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Economic Valuation of PFAS Remediation in New Hampshire Municipal Drinking Water Systems: A Contingent Valuation Approach

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ECONOMIC VALUATION OF PFAS REMEDIATION IN NEW HAMPSHIRE MUNICIPAL DRINKING WATER SYSTEMS: A CONTINGENT VALUATION APPROACH

BY

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DEDICATION

To my entire family
For the love and support they give to me every day

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TABLE OF CONTENTS

ABSTRACT

Economic Valuation of PFAS Remediation in New Hampshire Municipal Drinking Water Systems: A Contingent Valuation Approach

By

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In the past two decades there has been an increase in detection and awareness of PFAS (Per- or Polyfluoroalkyl substances) chemicals in groundwater and drinking water in the United States. In stark contrast to other known harmful chemical pollutants, little is known yet about the specific epidemiological and toxicological effects of prolonged intake and consumption of PFAS chemicals in environmentally occurring levels. New Hampshire in particular has encountered two high-profile episodes of PFAS contamination with hotspots in Merrimack, NH due to factory pollution and Pease International Tradeport in Portsmouth, NH due to military activity. These instances have brought increased attention to the issue from both the state legislature and residents.

The purpose of this study was to ask New Hampshire residents how much they value the removal of PFAS chemicals from their public drinking water systems to reduce the risk of possible negative health outcomes that come with PFAS intake. Using data from a September 2021 online survey of New Hampshire residents and employing the contingent valuation survey method in the form of Willingness-To-Pay, we used several regression techniques, we determined that NH residents are willing to pay an additional $13.07 to their existing water bill to remove the risk of negative health outcomes stemming from PFAS consumption. Throughout the models, the most important confounding factor influencing higher willingness-to-pay values was the presence of moderate or major existing health concerns about drinking tap water.

CHAPTER 1

INTRODUCTION

PURPOSE

Drinking water pollution has been a problem for human civilization for centuries. Pollution and hazardous runoff come with the building of streets, homes, markets, and everything that makes up a city. A myriad of different pollutants has caused a great many diseases and disorders over thousands of years. In the United States today, we have several high-profile cases of drinking water pollution from lead, to microplastics, to chemical runoff.

In the past decade news stories about lead poisoning in Flint, Michigan, have dominated headlines as the major drinking water contamination issue in the United States. Children in Flint exhibited elevated blood lead levels after the city switched its drinking water supply as a cost-saving maneuver, causing a number of serious health issues, especially in disadvantaged communities (Hanna-Attisha et al 2016). Water contamination in the United States is a continuous cycle of pollution and remediation as new contaminants are identified.

As one issue begins to only occupy space in the back of our minds, a new pollutant is rising to the forefront of the American psyche, PFAS. PFAS is shorthand for per- and polyfluoroalkyl substances, of which there are thousands (Sunderland et al 2019). The chemicals' ability to persist in the environment has resulted in them being dubbed "forever chemicals". PFAS does not readily break down and can persist in the environment, animals, and people for extended periods of time. The United States Environmental Protection Agency (EPA) within the last year released a road map full of recommended actions aimed at studying the causes and effects of, as well as reducing PFAS contamination. As of yet there are no nationwide PFAS regulations.

PFAS chemicals enter ecosystems and drinking water in several ways. Areas near facilities that produce the chemicals themselves often are subject to contamination due to leaks from the factories. Water near airports, military bases, fire stations, and petrochemical industrial sites can become contaminated due to the persistent use of AFFF (Aqueous Film Forming Foam). PFAS contamination affects the immediate area as well as surrounding civilian land. Waste processing facilities often leak large amounts of PFAS and other chemicals into the water and land. PFAS can also be released via airborne emissions and settle into groundwater previously considered outside of down-gradient areas (Schroeder et al 2021). Additionally, most of our current water treatment facilities are not designed to catch PFAS (Hu et al. 2016).

Given the multitude of uses for PFAS, there is widespread concern that levels of the chemicals are bioaccumulating in humans and animals alike. Elevated PFAS levels have now been linked to a variety of health problems in humans, such as cancers, immune deficiencies, reduced vaccine efficacy, liver problems, kidney disease, reproductive and developmental issues, and hormone disruption (Pelch et al. 2019) (Fenton et al. 2021). However, the data on the concentrations at which the chemicals have an impact is still evolving (Sinclair et al 2020). There is mounting evidence that original "no harm" concentration levels may need to be reviewed as new studies about their effects get published.

This study is a first attempt to gauge how New Hampshire residents feel about PFAS contamination via how much they are willing to pay for the removal of the chemicals from their public/municipal drinking water systems. Through a contingent valuation survey, we estimate respondent willingness-to-pay and uncover the factors that drive the valuations.

PFAS IN NEW HAMPSHIRE

In the last few decades PFAS have begun to be regulated worldwide, yet regardless of whether governmental institutions have agreed upon nationwide, statewide, or even local harmful contamination levels, there is a growing sense of anxiety regarding what should be done to combat these chemicals in our rivers and drinking water supplies. In 2016, the EPA set a combined lifetime drinking water advisory for PFOA and PFOS of 70 nanograms per liter (ng/L) (EPA 2016) but has yet to set a mandatory regulatory limit for any PFAS family chemical (Pelch et al 2019).

In the past several years two instances of PFAS contamination within New Hampshire have kickstarted a drive to combat the PFAS issue in the state. High levels of PFAS-contaminated water were detected in Portsmouth (related to the Pease Air Force Base) and in the town of Merrimack (Saint-Gobain Performance Plastics). In the summer of 2020, the New Hampshire state government passed House Bill 271 which set Maximum Contaminant Levels (MCLs) for four types of PFAS in drinking water. These limits are as follows: 11 ng/L for PFNA (Perfluorononanoic acid), 12 ng/L for PFOA (Perfluorooctanoic acid), 15 ng/L for PFOS (Perfluorooctane sulfonic acid), 18 ng/L for PFHxS (Perfluorohexane sulfonic acid) (LegiScan 2020). These MCLs are far stricter than the current EPA concentration advisory for PFOA and PFOS mentioned above.

In PFAS-impaired areas such as Merrimack where the Saint-Gobain performance plastics (SGPP) plant has released several harmful PFAS into the surrounding water, levels of well over 70 ppt have been recorded. In the seacoast area around the Pease Air Force base, recorded levels of PFAS have been in the hundreds of parts per trillion. In both cases, the primary chemicals were PFOA and PFOS. In Merrimack, readings along the river can be as much or more than 10 times the combined legal limit.

The drinking water surrounding the Saint-Gobain factory is no longer safe for consumption. In an agreement with the town, SGPP has had to supply hundreds of thousands of bottles of water to residents in recent years. In April of 2022, SGPP signed an agreement with NHDES and the relevant towns to permanently supply water to affected properties and to pay for Point of Entry Treatment (POET) (such as Reverse Osmosis or Granular Activated Carbon) until three consecutive years where PFAS levels are both under the MCLs and declining. According to the agreement, if levels begin to rise again, the payment for POET would be reintroduced (Hoplamazian 2022). As of right now, there is still contamination coming from the factory, and decrees such as these result from efforts made by citizens, non-governmental organizations, and the NHDES to put a stop to the release of these hazardous chemicals.

WATER TREATMENT FOR PFAS CONTAMINATION

Water system treatments for PFAS contamination are often costly and imperfect. The most well-regarded treatments for water-based PFAS are Reverse Osmosis (RO), Granular Activated Carbon (GAC), and Ion Exchange. RO can remove nearly all PFAS from a system but creates substantial amounts of wastewater. GAC is less costly and produces less wastewater but does require more frequent and expensive maintenance. This method (GAC) is becoming the favored treatment for PFOA and PFOS, but research remains ongoing on its effectiveness with other PFAS chemicals.

For an overview of how the granular activated carbon process works, water passes through columns or beds of GAC made from wood, and coal. As the water passes through the beds, contaminants are absorbed into the GAC and removed from the water. Eventually, the GAC becomes saturated with contaminants and needs to be replaced. At the moment there does not seem to be an effective way to safely dispose of PFAS-contaminated GAC at a cost-effective level for general consumers. Likely, most of the GAC waste ends up in landfills, which could contribute to leakage from those facilities (Sonmez Baghirzade et al 2021). The amount of time it takes for the GAC to become "spent" depends on many factors including the structure of the facility, the type of contaminants being absorbed, and the levels of those contaminants. Short-chain PFAS generally have lower loading capacities and shorter breakthrough times, necessitating shorter intervals between changing out old GAC for new (ITRC 2021).

Disposal of GAC laden with PFAS poses an issue given improper disposal of the GAC waste could re-introduce PFAS to the environment through leakage. One way to deal with this problem is through a process known as Thermal Regeneration. In thermal regeneration, GAC is submitted to a heating and drying process that both removes PFAS and allows GAC to be used again. Thermal regeneration can be both energy intensive and costly, for this process to be beneficial on an even larger scale these engineering issues must be tackled (Sonmez Baghirzade et al 2021).

Both RO and GAC have proven at least in the short term to successfully reduce and even remove PFOA and PFOS from home drinking water. Other PFAS may have weaker absorption characteristics and could break through before PFOA and PFOS. While these two systems can work, the costs of treatment combined with the costs of water testing can be a significant barrier for homeowners (Patterson et al 2019). Additionally, GAC and RO filtration systems remove other organic chemicals from water (MDH 2020) providing additional benefits for users outside the scope of PFAS remediation and removal.

Ion exchange (IX) is another treatment that can help remove some chemicals that GAC may miss but is very costly and has its own set of limitations. In ion exchange positively charged IX resins ionically bond to negatively charged PFAS and remove them from water. This technology has only recently been used for PFAS treatment, and as of now works best for water with only low levels of PFAS present (ITRC 2021). When any municipality or consumer considers how to treat their water, they must weigh the opportunity cost of human health against the monetary costs of implementation and maintenance of the chosen water treatment apparatus.

RESEARCH QUESTIONS AND APPROACH

Given the prevalence of PFAS proliferation in the nation and NH specifically, as well as its potential human health implications, we wanted to survey NH residents on their risk assessment and perception of the safety of tap water, and their willingness-to-pay for remediation of PFAS chemicals. Specifically, we asked what people might be willing to pay on top of their monthly water bill for the removal of PFAS from the municipal water system.

This research consists of two major parts, the first being the design and implementation of the survey dispersed to New Hampshire residents. The second was the econometric analysis of these data. The goal of this research was to determine what dollar amount the average NH resident is willing to pay to treat their public water in response to PFAS contamination, and what demographic or personal characteristics drove these valuations. If the willingness-to-pay number is significant, that would tell us that governments in NH, whether local or state, should consider immediate action to combat the issue. To our knowledge, no contingent valuation study on the removal of PFAS contamination has been done as of yet.

SURVEY METHODOLOGY

To elicit these responses, we employed the Contingent Valuation survey method, of the larger Contingent Behavior Method. Contingent valuation surveys are often used for passive-use or non-use environmental goods. These are goods for which there is usually no market and/or no previous direct participation by a consumer. Therefore, people generally have never contributed monetarily to solving the issue at hand. Because there is no past observable behavior, to value this good you must directly ask consumers what they would pay given a certain hypothetical situation (stated preference). By conducting a CV survey, you are able to ascertain a range (interval) or figure (depending on survey style) representing a monetary commitment people are interested in making if the hypothetical situation were to play out. Respondents are essentially being asked how they value clean drinking water, and the removal of (in our case) PFAS is the vehicle for that improvement in water quality and reduced risk of negative health outcomes.

Research with similar survey methodology has been done in New Hampshire regarding the public's risk assessment of Arsenic in the state's drinking water (Lemos et al. 2020), and consumer preferences for local produce (Werner et al. 2019). Although there is more name recognition and known health issues with Arsenic, PFAS' prevalence in the news and recent point-source issues in NH may provide residents with some degree of prior knowledge and risk aversion to the problem. The CV survey method allows us to precisely determine what that level actually is.

RESEARCH IMPACT

This research can help illuminate how New Hampshire municipal water users value the risk of diseases and negative health outcomes that may be related to the intake of drinking water contaminated with PFAS chemicals. The results from the two willingness-to-pay methods can provide lawmakers in the state, at the local or state level, with initial insight into how this issue is valued. From these valuation data, policymakers can make better-informed decisions regarding the implementation of further legislation as it relates to PFAS within the state. Given that this is a first-of-its-kind study in NH, this project should help foster further research into risk assessment for PFAS and potentially other emergent chemicals.

OVERVIEW

This thesis contains a total of five chapters. As a preface to this study, Chapter II is an exploration and review of the literature on PFAS. This literature review highlights what exactly PFAS are, how they've come to be present in our environment and water systems, as well as presenting a basis for our study design and data analysis methods. Chapter III delves into detail regarding our specific research design and methods. The results of the research are described in Chapter IV. Chapter V concludes the thesis with a discussion of the results and an evaluation of what future action may be possible to limit negative outcomes from PFAS contamination.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW INTRODUCTION

In this chapter, published literature will be examined and discussed as they relate to PFAS chemicals, chemical pollution in the United States, and contingent valuation studies. The literature review on PFAS discusses chemical composition and production background alongside the properties and characteristics of the chemicals in use and in the environment. The toxicology and epidemiology review section focuses on the current breadth of knowledge on the occurrence and potential dangers and adverse health outcomes that may be associated with PFAS. The literature review on PFAS legislation focuses on current legislative action in the United States as a whole and specifically in New Hampshire. Finally, the contingent valuation survey method is explained and a rationale and justification are given for its use with environmental goods and specifically for this research.

PFAS REVIEW

PFAS (Per or Poly-fluoroalkyl substances) are a large group of over 4,000 chemicals (Sunderland et al 2019) nicknamed “forever chemicals”, a name that reflects their ability to persist in the environment. PFAS are man-made chemicals first used in the 1940s, they are fluorinated organic chemicals that confer oil and water resistance, temperature resilience, as well as friction reduction qualities (ITRC 2020). These synthetic compounds have been used in Teflon and Scotchgard, as well as numerous other products (textiles, furniture, medical equipment) due to their non-stick and waterproofing qualities (Pelch et al., 2019). An additional large source of PFAS is fire retardant foam (aqueous film forming foams, AFFF) used by the military, the petrochemical industry, and the aviation industry (EPA 2021).

The most common classification system for PFAS chemicals is based on the number of carbon atoms in the compound. Long-chain PFAS generally have greater than 6 carbons (example: PFOA, perfluorooctanoic acid) while short-chain have fewer (example: PFBA, perfluorobutanoic acid). Both long-chain and short-chain were initially manufactured (as all PFAS are) however, short-chain PFAS can also be the result of long-chain compound degradation (AWWA 2019). Short-chains have more recently been used as a substitute for long-chains as the latter has been phased out and even banned by various governing bodies. Unfortunately, short-chain PFAS while being generally more detectable, are also more persistent, mobile, harder to remove, and thus more dangerous to public and ecosystem health (Li et al. 2019).

TOXICOLOGY AND EPIDEMIOLOGY

Given the mounting pressure and priority level of this rising contamination issue, researchers are racing to study and reveal the epidemiological effects of PFAS contamination on humans. Very few studies have concluded definitively that PFAS are in fact carcinogenic, but evidence may be trending that way. In fact, one study found that PFOA is positively associated with an increased risk of renal cell carcinoma (RCC) (Shearer et al 2021). There is no association between PFAS and cancer that has been consistent across many studies, even though there are associations between PFOA and RCC as well as with testicular cancer (Steenland and Winquist 2021). This fact highlights the need for further research.

The National Toxicology Program of the United States Department of Health and Human Services has concluded that PFOA is a presumed immune hazard to humans because it affects the immune function in people by weakening antibody response (NTP 2016). The same study concludes that PFOS is also a presumed immune hazard to humans. PFOS potentially weakens infectious disease resistance as well as natural killer cell activity. The mechanisms for how both PFOS and PFOA do this is yet to be understood but we can with confidence observe these effects (NTP 2016).

In addition to immune response, there is evidence that certain PFAS can negatively impact vaccine responses in people. Raised concentrations of PFOA in adults can increase the risk that after receiving an influenza vaccine the body may not reach the antibody level necessary for long-term protection from the particular strain of virus (Looker et al 2014). In infants, elevated levels of PFAS from breastfeeding (PFAS is excreted in breastmilk) are associated with antibody-deficient immune responses. Negative associations in early infancy were stronger than at 18 months and five years, highlighting the highly vulnerable nature of the immune response at that stage of life (Grandjean et al 2017).

PFAS LEGISLATION

In the United States and Europe many long-chain PFAS have been phased out after health concerns arose in the early 2000s, in 2002 3M phased out PFOA in their manufacturing. However, in many developing nations in Asia long-chain PFAS such as PFOA and PFOS are still in development (Land et al 2018). Due to the widespread use of PFAS over the past 60-80 years, and PFAS' ability to persist in the environment, contamination is ubiquitous across surface waters in the US. Estimates regarding total contamination levels are still few are far between; however, it is likely that 18-80 million people in the US receive tap water with greater than 10 ng/L combined concentration of PFOS and PFOA, and that 200 million people in the US receive tap water with greater than or equal to 1 ng/L combined concentration (Andrews and Naidenko 2020). Further, it is estimated that more than 6 million people in the US receive drinking water with greater than the 70 ng/L combined concentration of PFOA and PFOS (Hu et al 2016).

Major PFAS hotspots in the United States include areas in West Virginia and Michigan, however, PFAS has been detected in 49 states thus far. In the case of West Virginia, contamination comes from a factory owned by DuPont that had been using PFOA since 1951 (Bartell et al 2010). The state of Michigan has identified more individual PFAS contamination sites than any other state, however, this may be in part due to more prevalent testing (MPART 2022) than most if not all other states.

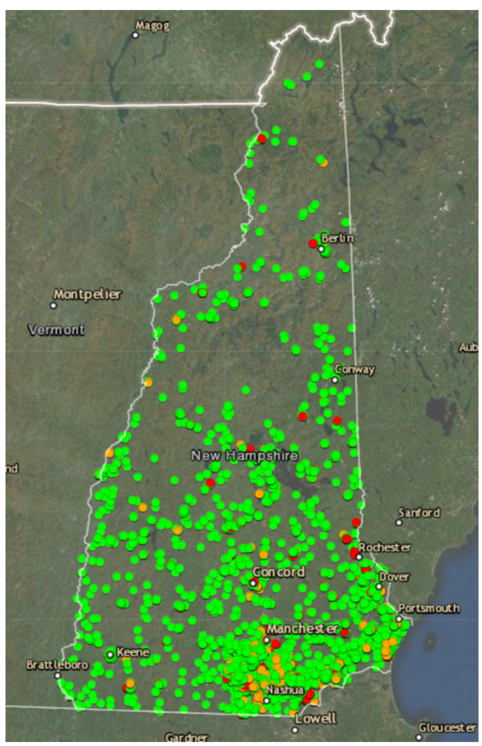

Figure 1. NH DES PFAS sampling map. Green, yellow, and red dots represent PFOA+PFOS > 70 ppt, PFAS > MCL and PFAS ≤ MCL, respectively.

In New Hampshire, the state with arguably the most stringent regulations, two major PFAS hotspots are present. One is in Merrimack, NH from pollution by the Saint-Gobain Performance Plastics factory (SGPP), and the other is in Portsmouth at the Pease Tradeport (former U.S. Air Force Base) from military activity. At Pease, PFAS were found in a drinking water well in 2014; contamination most likely occurred over time because of consistent usage of Aqueous Film Forming Foam (AFFF), fire foam. This foam had been used by the military there to train firefighters as well as to put out oil and gas-based fires up until the base was decommissioned in 1991. Of the people sampled in the 2015 Pease PFAS serum testing program, 94% had detectable levels of PFOS, PFOA, and PFHxS in their serum (Daly et al 2018). In Merrimack, PFOA and PFOS were detected in the public drinking water system in 2016 at alarming levels. The contamination came from air emissions from the SGPP factory along the Merrimack River (Panikkar et al 2019). The NH PFAS legislation came as a response to the issues in Portsmouth and Merrimack.

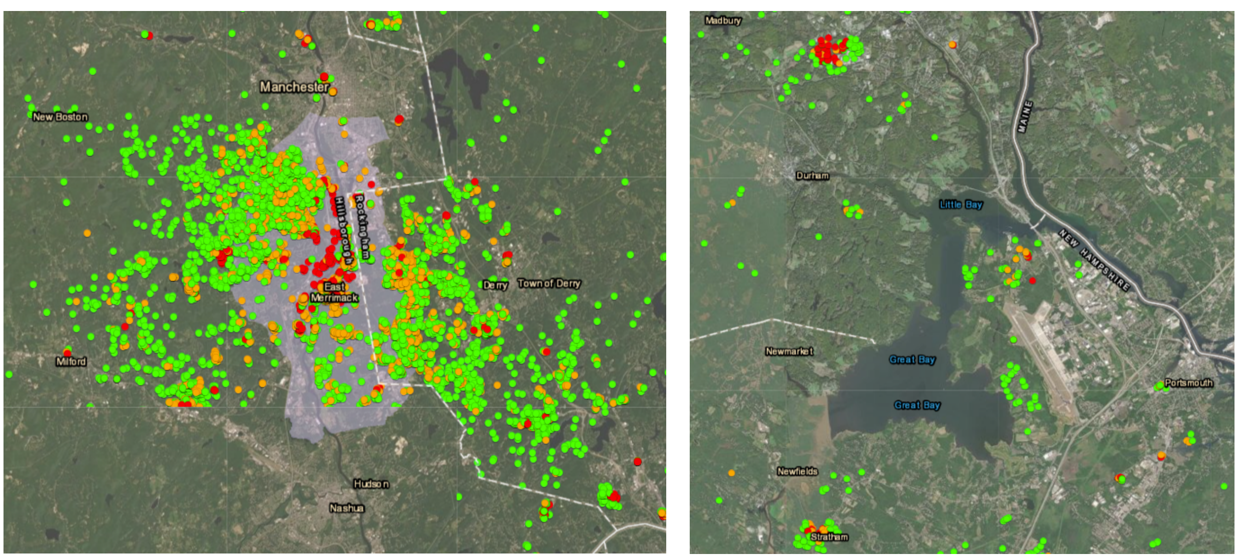

Figure 2. NH DES map of PFAS groundwater sampling in Merrimack, NH (Left) and Portsmouth, NH (right).

According to the EPA's 'PFAS Roadmap', the federal government plans to propose PFAS regulations in the fall of 2022 with a final rule in place by the fall of 2023 (EPA 2021). Many states have moved ahead of the federal government and instituted their own PFAS regulations both above and below the EPA advisory of 70 ng/L combined concentration of PFOA and PFOS. Up to today, 31 states have at minimum issued or proposed guidance or advisories regarding the use of PFAS, and seven states have enforceable regulations on PFAS levels in water (New Hampshire, Maine, Vermont, Massachusetts, New York, New Jersey, and Michigan).

ECONOMICS OF PFAS

While the research on the epidemiological side of PFAS is accelerating, there are virtually no studies on the economic effects, both on a micro and macro scale. We do not at the moment know how businesses, industries, and people value PFAS contamination, treatment, and prevention. One study investigated how PFAS might be affecting the real estate market presently and in the future. Bell and Tachovsky (2021) hypothesized that real estate valuation professionals may now be forced to study the potential impacts of PFAS on property and mass group property values. They hypothesize that PFAS contamination will grow as a factor in how single homes as well as communities are valued on the real estate market. The authors discuss several mass appraisal techniques such as multiple regressions, simple regressions, sale/resales, etc. that could be used to do this singularly or jointly to include the uncertainty of the PFAS issue into property valuations.

CONTINGENT VALUATION METHOD

This study employs the contingent valuation (CV) survey method. The CV method has been around for more than half a century and is most often used for valuing environmental and public goods (Mitchell and Carson 1989). A pure public good is one that is both non-exclusive and non-rival, meaning one person's use doesn't exclude another's, nor does it diminish the amount in which another can use it. Environmental goods such as clean air and water generally fall under this classification. Once the good is "created", no one can theoretically be excluded from receiving it. In this scenario, a market is thus not suitable for these types of goods.

A CV survey elicits responses to a hypothetical situation where respondents provide a dollar value they would pay for the action, which is termed willingness-to-pay (WTP) (Mitchell and Carson 1989). The WTP value is *contingent* on the hypothetical arrangement, or market. In this form, WTP values are stated preference values, direct valuations from consumers. To achieve quality WTP figures respondents must have a 1) detailed description of the goods and hypothetical circumstances, 2) specific questions that directly ask for WTP values and 3) questions about the respondents' characteristics, behaviors, and demographics (Mitchell and Carson 1989). Information plays a vital role in a CV survey. The validity of the entire survey can hinge on the nature of the information provided to survey takers (Venkatachalam 2003). Incomplete or inaccurate information can lead to respondents undervaluing or overvaluing the benefits or services, respectively (Bergstrom et al 1990). If these guidelines are met, the sample size is sufficient and representative, and adjustments to "bad" data are made then quality results can be obtained from a CV survey.

The CV method has its strengths and weaknesses, while asking what people would pay results in a direct answer, it is still hypothetical and not an observation of actions taken by consumers. Not all data from the survey is usable, "bad" data will need to be adjusted or deleted for the data to be analyzed appropriately. Responses can be deemed unusable for several reasons, biases, misunderstanding of the questions, and protest bids all pose different problems for researchers using the CV method.

BIASES IN CONTINGENT VALUATION

There are several different types of biases that can affect responses: strategic bias, hypothetical bias, starting-point bias, vehicle bias, interviewer bias, information bias, non-response bias to name a few. Strategic bias is an under or overstatement where the respondent either doesn't think they will have to pay to receive the benefit or understate if they don't think they will receive the benefit at all. Hypothetical bias occurs when hypothetical questions lead to hypothetical answers untethered from reality. Starting-point bias happens when an initial value from the interviewer anchors the answers from respondents. In vehicle bias the respondent does not agree with the manner in which payments are received (potentially higher taxes). An interviewer bias stems from the characteristics of the interviewer as determined by the interviewee. Information bias can occur when a respondent has more information than is provided in the survey. Non-response bias takes effect if non-responders have similar preferences to respondents, affecting willingness-to-pay (Venkatachalam 2004).

Protest bids are bids in which the respondent opposes or does not approve of the survey and doesn't respond, gives invalid outlying responses, or responds with zero for something they do indeed value (Halstead et al 1992). If a respondent deems it unethical to place a dollar value on a good (such as scenery or spiritual land) they may refuse to answer. To determine if these bids should be removed from the dataset you must consider the survey response rate and/or the rate of protest bids themselves (Halstead et al 1992).

Another concern when employing a CV survey approach is uncertainty. As this approach is typically used for valuing nonmarket goods and resources there is no history of behavior for consumers on which to base their valuations. There is therefore some level of inherent uncertainty embedded within a CV survey. So, any researcher logically assumes the presence of preference uncertainty (Hanemann et al 1996). We can assume that while a true valuation exists, the respondent may not know it themselves. It is then possible or even likely that a stated Yes may be higher than what they'd truly pay, or that a No would be lower (Li and Mattsson 1995). An undervaluation of the good or service may lead to underinvestment while an overvaluation may lead to costs outweighing the benefits of the good or service. One method for minimizing uncertainty is to calibrate WTP values based on surety in response. Employing a scale from 1-10 where 10 is 'very sure' and 1 is 'not sure at all' you'd pay the stated figure, can sufficiently quantify certainty. Blomquist et al (2009) demonstrates that increases in certainty (certainty $\geq$8) decrease WTP values.

Several contributing factors or variables impacting general willingness-to-pay and willingness-to-pau for improved water quality have been established. Of these are gender, age, income, presence of children in the household, health concerns, and risk aversion. It's generally assumed that more risk-averse individuals are willing to pay more to eliminate risk than those less risk averse (Eeckhoudt and Hammitt 2004), women and younger people generally have higher WTP values than men and older individuals (Jordan and Elnagheeb 1993), and households with children and households with higher household incomes are on average willing to pay more (Genius et al 2008). Chatterjee et al (2017) demonstrated that trust in local government and trust in the body undertaking the treatment process positively affects how much people are willing to pay.

Consequently, contingent valuation studies along with willingness-to-pay data do not mean to suggest that taxpayers or consumers should pay in the case of government inaction or private pollution. Willingness-to-pay is at its core a valuation not a pledge. However, these figures could signal interest or preference (or lack thereof) for immediate solutions.

CONTINGENT VALUATION IN PRACTICE

There is a robust volume of literature using contingent valuation for various interests related to water quality. Previous literature has used contingent valuation to value tiers of water quality on a national level, asking survey takers to value water quality as boatable, fishable or swimmable (Carson and Mitchell 1993). This study tasked interviewees with stating a WTP value for national water quality at each tier (boatable, fishable, swimmable). Respondents were then given multiple opportunities to change their bids based on whether they were sure they would pay that amount, after they were informed what households in their income group actually pay, and a final 'pushed' WTP value by being told their previously stated amounts were not enough to reach the three goals. The purpose of the study was to attempt to determine whether or not the policy action and goals of the Clean Water Act would result in economic benefits. The results of this study dictate that net economic benefits would not be created (Carson and Mitchell 1993).

Residents in Jacksonville, Florida were asked what they'd be willing to pay for improvements to the quality of tap water (Chatterjee et al 2017). The respondents were asked a close-ended (payment-card) willingness-to-pay question where interviewers provided certain dollar amounts as an increase to their monthly water bill. The improvements specific to this case are in relation to the removal of a number of different chemicals as well as a foul odor from the drinking water. Importantly, the more concerned a respondent was about the safety of their tap water, the greater their willingness-to-pay.

New Hampshire residents were willing to pay $35.43 per month for reduced cancer morbidity and mortality risk by lowering arsenic levels in drinking water from 10 to 3 ppb (Lemos et al 2020). New Hampshire respondents were asked that assuming a treatment method could reduce arsenic contamination from 10 ppb to 3 ppb, increasing the quality of their drinking water, what would you be willing to pay monthly for this treatment? Lemos et al (2020) used a double-bounded dichotomous-choice method to elicit responses. Using this technique, respondents who answer yes to the initial value are asked a follow-up value double that of the initial value. If they answered no to the initial value, they were then asked if they would pay a value half of the initial value. This method is another example of a close-ended willingness-to-pay.

Contingent valuation has proved to be a well-documented methodology for evaluating nonmarket environmental goods. Both open-ended (what would you be willing to pay) and close-ended (are you willing to pay *x* amount) have been widely used and analyzed. For this reason, we decided to implement both types in our research, using the payment-card approach for the close-ended willingness-to-pay.

CHAPTER 3

METHODS

METHODS INTRODUCTION

This study uses response data from an October 2021 contingent valuation survey administered online to New Hampshire residents that elicits information on respondents' willingness-to-pay in addition to their monthly water bill for the removal of PFAS chemicals from their municipal drinking water. The willingness-to-pay monthly increase reflects their valuation of potentially reduced risk of adverse health consequences that may be related to consumption of PFAS-contaminated drinking water. Respondents were gathered using a targeted online sample from Marketing Systems Group and potential survey-takers were provided a link for survey access. Respondents were limited to New Hampshire residents, people at least 18 years of age, who receive their drinking water from a municipal/town system and consume at least 25% of their water from the tap. The "25% of consumption from the tap" question is a subjective value we hoped would exclude users who only rarely or infrequently use their tap for drinking water.

SURVEY

We surveyed only those NH residents whose primary water source is tap water derived from a public water system. We excluded well-water users for several reasons, most importantly, because well-users often view private well water as being of higher quality than public-water users (Jordan and Elnagheeb 1993). Therefore, their willingness-to-pay figures would not necessarily be directly comparable to the public consumer. Second, including both well and municipal water users would have required a larger dataset than was feasible for this project.

To estimate WTP values, we used the Contingent Valuation Method (CVM), a stated preference survey method. In its most basic form, it asks respondents to answer Yes or No to a hypothetical question as it relates to increases in their monthly water bill. The survey consists of five sections: (1) a cover letter explaining the background for the new PFAS rules, (2) a series of questions eliciting responses regarding respondents' perceptions of tap-water safety and steps they take for self-protection as it relates to drinking water, (3) an information sheet providing details about the potential health risks associated with PFAS contamination, (4) the contingent valuation questions, these questions elicit the specific valuations for the removal of PFAS from the system and subsequently the improved water quality and reduction of hazard, and (5) a set of questions eliciting demographic characteristics and information. The full survey can be found below in Appendix B.

Section 4 of the survey contained the contingent valuation questions that elicit the respondents' WTP to remove PFAS from their drinking water. The questions were framed as an increase in payment to their monthly water bill that would employ a filtration system that removes PFAS from the water and thus any possible associated negative health consequences. Two types of questions were used to elicit WTP values, one open-ended question and one payment card method. The open-ended question asks the maximum figure respondents could accept for the removal of PFAS and is as follows:

> *What is the **maximum amount** you would be willing to pay per month in addition to your average water bill to avoid possible adverse health consequences associated with consuming PFAS chemicals?*

The second WTP valuation question employed a payment ladder where respondents were shown a value and asked; are you willing to pay "x amount" or are you not? The question preceding the payment ladder is as follows:

For each of the dollar values below, please indicate if you WOULD or WOULD NOT be willing to pay that additional amount each month as a part of your monthly water bill to avoid ***possible*** *adverse health consequences associated with consuming PFAS chemicals.*

The respondent's stated range of values comes from the idea that WTP value lies between their highest stated yes value and the lowest stated no in the WTP ladder. This approach is important as people are more willing to state a range of values as opposed to one specific value when it comes to "environmental goods" (Hanley et al 2009). By obtaining WTP from two separate questions, we were able to obtain one specific value as well as a range of WTP values.

Increase in Water Bill per Month ($)	Yes, I would definitely pay this additional amount per month	No, I would definitely NOT pay this additional amount per month
$1		
$2.50		
$5		
$7.50		
$10		
$12.50		
$15		
$17.50		
$20		
$22.50		
$25		
$30		
$40		
$50		
$75		
$100		

Figure 3. Willingness-To-Pay Payment Card.

Once all the data were received, they had to be coded in a way that could be used in the econometric models. For example, if a respondent answered 'female' to the question on gender, their response was coded to 1, and males coded to 0. Almost all responses had to be coded in this way with a baseline response being '0', and each following response labeled 1, 2, 3, etc. The full codebook with all of the data translation can be found in (Appendix C).

Some respondent answers to the payment card WTP were unusable most likely due to a misunderstanding of the ladder system. A small handful of respondents recorded a Yes answer at a higher value than one to which they had answered no. These respondents were removed from the analysis of the WTP valuation. For example, if a respondent indicated Yes they would be willing to pay $10, No they would not be willing to pay $12.50, and then indicated Yes they would be willing to pay $15, their responses were treated as unusable and excluded from payment WTP analysis. In this scenario, there is no discernible Highest Yes and Lowest No interval. Instead of disregarding the higher yes above the lowest no, we simply excluded their payment card responses. Potential protest bids were noted within the open-ended WTP responses. Answers such as $350 (max) however potentially unrealistic, were still included.

To initially calculate open-ended WTP for the entire sample we calculated the mean response. For the payment card approach, we used both the means for Highest Yes and Lowest No responses. These values can be found alongside the sample summary statistics in Table 1.

ORDINARY LEAST SQUARES REGRESSION

Using Ordinary Least Squares Regression (OLS) and Interval Regression techniques we are able to ask more targeted questions that seek to unpack what drives WTP. Ordinary Least Squares regression is a commonly used technique that estimates coefficients of linear relationships between one or more independent variables and one dependent variable. OLS is commonly used in a number of fields including meteorology, biology, and economics (XLSTAT). In this project, OLS was used to determine factors influencing open-ended WTP, the dependent variable. If someone's open-ended WTP is observed as Y and is related to the person's characteristics, then

$$Y = \beta_0 + \beta_1 X_1 + \beta_1 X_2 + \beta_2 X_3 + \varepsilon$$

where β is the regression coefficient for each independent variable and ε is random error. The coefficients are produced using the regression command (reg) in STATA 13.1.

INTERVAL REGRESSION

The Interval Regression technique was used to calculate WTP from the payment card interval where true WTP lies between the interval Highest Yes and Lowest No. To calculate these WTP estimates, again we assume each person's WTP for risk reductions associated with PFAS exposure is equal to Y and related to the person's characteristics X_1,

$$Y = X_1 \beta + \varepsilon$$

So that ε is random error normally distributed and β is the corresponding coefficient. In this case, Y is not observed but lies somewhere within the interval $[Y_1, Y_2]$ based on the payment card approach. Consequently, for these observations the likelihood contribution is

$$PR(Y_1 < Y < Y_2),$$

Where Y denotes the random variable representing the dependent variable in the model. The interval regression thus estimates the probability that the person's WTP variable (Y) exceeds one threshold but is less than another. In other words, it estimates the probability that WTP falls within a certain interval (StataCorp 2007). The maximum likelihood function is estimated in STATA 13.1 using interval regression (intreg).

The results of both these regressions are used to estimate willingness to pay based on the model by multiplying the sample mean for each variable included by the coefficient on that variable and summing. For the models described above, the following equation is used to calculate mean WTP (Hanemann 1989):

$$Mean\ WTP = \sum_i (\beta_i * \overline{X_i}) + Cons,$$

where $\overline{X_i}$ represents the mean value of each individual independent variable used in the model, and *cons* represents the regression constant for each model.

In summary, we determined mean willingness-to-pay from the entire sample's responses to the open-ended question and the payment card (via highest Yes, lowest No interval). We then ran models with selected independent variables to determine actual willingness-to-pay. Additionally, we selected for various levels of certainty in response and ran additional models investigating other potentially explanatory values. The results of these models are presented in the following chapter (Chapter 4, Results) and further discussed and explained in Chapter 5.

CHAPTER 4

RESULTS

SAMPLE STATISTICS

The characteristics of our sample are not dissimilar to the population characteristics of the state of New Hampshire (Table 1.) Our sample had a higher percentage of females than the state average (64.7% vs. 50.5%) while the average age was nearly identical (42.6 vs. 42.4). Household income is lower than the NH mean (56k vs. 71k) while on average our respondents reported a child in the household at a higher percent (38.78% vs. 30.5%) and more households of three or more individuals than the NH mean (52.3% vs. 36.3%). Roughly one in five (19.9%) respondents had moderate or major health concerns about tap water while about one-third (36.5%) reported use of some type of at-home water filtration system.

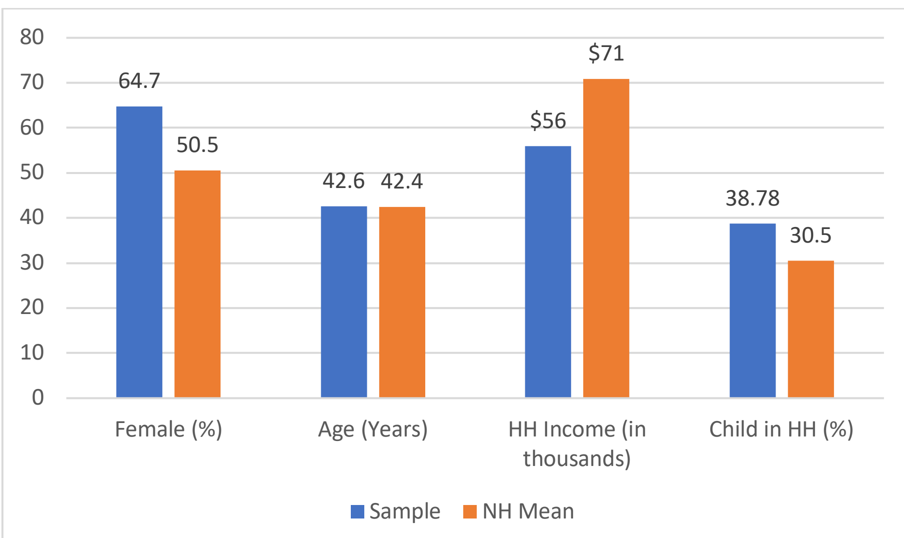

Figure 4. Summary statistics, sample vs New Hampshire means (from census lookup).

The mean open-ended willingness-to-pay from the entire sample was $22.21 per month, which extrapolated comes to $266.52 annually in addition to the current water bill. However, the median response was $10 per month while the maximum response was $350 and an additional eight respondents reported WTP values of $200 per month. Likely, this open-ended question is significantly affected by the presence of these outlying responses when comparing the mean to the mean Lowest No ($14.08) and Highest Yes ($14.05) values from the payment card WTP and the median response. The payment card values more closely resemble the median open-ended value adding to the likelihood that the open-ended mean value is more sensitive to outliers. The large discrepancy between the open-ended mean and median responses highlights how large of an effect high outlying responses have on willingness-to-pay.

Table 1. Summary Statistics

	Full Sample	NH Mean
Female	64.7%	50.5%
Age	42.6	42.4
Annual HH Income	$55,973	$70,936
Child in Household	38.78%	30.5%
Household Size		
1	15.7%	25.5%
2	33.7%	38.1%
3+	50.3%	36.3%
Health Concern (Yes = 1)	19.9%	
Home Filter (Yes = 1)	36.5%	
Open-Ended WTP		
Mean	$22.21	
Median	$10	
Min	$0	
Max	$350	
Payment Card WTP		
Mean of ‘Highest Yes’	$14.05	
Mean of ‘Lowest No’	$14.08	
# of Respondents	308	

Notes: New Hampshire means are derived from the US Census American Fact Finder System.

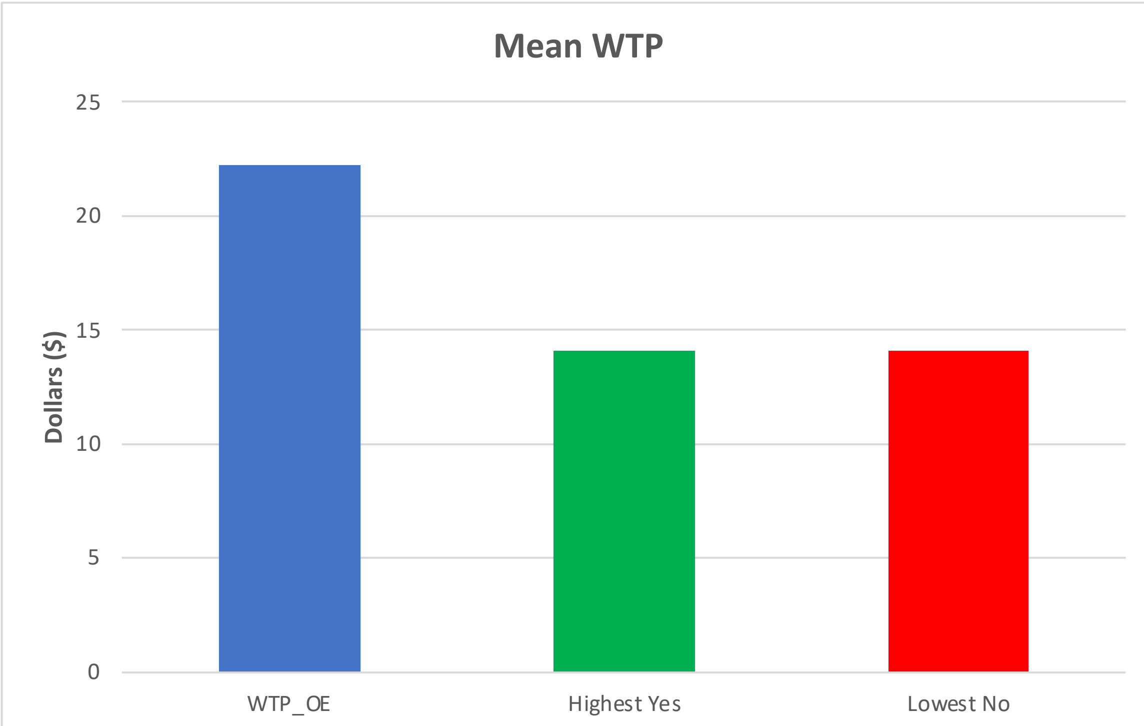

Figure 5. Mean Willingness-To-Pay for open-ended and payment card methods. Values available in Table 1.

ORDINARY LEAST SQUARES REGRESSION

Table 2 below displays results from our OLS model of the open-ended WTP question. Responses to the open-ended question reveal several explanatory variables that significantly contribute to the WTP to remove PFAS contamination from their water and reduce the risk of potential adverse health consequences from exposure. Women and younger people had higher WTP than men and older individuals. The presence of a child in the household positively influenced WTP, while the presence of a moderate or major health concern most substantially affected WTP. Accounting for all variables explored in the model, NH residents in our open-ended question indicated a monthly WTP of $19.54. If extrapolated out, that figure comes to an annual amount of $234.48. Income, house size, filtration, and certainty had no effect on WTP.

Table 2. Ordinary Least Squares Regression Results and Derived Willingness-To-Pay Measures

	Model
Constant	32.705***
	(11.461)
Female (Yes = 1)	-11.451**
	(4.565)
Age	-0.331**
	(0.150)
HH Income	2.026*
	(1.077)
Child in HH (Yes = 1)	5.959**
	(2.673)
Household Size	-2.928
	(2.204)
Health Concern	26.374***
	(5.347)
Filtration	1.729
	(4.462)
Certainty	0.319
	(0.843)
N	308
WTP (Monthly)	*$19.54*
WTP (Annually)	$234.48

Notes: Numbers as displayed are coefficient estimates and numbers in parentheses are their associated standard errors. *, **, *** indicate statistical significance at the 0.10, 0.05, and 0.01 levels, respectively.

INTERVAL REGRESSION

Table 3 presents the results from the interval regression model of the payment-card data using the same explanatory values as the OLS regression. The ‘full sample’ model shown below was initially run separately to include the variable ‘certainty’. In that model certainty was a significant factor (P-value 0.004) indicating that the more certain an individual was, the more they’d be willing to pay. Knowing certainty played a role in the payment-card WTP, we ran three models separating respondents into thirds 1) with the full sample, 2) with certainty > 4, and 3) with certainty > 7 (Table 3).

Table 3. Interval Regression Results and Derived Willingness-to-Pay Measures, by Certainty Level of Respondent

	Model 1: Full Sample	Model 2: Certainty > 4	Model 3: Certainty > 7
Constant	14.744***	16.301***	16.638***
	(4.959)	(5.152)	(6.078)
Female (Yes = 1)	0.281	0.197	--1.025
	(2.247)	(2.336)	(2.790)
Age	-0.080	-0.079	-0.108
	(0.074)	(0.076)	(0.089)
HH Income	0.974*	0.936*	1.572*
	(0.529)	(0.552)	(0.647)
Child in HH (Yes = 1)	0.633	1.693	0.211
	(1.334)	(1.481)	(1.828)
Household Size	-1.459	-1.844	-1.667
	(1.085)	(1.169)	(1.409)
Health Concern (major)	7.119***	7.019***	4.674
	(2.624)	(2.671)	(3.171)
Home Filter (Yes = 1)	2.012	1.493	2.995
	(2.199)	(2.289)	(2.706)
N	308	280	196
WTP (Monthly)	*$13.07*	*$13.94*	*$13.84*
WTP (Yearly)	$156.84	$167.28	$166.08

Notes: Numbers as displayed are coefficient estimates and numbers in parentheses are their associated standard errors. *, **, *** indicate statistical significance at the 0.10, 0.05, and 0.01 levels, respectively.

The above results demonstrate one key factor influencing WTP, that is the presence of health concerns (moderate or major). Therefore, according to our models those who have an existing moderate or major health concern are consistently more likely to be willing to pay more than those with minor or no existing health concerns regarding tap water.

Accounting for all confounding factors, NH residents indicate being willing to pay an additional $13.07 per month on the water bill for the potential risk reduction associated with removing PFAS from their drinking water. An extra $13.07 translates to $156.84 annually on top of the existing water bill (Table 3, Model 1). Results from the interval regression of the full sample (Table 3, Model 1) can be compared to results from two separate models when allowing for the effects of increased certainty of response. Model 2 (Table 3) presents a model including only those who responded to the question "how certain are you that you would be willing to pay [the amounts you indicated above]" (scale 1-10, 10 suggesting 'completely sure') with a certainty > 4. Model 3 (Table 3) includes only those individuals who responded to the certainty question with certainty > 7.

For those whose certainty was > 4, monthly willingness to pay was $13.94 ($167.28 annually) while those whose certainty was > 7, monthly willingness to pay was $13.84 ($166.08 annually) (Table 3). Willingness-to-pay based on the degree of certainty indicates that increased certainty from relative uncertainty to more certain is associated with higher willingness-to-pay.

Table 4 presents results interval regression results from new models investigating potential factors including political views (democrat or republican), whom they trust as environmental news sources, whom they trust for news, and whom they think should pay for water treatment. Three models again include the full sample (Table 4, model 1), with certainty >4 (Table 4, model 2), and certainty >7 (Table 4, model 3). The "Trust Env." variable is a dummy variable for responses to the question "When it comes to environmental issues, who do you trust more?" when respondents answered, "Don't trust any". The variable, "Trust News" is a dummy variable for the question "Where would you normally look to get news and information" where respondents selected only "Fox News". Finally, the "Polluter" variable is a dummy variable for answers to the question "In your opinion, how do you think the safety of tap water should be paid for" where respondents answered only "Charge polluters of the water, if they can be identified". All questions and possible answers to these questions can be found in the full survey in Appendix B.

Table 4. Interval Regression Results, by Certainty Level of Respondent

	Model 1: Full Sample	Model 2: Certainty > 4	Model 3: Certainty > 7
Constant	15.569***	17.329***	16.523***
	(5.132)	(5.341)	(6.221)
Female	0.086	0.064	-1.107
	(2.273)	(2.369)	(2.803)
Age	-0.078	-0.080	-0.101
	(0.074)	(0.077)	(0.089)
Income	1.012*	0.986*	1.639**
	(0.535)	(0.557)	(0.652)
Child in HH	0.573	1.768	0.376
	(1.338)	(1.490)	(1.862)
House size	-1.448	-1.953	-1.884
	(1.105)	(1.200)	(1.447)
Health Concern	7.129***	6.835**	4.729
	(2.643)	(2.696)	(3.188)
Home Filter	2.018	1.634	2.987
	(2.203)	(2.296)	(2.708)
Democrat	-1.411	-2.051	-1.542
	(2.480)	(2.547)	(3.212)
Republican	-2.610	-1.694	-0.898
	(2.966)	(3.176)	(3.503)
Trust Env.	1.380	1.577	-0.570
	(3.711)	(4.050)	(4.924)
Trust News	0.393	1.559	4.266
	(4.525)	(5.025)	(6.590)
Polluter	-0.631	-0.481	1.467
	(2.235)	(2.336)	(2.783)
WTP (monthly)	*$13.08*	*$13.98*	*$13.81*
N	308	280	196

Notes: Numbers as displayed are coefficient estimates and numbers in parentheses are their associated standard errors. *, **, *** indicate statistical significance at the 0.10, 0.05, and 0.01 levels, respectively.

Based on interval regression results shown in Table 4., none of the new potential explanatory variables are significant drivers of willingness-to-pay for our survey respondents (Model 1, Table 4). Even when interval regressions account for certainty in response (Model 2 and Model 3, Table 4) none of the chosen variables show a significant effect on responses to the payment-card willingness-to-pay question.

This chapter has presented all results from the econometric modeling performed with the data from our survey. The results presented in this chapter will be examined and discussed further in the following chapter. Included in this discussion will be what these results mean in terms of evaluating risk awareness, which independent variables affect willingness-to-pay for PFAS treatment in New Hampshire, and what value this research may hold for future research and possible policy action.

CHAPTER 5

DISCUSSION

DISCUSSION INTRODUCTION

This thesis research is aimed at investigating how New Hampshire residents value the safety of their tap water specifically as it relates to PFAS chemical contamination. This chapter of the thesis wades through the results of the econometric modeling, interprets those results as a valuation of risk-aversion, and attempts to situate these results with other contingent valuation surveys and the broader umbrella of chemical contamination remediation and removal. Finally, this chapter will end with concluding remarks about the research and its implications as well as opportunity for future work in the area.

ECONOMETRIC MODELING

We conducted a survey of New Hampshire residents to assess general concerns about municipal tap water safety as they regard PFAS contamination and the negative health outcomes that may come with ingesting PFAS-contaminated water. Employing a contingent valuation survey, we were able to derive respondent willingness-to-pay estimates for PFAS remediation in the form of an increase to their individual monthly water bill. The removal of PFAS from drinking water would theoretically reduce or remove the risk of the negative health outcomes associated with PFAS intake. We used maximum likelihood estimation from our payment-card WTP interval via interval regression to estimate WTP by multiplying the sample mean for each explanatory variable by its respective regression coefficient to determine mean willingness to pay for our respondents. For the open-ended question, willingness-to-pay was estimated via

Ordinary Least Squares Regression by again multiplying the regression coefficient for each variable by the same mean for that variable and summing.

Of the primary explanatory variables, the presence of moderate or major health concerns about drinking tap water proved to be the most significant confounding factor affecting willingness-to-pay. Respondents with moderate or major health concerns have a consistently higher probability of choosing “yes” to increased monthly water bills in exchange for improved water quality when compared to those with minor or no existing health concerns about drinking their tap water. Once all confounding factors are accounted for, New Hampshire residents indicate being willing-to-pay an additional $13.07 per month or $156.84 per year to their water bill for removal of PFAS from their drinking water.

Comparing these annual figures to the prices of existing treatment systems known to reduce the levels of PFAS in water is one way to anchor these results to real-world possibilities. Would residents rather pay taxes or fees to clean up the water for everyone, or pay roughly that same annual amount for a home drinking water treatment system that protects the respondent and anyone who shares the household? Might it in turn be more cost-effective for the state/polluter to supply affected properties with home treatments rather than installing a system-wide treatment? We were able to determine that already using a home filtration system doesn’t affect willingness-to-pay, which could indicate that the use of home filtration (note, filtration may not be set up to capture PFAS) may not be enough for consumers to feel safe about drinking their water.

Moderate and major health concerns were not the only significant factor when respondents were asked to state a figure that they would pay without the framework of the payment card. Gender, age, household size, and the presence of a child in the household all played a role. In this model female respondents were more likely to state lower values, a result in contrast to established risk-aversion and willingness-to-pay literature. For every year older a respondent was, the less likely they were to state a higher value, while the larger the household size the more likely the willingness-to-pay figure would be greater. Finally, the presence of a child in the house increased the likelihood of a higher response. Based on this question, residents indicated they would be willing to add $19.54 a month or $234.48 a year to their existing water bill for the removal of PFAS from their water.

A six-dollar increase in mean response from the open-ended question in comparison to the payment-card mean may be explained in several ways. For one, the presence of outlying responses such as $200 per month or higher in the open-ended responses inevitably drags this value up. It is highly unlikely the value of clean drinking water from the tap to a consumer is worth $200 dollars a month ($2400 annually) when considering the price of bottled water or other treatment methods. Home drinking water treatments can be purchased for several hundred dollars and once installed often last upwards of a decade. The discrepancy between mean responses to the two willingness-to-pay questions can also be partially explained by how close-ended CV surveys resulting in a consumer payment interval elicit more truthful expressions than open-ended questions (Hanley et al 2009). The framing provided by the payment-card protects against protest bids and extreme outlying responses. In conclusion, due to these issues the willingness-to-pay data elicited from our open-ended question is likely not meaningful and the focus should be on the payment-card results.

CERTAINTY IN RESPONSE

Given how little we know epidemiologically regarding PFAS intake on human health, a great deal of uncertainty underlies this issue. To try and tackle this issue we asked respondents to dictate how certain they were that they would indeed pay the amount they stated on a scale of 1-10. With certainty >4 willingness-to-pay went up to $13.94 per month, indicating that more certainty in response leads to a higher probability of answering “yes” to the payment-card question. With certainty increased to certainty >7, willingness-to-pay is $13.84 per month. Greater certainty in response could come from substantial prior knowledge regarding PFAS or a high degree of personal risk-aversion. Respondents were not asked why they were or were not certain that they would be willing to pay the figure they stated.

ADDITIONAL MODELS

In addition to the initial models, we also investigated whether factors such as political affiliation, trust in environmental news outlets/institutions/organizations, news sources, and whom they feel should pay for tap water safety affect willingness-to-pay. Previous contingent valuation studies have shown that trust in institutions, local governments, and who is carrying out the treatment itself has an effect on willingness-to-pay for drinking water quality. The less an institution is trusted, the fewer people are willing to pay (Chatterjee et al 2017).

Another area of intrigue was whether political affiliation plays any role, such as, is the PFAS issue in NH political in any way? We investigated whether politics helped frame responses. Americans who identify as Republican trust Fox News as a news source more than any other news outlet (Guskin 2018) and Fox News has an impact on people’s perceptions of science, especially when it comes to skepticism or denial of climate change and more recently the Covid-19 pandemic (Hoewe et al 2020).

While asking for residents’ willingness-to-pay may inherently imply the responsibility of payment lying with the resident, that is not necessarily our view. Therefore, we inquired as to whether a respondent who stated that only polluters should pay (if identifiable) is more likely to select a higher Yes value on the payment card. When specific polluters cannot be found or while settlements/agreements are negotiated, likely the only way to pay for remediation would lie in fees or taxes to users. Theoretically, for someone who does not believe taxes should be raised or that fees be applied to consumers, the willingness-to-pay value represents the value of risk-aversion rather than what they think they should pay themselves.

According to our models, none of the aforementioned variables confer a significant effect on New Hampshire respondents' willingness-to-pay nor is the monthly willingness-to-pay affected. Thus, we can conclude that this particular issue is not of partisan nature in the state. Where people get their news and whom they trust for environmental news also plays no meaningful role. Additionally, believing that only identifiable polluters should pay for the removal of PFAS was not a significant factor either.

Examining these same variables under different levels of certainty provided no additional significance for responses. For both certainty >4 and certainty >7 none of the confounding variables proved significant. Again, these results highlight that New Hampshire residents do not view the issue of PFAS contamination with a partisan lens. New Hampshire is a state that prides itself on being moderate or centrist and having the ability to resolve issues through bipartisan legislation. According to our findings, the issue of PFAS contamination itself is not partisan. However, New Hampshire citizens generally resent tax increases and government actions that require additional funding and therefore we may expect that while the economic valuation of the issue itself may not be political, the payment vehicle used to address it could very well be.

LIMITATIONS

This research provides valuable insight into how New Hampshire residents view the PFAS contamination issue within the state, however, there are several limitations to this work. First, the study sample may not be a perfect representation of New Hampshire residents. While the mean age of our respondents was in line with the state average, there was a noticeable discrepancy between mean gender and household income. Given that the average household income from our sample was lower than the state average, there is a possibility that our willingness-to-pay calculations are actually an underestimate.

Second, our open-ended willingness-to-pay question was influenced by a number of outlying responses. Eight respondents replied that they would pay $200 extra monthly, and one responded with $350. Either these respondents mistook the question for an annual number, or their response was a protest bid. Regardless, these highly unlikely responses elevate the mean response. Additionally, the regression results to the open-ended question indicate that women are less likely to pay, which lies in stark contrast to the existing literature. Therefore, it is likely that the willingness-to-pay results from the open-ended question may not accurately display how New Hampshire residents evaluate the issue.

Third, regarding the questions about trust, news sources, and who should pay for treatment. The 'select all that apply' option allowed for a convoluted set of responses that proved difficult to code. In future research these questions should require respondents to indicate whom they trust the most, the one outlet they receive the most news from, and whom they think should be the primary contributor when it comes to paying for PFAS remediation and removal. Finally, while we did not include any questions about the effects of the ongoing Covid-19 pandemic, there is likely to be some effect derived from rapidly changing social and economic realities that should be investigated in future work.

RECOMMENDATIONS

The first recommendation would be to expand this study to include more respondents and better incorporate a spatial component to determine where interest peaks in the state. It could be hypothesized that concern is greater for residents nearer to identified hotspots such as Merrimack or Portsmouth. Second, the state should expand its testing mechanisms to include more properties around hotspots and to include previously untested regions. Expanded testing would not only illuminate the scope of the issue but could be used to help educate and inform the general public about how PFAS gets into the environment, how dangerous it may be, and what they can and should do to lower their risk of PFAS-related negative health outcomes. Finally, the NH legislature should craft legislation creating structural procedures for cleanup that would speed up the litigation/settlement process so that actions can be taken more swiftly than in the case of Saint-Gobain in Merrimack.

CONCLUDING STATEMENTS

The issue of PFAS contamination is multifaceted and complex. Research is ongoing regarding how harmful the chemicals are to people and to what degree. More work is required to determine how mobile PFAS are and through what pathways they enter ecosystems and organisms. Additionally, rigorous testing needs to begin in many places and where there is testing, it must expand and intensify if we are to learn how widespread this issue truly is. In the meantime, we cannot wait to act until all these factors are determined, but without that information, specific legislative action and remediation are more difficult. Clean water is often regarded in economics as a public good, and as is the nature of public goods there is no established market. To determine the economic viability of action this thesis attempts to dig into how consumers of New Hampshire public drinking water value, in dollars, solving this problem.

Our results suggest that people are willing to contribute monetarily to ensure their safety in regard to PFAS, specifically. The amounts indicated by our respondents display in our view a meaningful insight into risk awareness and how risk-averse people already are about PFAS. We do not mean to suggest that residents who have played no role in the contamination of their water should foot the bill for the cleanup. However, in the absence of top-down action from local and state governments or forced action through identified polluters, contributions from citizens may be one reliable pathway to short-term solutions. Willingness-to-pay within that framework can be seen as a perceived value of undertaking a treatment plan, whatever that may be. If people are willing to provide funding equal to or exceeding the costs of in-home treatment, local governments should look to provide affected consumers with home treatment systems in settlements with polluters.

In the case of Saint-Gobain Performance Plastics pollution of drinking water in Merrimack, NH, and surrounding towns, the state and local governments have come to multiple settlements forcing the company to provide bottled water, additional waterline connections, and point-of-entry treatment for affected properties. However, other hotspots of PFAS exist in New Hampshire where there is no single identified polluter. These instances present a more difficult issue to resolve as actions by state agencies will need to be funded explicitly by taxpayers in lieu of a culpable business. Regardless of the source, it is imperative that statewide testing increase to fully capture the depth of the issue within the state, as our data demonstrate public interest in combatting the problem.

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APPENDIX A - IRB SURVEY APPROVAL LETTER

University of New Hampshire

Research Integrity Services
51 College Road, Durham, NH 03824
research.integrity@unh.edu

Sep 1, 2021 11:05:51 AM EDT

John Halstead
Management, Natural Resources & The Environment

Study Title: PFAS Contamination Survey
IRB #: IRB-FY2022-79
Approval: September 1, 2021

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 104(d). Approval is granted to conduct your study as described in your protocol.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, Responsibilities of Directors of Research Studies Involving Human Subjects. Please read this document carefully before commencing your work involving human subjects.

Note: IRB approval is separate from UNH Purchasing approval of any proposed methods of paying study participants. Before making any payments to study participants, researchers should review the Payment of Incentives/ Compensation to Research Participants guidance to ensure they are complying with institutional requirements. If such institutional requirements are not consistent with the confidentiality or anonymity assurances in the IRB-approved protocol and consent documents, you may need to request a modification from the IRB.

Upon completion of your study, please submit a study closure form through Cayuse IRB/Human Ethics along with a report of your findings.

If you have questions or concerns about your study or this approval, please feel free to contact Melissa McGee at 603-862-2005 or melissa.mcgee@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson

Julie F. Simpson
Director

Appendix B - PFAS SURVEY

SECTION 1: INTRODUCTION AND FILTER QUESTIONS

Our research team from the University of New Hampshire is conducting a survey to gather information on risk perceptions and preferences associated with Per- and Polyfluoroalkyl Substances, more commonly referred to as PFAS, a set of manmade chemicals used in a variety of household and industrial applications, many of which are found in residential drinking water (i.e. tap water) throughout New England. Ingesting these chemicals though drinking water has the potential to increase the risk of a wide range of health effects, including testicular and kidney cancer, though the exact risk from exposure to PFAS is still largely uncertain. Currently, states around the region are undertaking an investigation to pinpoint the scope of the problem, which will help to identify the potential benefits and costs to additional treatment for public water systems and their customers.

In order to participate in this survey, you must be at least 18 years old. This survey will take approximately 10 minutes to complete. Survey participation is voluntary and you will not receive any compensation for participating. There are no potential risks for participating in this study. This survey is funded by the University of New Hampshire.

We seek to maintain the anonymity of all data and records associated with your participation in this research. We will report the data in aggregate, assessing trends in individual preferences and perceptions related to arsenic in drinking water. The results may be used in reports, presentations, and publications.

If you have questions about your rights as a research subject you can contact Melissa McGee at UNH Research Integrity Services at 603-862-2005 or melissa.mcgee@unh.edu. If you have questions about this research project or would like more information, you may contact project leader John Halstead, Professor of Environmental and Resource Economics, University of New Hampshire at 603-862-3914 or john.halstead@unh.edu.

In order for you to help us with this study, you must be at least 18 years old. Are you at least 18 years old?

Yes
No

In what state is your primary residence?

New Hampshire
Maine
Vermont
Other

What is your household zip code?

____

Do you consume at least 25% of your drinking water from the tap, either at home or away from home?

Yes
No

What percentage of your drinking water do you consume from the tap, either at home or away from home?

0%
1%-24%
25%-50%
51%-75%
76%-100%

How do you receive tap water in your home?

Public or municipal water supply (incl. community wells)
Private Wells

SECTION 2; SELF-PROTECTION AND PERCEPTIONS OF SAFETY OF TAP WATER

Apart from receiving water from the municipal water utility or community well, what are the other sources of your household drinking water?
(Select all that apply)

Bottled Water
Water Delivery System
Other (please specify)
*No other sources
*I don't know

How much money do you estimate that your household spends on purchased drinking water (e.g. bottled water, water delivery service) per month (in dollars)?

None
$25 or less
$26 - $50
$51 - $100
$101 or more

When purchasing drinking water from sources outside of your home tap (i.e. bottled, water delivery service, etc.), you do so mostly because of ...

Convenience
Taste
Health concerns about tap water
Other (please specify)

Do you use a home water filtration system of any kind in your household? This can include containers with a filter, on the faucet systems, or whole house systems.

Yes (please specify)
No

How much did your water filtration system cost to purchase?
$50 or less
$51 - $100
$101 - $200
$201 - $300
$301 or more

We would like to get a sense of the percentage of the water you consume from different sources. In the table below, please fill in your best guess of the percentage of water you personally consume from the different sources identified below.
(The total from all sources should add to 100%)
Water direct from tap without any home filtering or treating
Tap water from sources other than at home
Home filtered or treated tap water
Purchased drinking water (e.g. bottled water, water delivery service)

Do you test the quality of your home tap water, either by in-home sampling tests or by sending them to an external lab?
Yes, I test the quality of my home tap water using in-home tests
Yes, I test the quality of my home tap water by sending a sample to an external lab
No, I do not test my home tap water

We would like to know whether you have any health concerns about drinking your household tap water before any additional filtering (i.e. through a Brita, etc.). Please choose the one statement that best reflects your personal opinion.
No health concerns. I feel that tap water does not pose a problem for my personal or my family's health
Minor health concerns. I feel that drinking tap water may pose a minor problem for my personal or my family's health
Moderate health concern. I feel that drinking tap water may pose a moderate problem for my health or my family's health
Serious health concern. I feel that drinking tap water may pose a serious problem for my health or my family's health

SECTION 3: HEALTH EFFECTS OF PFAS EXPOSURE FROM TAP WATER

Q16 Please read the information below on PFAS and its potential adverse health effects before moving on to the next page...

PFAS are a large family of manmade chemicals which have been used for much of the 20th and 21st centuries across numerous industries. Due to the many helpful qualities of various PFAS chemicals (waterproof, greaseproof, nonstick), they have been used in plastic packaging, nonstick kitchenware, Teflon, Scotchgard, as well as fire-fighting-foam (AFFF), among many other applications. Almost all (>98%) Americans have a detectable amount of PFAS in their blood, and due to their persistence in nature, PFAS are also referred to as forever chemicals.

While the ubiquity of various PFAS chemicals is known, less is understood however about direct human health effects resulting from prolonged PFAS contamination. There are currently no federal PFAS regulations in the United States and only a handful of states have their own varying mandates. New Hampshire, being one of the most negatively affected states, has arguably the most stringent regulations (passed into law in the summer of 2020). The bill outlined restrictions for 4 specific PFAS at varying concentrations from 11-18 ppt (parts per trillion), below the EPA's recommended combined maximum concentration of 70 ppt. While no study has yet to directly link specific adverse health conditions to PFAS, many have outlined diseases that have shown to be associated with elevated levels of PFAS contamination of drinking water. Below are some of the possible human health concerns from PFAS:

Potential Adverse Health Effects from PFAS Exposure
Cancer (testicular, kidney)
Liver effects (serum enzymes/bilirubin, cholesterol)
Immunological effects (decreased vaccination response, asthma)
Developmental effects (birth weight)
Endocrine effects (thyroid disease)
Reproductive effects (decreased fertility)
Cardiovascular effects (pregnancy induced hypertension)

SECTION 4: VALUATION OF HEALTH RISK REDUCTIONS FROM INCREASED WATER QUALITY

We would like to know your opinions about the management of tap water quality in your state. The following section will ask you to respond to questions regarding your willingness-to-pay to improve drinking water quality in your state by removing some (if not all) PFAS in the water system, and thus lowering your chances of any variety of adverse health effects as described above.

Please note, we know that responses from surveys are often not a reliable indication of how people will actually choose. In surveys, some people ignore the sacrifices they would need to make if their choice actually meant they would have less money to spend. We'd like you to respond to the following questions as if this were a real choice -- imagine that you actually have to dig into your pocket and pay the additional charges on your water bill if the majority agreed with your choice. Note that by paying more on your water bill you would have less money to spend on other things.

Assume there is a water filtration system that can be implemented at your community water supply that would filter out PFAS, and thus lower your risk of adverse health consequences from PFAS exposure.

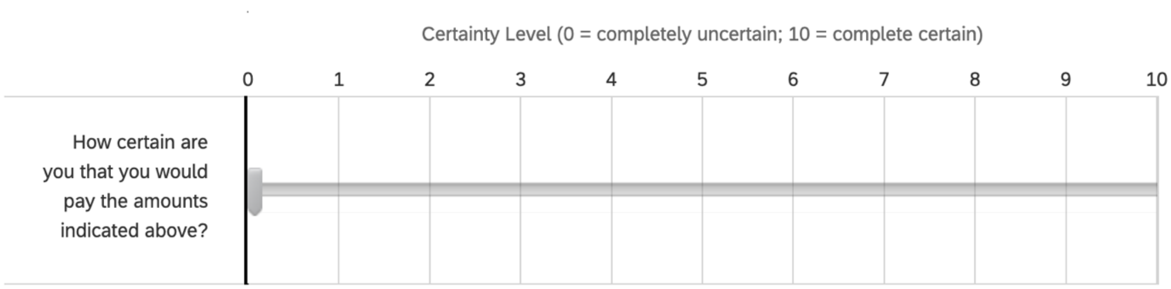
For each of the dollar values listed below, please indicate if you WOULD or WOULD NOT be willing-to-pay this additional amount on top of your average monthly water bill to have this water filtration system implemented.

	YES, I would definitely pay this amount per month in addition to my normal water bill to filter out PFAS from my drinking water	NO, I would definitely NOT pay this amount per month in addition to my normal water bill to filter out PFAS from my drinking water
$1	○	○
$2.50	○	○
$5	○	○
$7.50	○	○
$10	○	○
$12.50	○	○
$15	○	○
$17.50	○	○
$20	○	○
$22.50	○	○
$25	○	○
$30	○	○
$40	○	○
$50	○	○
$75	○	○
$100	○	○

What is the **maximum amount** you would be willing to pay per month in addition to your average water bill to avoid possible adverse health consequences associate with consuming PFAS chemicals?

____

In terms of the amounts you indicated above, how **certain** are you that you would be willing to pay this amount? Use the slider below to choose your certainty level, where 0 suggests you are **completely uncertain** about your stated willingness to pay per month and 10 suggests you are **completely certain** about your stated willingness to pay per month.



SECTION 5: RESPONDENT INFORMATION

For a variety of reasons, people of different age, gender, and backgrounds may face different health effects from exposure to PFAS. For the purposes of this study, it will be important for us to know some of these details about you. Please continue to the next page and respond to the following questions about yourself.

What is your gender?

- Male
- Female
- Prefer not to disclose

What is your current age?

____

How many people currently live in your household, including yourself?

- 0
- 1
- 2
- 3
- 4
- 5
- 6 or more

How many children under the age of 18 live in your household?

- 0
- 1
- 2
- 3
- 4
- 5
- 6 or more

What is the highest level of schooling you have completed?

Some high school
High school
Some College
Associates
Bachelors
Graduate/Professional

What is your current employment status?

Student
Retired
Full-time
Part-time
Self-employed
Unemployed

What is your approximate annual household income from all sources, before taxes?

Less than $15,000
$15,000-$29,999
$30,000-$44,999
$45,000-$59,999
$60,000-$74,999
$75,000-$89,999
More than $90,000

Select any (or all) of the long term health conditions that you have.

Food Allergies
Any other allergies (please specify)
Asthma
Arthritis or rheumatism
Back problems, excluding arthritis
High blood pressure
Migraine Headaches
Chronic Bronchitis or emphysema
Sinusitis
Diabetes
Epilepsy
Heart Disease
Cancer (please specify)
Stomach or intestinal ulcers
Effects of stroke
Any other long-term condition that has been diagnosed by a health professional (please specify condition
*No long-term health issues

In your opinion, how do you think the safety of tap water should be paid for?
(Select all that apply)

Increase federal, state, or municipal taxes
Increase fees to tap water users
Charge polluters of the water, if they can be identified
Other (please specify)

Where would you normally look to get news and information?
(Select all that apply)
CNN
MSNBC
Fox News
BBC
NPR
AP
Social Media
Other (please specify)
DailyWire
Newsmax

When it comes to protection/environmental health information, what sources would you trust the most?
(Select all that apply)
United States Environmental Protection Agency (EPA)
Your state's Department of Environmental Services (DES)
Local News Outlets
National News Outlets
Independent Environmental Groups (ex: The Nature Conservancy, World Wildlife Fund, The Sierra Club, etc.)
Other (please specify)

When it comes to environmental issues, who would you trust more?
Government sources (local, state, national)
Independent Research Institutions (incl. research colleges and universities)
Private Companies
Trust them all equally
Don't trust any

Generally speaking, do you usually think of yourself as a Republican, a Democrat, an Independent, or something else?
Democrat
Independent
Republican
Other party
Don't know/not sure

Would you consider yourself a strong Democrat or a not very strong Democrat?
Strong democrat

Not a strong Democrat

Would you consider yourself a strong Republican or not a very strong Republican?

Strong republican

Not a strong republican

Appendix C - Codebook

Question #	Question	Variable Name	Values	Label
Q11	Do you use a home water filtration system of any kind in your household? This can include containers with a filter, on the faucet systems, or whole house systems. - Selected Choice	filtration	1=yes	
Q14	Do you test the quality of your home tap water, either by in-home sampling tests or by sending them to an external lab?	qualitytest	0 1 2	No Yes (home) Yes (lab)
Q15	We would like to know whether you have any health concerns about drinking your household tap water before any additional filtering (i.e. through a Brita, etc.). Please choose the one statement that best reflects your personal opinion.	healthconcern	0 1 2 3	None Minor Moderate Major
Q18_1	Would you pay $1	pc1	1=yes	
Q18_2	Would you pay $2.50	pc2.5	1=yes	
Q18_3	Would you pay $5	pc5	1=yes	
Q18_4	Would you pay $7.50	pc7.5	1=yes	
Q18_5	Would you pay $10	pc10	1=yes	

Q18_6	Would you pay $12.50	pc12.5	1=yes	
Q18_7	Would you pay $15	pc15	1=yes	
Q18_8	Would you pay $17.50	pc17.5	1=yes	
Q18_9	Would you pay $20	pc20	1=yes	
Q18_10	Would you pay $22.50	pc22.5	1=yes	
Q18_11	Would you pay $25	pc25	1=yes	
Q18_12	Would you pay $30	pc30	1=yes	
Q18_13	Would you pay $40	pc40	1=yes	
Q18_14	Would you pay $50	pc50	1=yes	
Q18_15	Would you pay $75	pc75	1=yes	
Q18_16	Would you pay $100	pc100	1=yes	
Q19	What is the maximum amount you would be willing to pay per month in addition to your average water bill to avoid possible adverse health consequences associate with consuming PFAS chemicals?	wtp_oe	(number)	
	Lowest No (from payment card)	ln	(number)	
	Highest Yes (from payment card)	hy	(number)	
	Anomalous behavior (ln<hy)	anomaly	1=yes	
	Adjusted Lowest No (from payment card)	ln_adj	(number)	

	Adjusted Highest Yes (from payment card)	hy_adj	(number)	
Q20_1	In terms of the amounts you indicated above, how certain are you that you would be willing to pay this amount? Use the slider below to choose your certainty level, where 0 suggests you are completely uncertain about your stated willingness to pay per month and 10 suggests you are completely certain about your stated willingness to pay per month.	certain	1-10	Scale (1=lowest, 10=highest)
Q22	What is your gender?	gender	0 1	Male Female
Q23	What is your current age?	age	(integer)	
Q24	How many people currently live in your household, including yourself?	housesize	(integer)	
Q25	How many children under the age of 18 live in your household?	under18	(integer)	
Q26	What is the highest level of schooling you have completed?	educ	0 1 2 3 4 5	Some High school High School Some College Associates Bachelors Graduate/Professional

Q27	What is your current employment status?	employment	0 1 2 3 4 5	Unemployed Self-Employed Part-time Student Full-time Retired
Q28	What is your approximate annual household income from all sources, before taxes?	income	0 1 2 3 4 5 6	Less than $15,000 $15,000-$29,999 $30,000-$44,999 $45,000-$59,999 $60,000-$74,999 $75,000-$89,999 More than $90,000
	Any long-term health issues	lthealth	1=yes	
Q31	In your opinion, how do you think the safety of tap water should be paid for?	polluter	1= Charge polluters of the water, if they can be identified	
Q36	Where would you normally look to get news and information?	trustn	1=Fox News	
Q38	When it comes to environmental issues, who would you trust more?	truste	1=Don’t Trust Any	
Q34	Generally speaking, do you usually think of yourself as a Republican, a Democrat, an Independent, or something else?	polview	0 1 2 3 4	Democrat Republican Independent Other Party Don’t know/not sure
		educ1	1= cases > associates	
		std	1= student	
		unemp	1= unemployed	
		femp	1= yes	
		retired	1= retired	
		dreason	1= if health concern	

		dtest	1= if they test water quality	
		dhealth	1= moderate + serious health concern	
		democ	1= democrat	
		repub	1= republican	