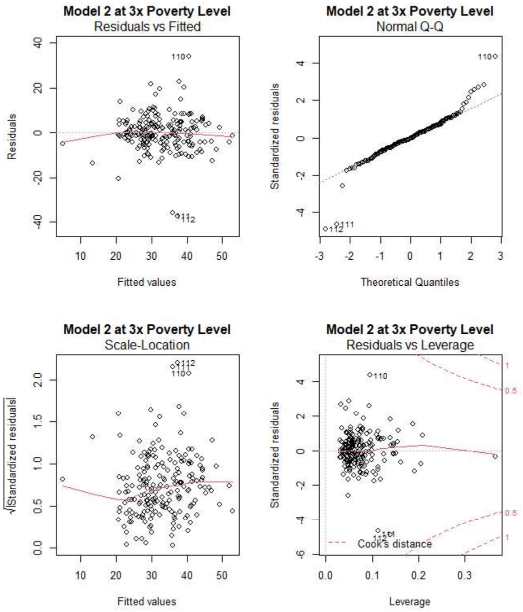
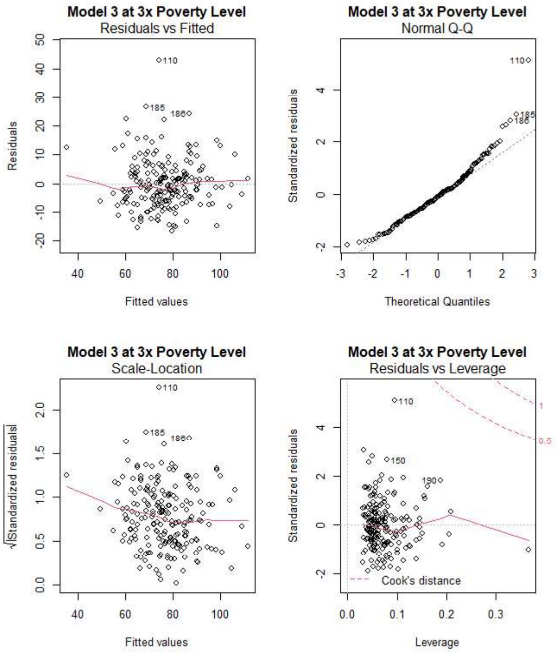


Figure B.3.3: Model 3



Appendix B.4: 4x Poverty Level

Figure B.4.1: Model 1

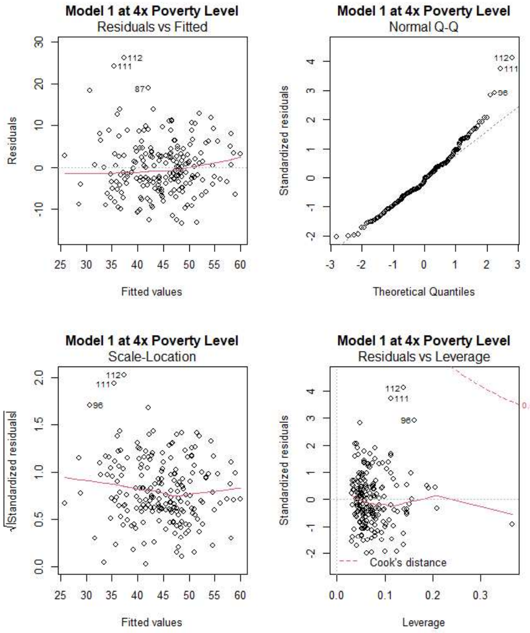


Figure B.4.2: Model 2

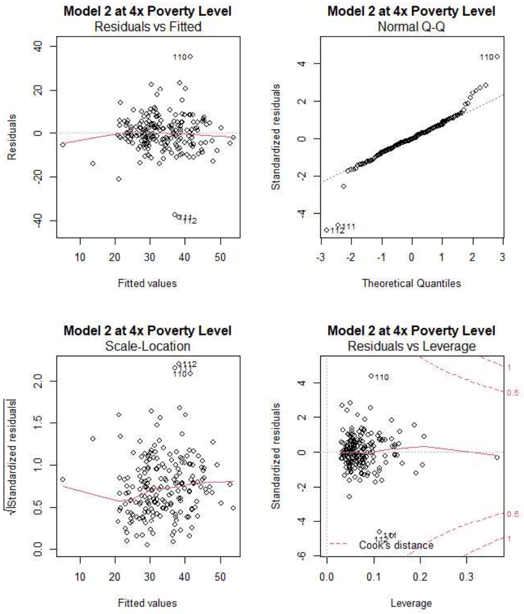
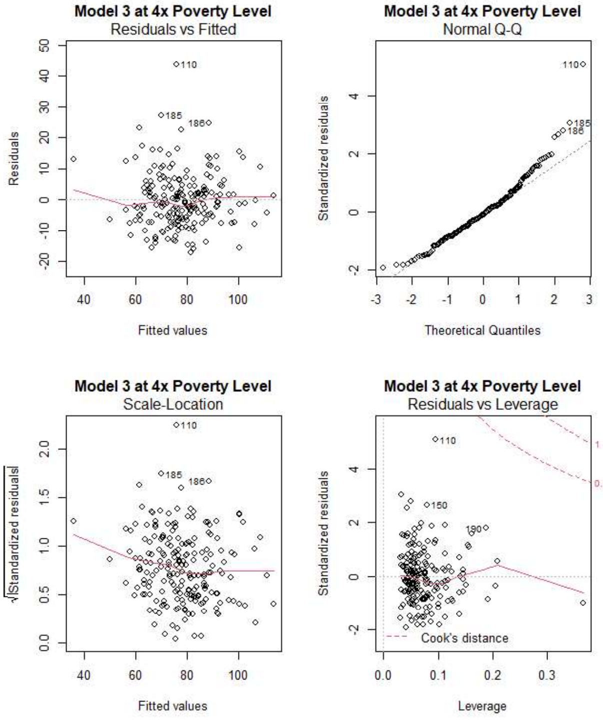


Figure B.4.3: Model 3



Appendix C: Plot of Time-Series Residuals

Appendix C1: Poverty-Level Time-Series Residuals

Figure C1.1: Model 1

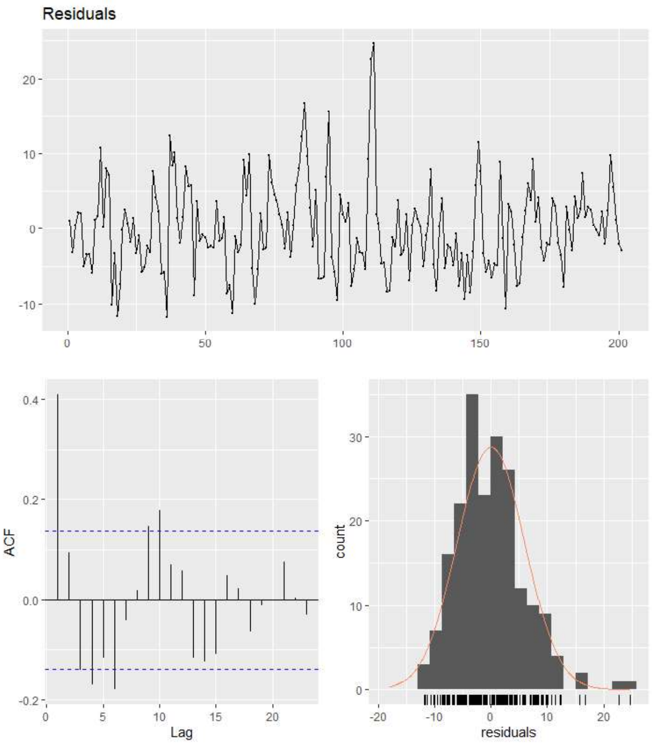


Figure C1.2: Model 2

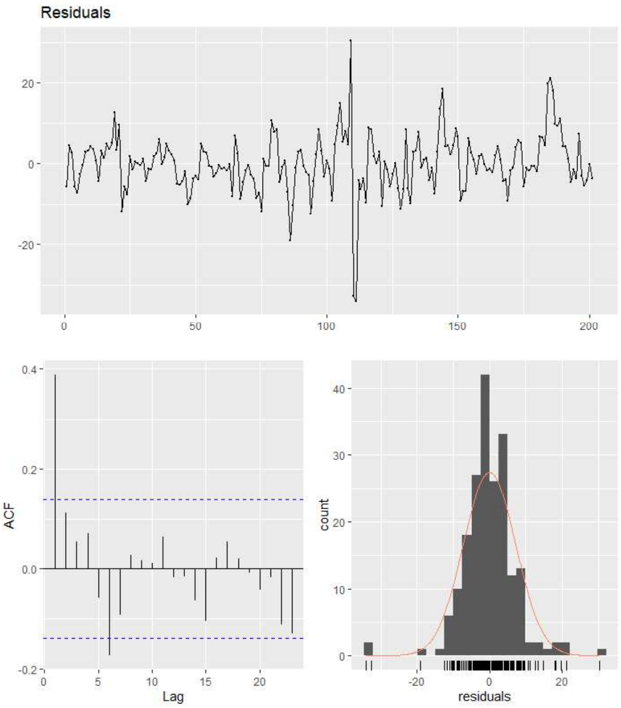
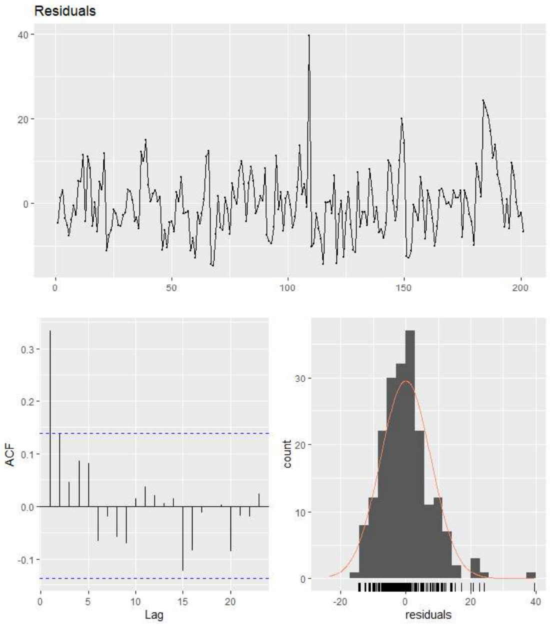


Figure C1.3: Model 3



Appendix C.2: 2xpoverty-Level Time-Series Residuals

Figure C.2.1: Model 1

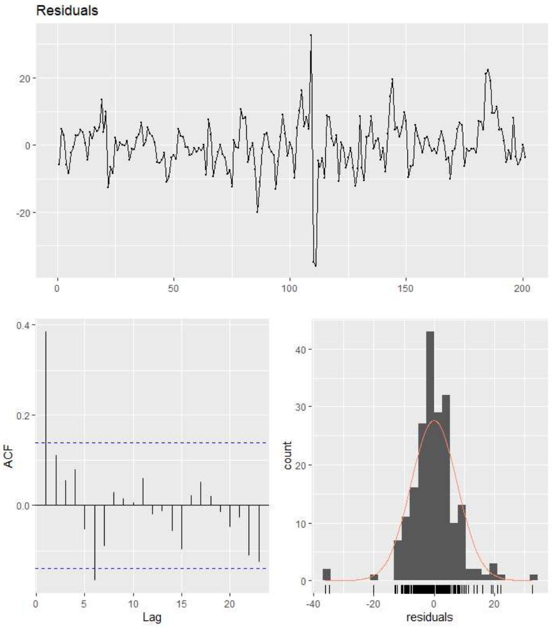


Figure C.2.2: Model 2

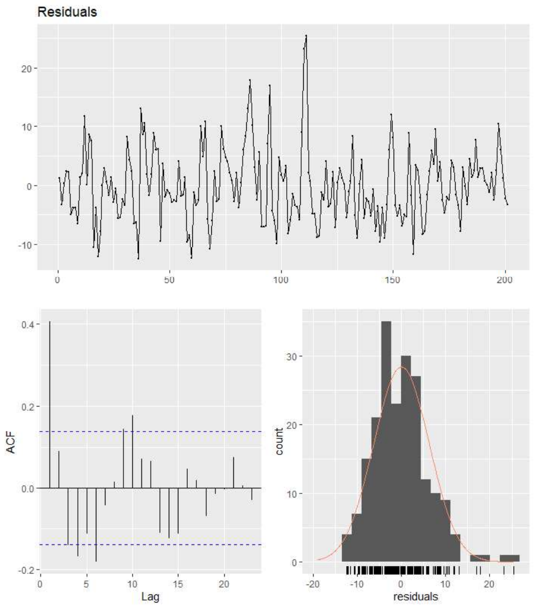
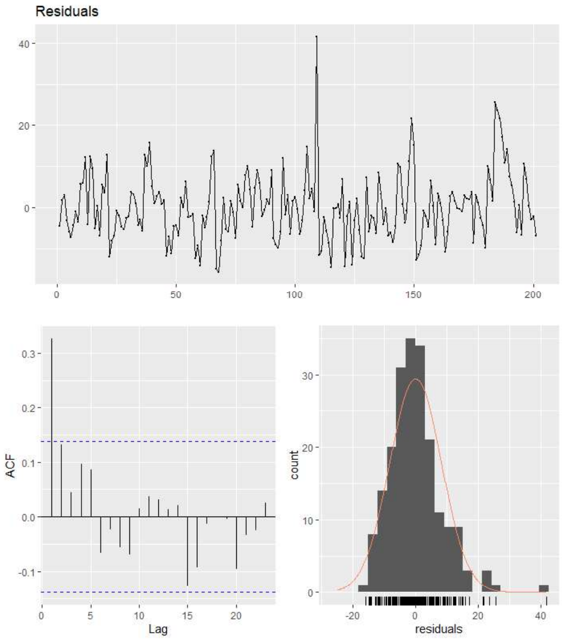


Figure C.2.3: Model 3



Appendix C.3: 3x Poverty Income-Level Time Series Residuals:

Figure C.3.1: Model 1

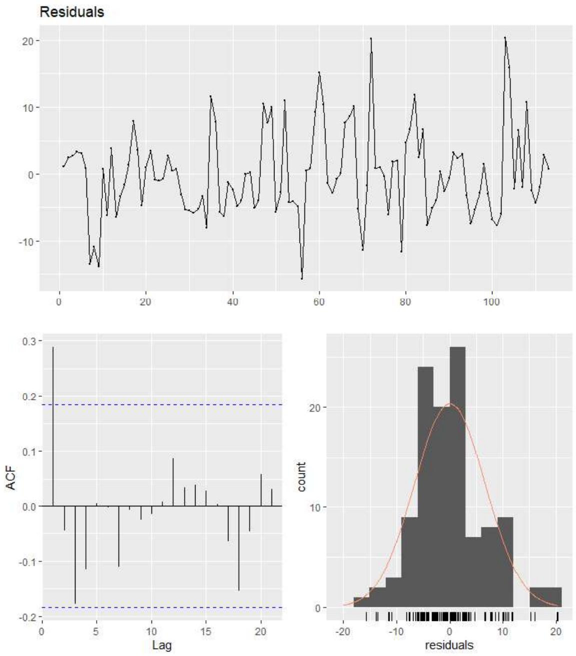


Figure C.3.2: Model 2

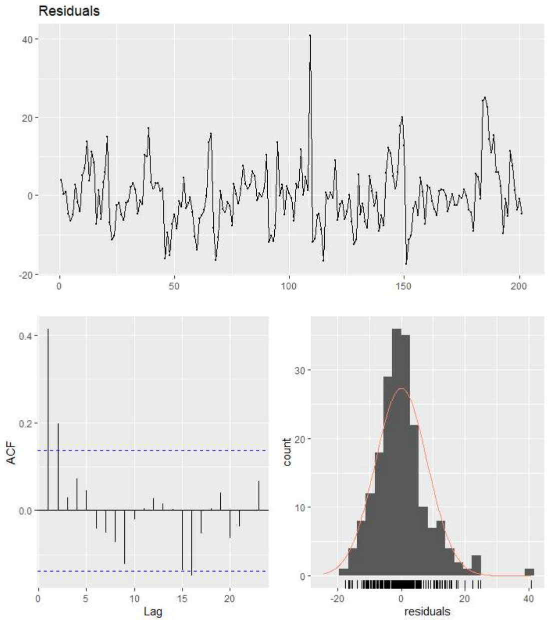
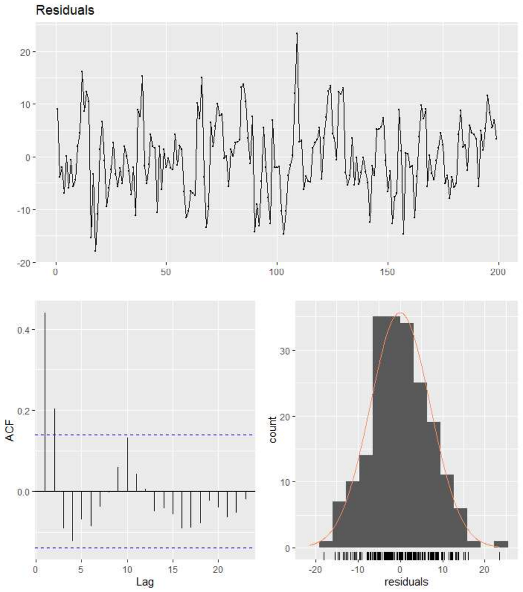


Figure C.3.3: Model 3



Appendix C.4: 4x Poverty Income Level Time Series Residuals

Figure C.4.1: Model 1

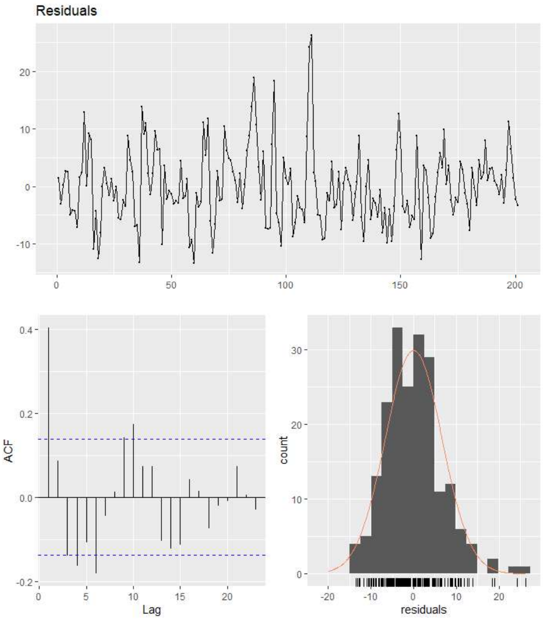


Figure C.4.2: Model 2

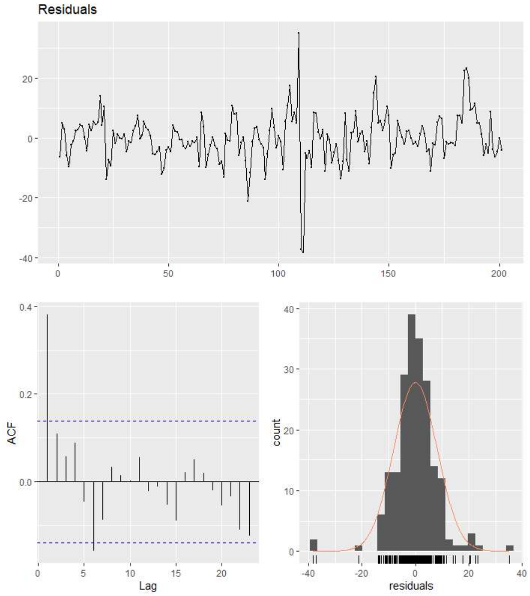
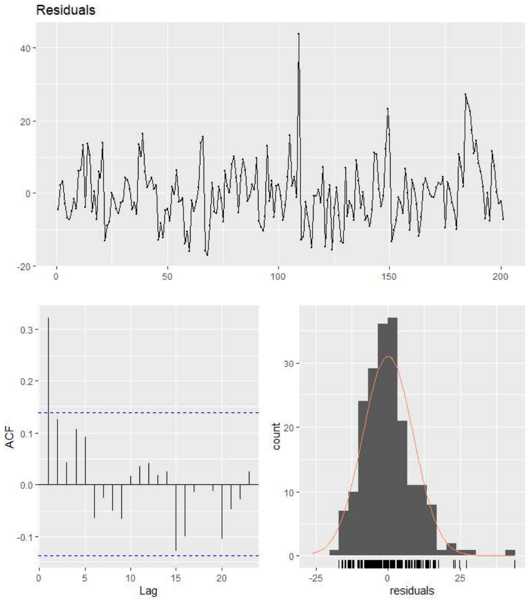


Figure C.4.3: Model 3



Appendix D:

The values for α are the results of an OLS regression conducted by Cardoso and Wichman (2020). The correspond to **Equation 4.1.**

Table D.1

α	Variable	Value
α_0	Constant	3.360937
α_1	Median Income	0.099906
α_2	Population	0.045330
α_3	Marginal Base Rate	-0.002744
α_4	Rate5c	-0.295208
α_5	Rate10c	0.009430
α_6	Climate Zone 2A	-0.111037
α_7	Climate Zone 3A	0.088472

Appendix E:

Data on different poverty-level income at different household sizes was taken from the Alabama Department of Health, and then a linear model was fitted to find the relationship between poverty-level income and household size. The following model describes that relationship. The values for γ_1 is 7080, and the value for γ_0 is 13305.

$$Model\ E.1: I_{poverty} = \gamma_1(hhsize) + \gamma_0$$