Economic Effects of Environmental Crises: Evidence from Flint, Michigan*

Peter Christensen[†], David A. Keiser[‡], and Gabriel E. Lade[§]

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Abstract

In April 2014, Flint, Michigan switched its drinking water supply from the Detroit water system to the Flint River as a temporary means to save $5M. Over the course of eighteen months, it was revealed that the switch exposed residents to dangerous levels of lead, culminating in an emergency declaration in October 2015. In this paper, we examine economic impacts as this crisis unfolded. We estimate that averting expenditures since the switch have exceeded $20M and the value of the Flint housing stock has fallen by $345M to $500M. Over this same period, state and federal spending has exceeded $343M.

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[†]Email: pchrist@illinois.edu. Assistant Professor, Agricultural and Consumer Economics, University of Illinois, 431 Mumford Hall, 1301 W. Gregory St. Urbana, Illinois 61801.

[‡]Corresponding Author. E-mail: dkeiser@iastate.edu. Assistant Professor, Department of Economics and Center for Agricultural and Rural Development, Iowa State University, Ames, IA 50010.

[§]Email: gelade@iastate.edu. Assistant Professor, Department of Economics and Center for Agricultural and Rural Development, Iowa State University, Ames, IA 50010.

1 Introduction

On April 15, 2014, Flint, Michigan switched its drinking water supply from the Detroit water system to the Flint River as a temporary measure to save the city $5 million over two years (Guyette, 2018). The more corrosive Flint River, combined with administrative failures, caused toxic lead to contaminate the city's water supply. These events triggered one of the most notorious public health crises in modern U.S. history. In only a short period, the Flint crisis has become the subject of intense presidential debates, documentary films, and extensive news coverage. This paper uses the unfortunate events surrounding the Flint crisis to quantify the economic damages of a major public policy failure.

At every level of government, policies are designed to safeguard human health and well-being. This covers the gamut of human activities including food, occupational and transportation safety, fire and crime, and the provision of safe drinking water and clean air. The U.S. spends tens of billions of dollars on these programs each year, and most federal regulations are thought to pass a cost-benefit test (OMB, 2013; Keiser et al., 2019). However, benefit estimates used to assess these policies often arise from studies of marginal changes in risk, environmental quality, or other measures of well-being. The events in Flint provide a unique opportunity to assess the consequences of a disastrous, non-marginal policy failure. These types of catastrophic events have played an important role in understanding the policy responses to natural disasters and climate change (Nordhaus, 2011; Weitzman, 2014; Gallagher, 2014; Martin and Pindyck, 2015; Gallagher and Hartley, 2017; Deryugina et al., 2018; Beatty et al., 2019). Arguably, they are poorly understood in many other public policy contexts. What happens when a basic public good like safe drinking water is no longer available? How do households and markets respond to uncertain information about the length and severity of large crises? How do economic impacts of this type of event inform current policy decisions? This paper seeks to shed light on these questions.

We focus on two periods of the Flint crisis. The first, the 'switch,' spans April 2014 to September 2015, the period after the city changed its water supply but before any public health emergency declarations. Flint residents were inundated with conflicting information during this time. Many residents noticed a stark difference in their drinking water quality and the city issued several boil advisories due to safe drinking water violations unrelated to lead. However, residents were also continually reassured by local, state, and federal officials that their water was safe for consumption. Dayne Walling, the mayor of Flint at the time,

[1] See https://www.wnem.com/news/flint-s-mayor-drinks-water-from-tap-to-prove-it/article_bad3b738-63f5-56d3-bcb7-52b40d591b20.html.

drank a cup of water on TV in a bid to reassure citizens the water was safe.[1] A concerted effort by outside parties led public officials to finally declare a public health emergency, admitting that Flint's water was unsafe. The declaration marks the start of our second period, the 'crisis,' spanning October 2015 to the end of our study, June 2017. During this period, government and private groups lead efforts to identify homes with lead service lines, test lead concentrations in homes throughout Flint, and distribute bottled drinking water and water filters to homes.

We use matched difference-in-differences and event study research designs to study the impacts of the crisis on averting behaviors and Flint's housing market during these two periods. We first consider two prominent averting investments available to all Flint residents – bottled water and water filter purchases. Event study estimates show a small, but steady increase in bottled water purchases following the switch, especially for larger quantities of water. These estimates then show a larger, sustained 20% to 30% increase following several boil advisories and public protests over the city's water quality in the first quarter of 2015. Bottled water sales remained elevated until the emergency declaration, after which they fell by over 120% relative to pre-crisis levels as bottled water became freely available throughout the city. In contrast, we find little evidence of water filter sales increases until the emergency declaration, when sales of certain approved water filter systems increased temporarily to 70% above pre-crisis levels.

Next, we examine how the crisis affected Flint home prices. After the switch, average home values in the city declined 9% to 25% relative to our control markets. Prices fell an additional 13% to 20% after the emergency declaration. In our preferred specification, this yields a $345 million to $497 million loss of value to a large portion of Flint's housing stock. This loss occurred despite $343 million in state and federal spending to curb the negative impacts of the crisis. We also explore heterogeneous impacts using baseline Census Block Group demographic data from the 2010 Census, parcel-level data on service lines, and around 30,000 in-home lead test results. We find little evidence of differential impacts across homes within Flint based on lead risk, suggesting a limited effect of the city's lead risk information campaign. We find suggestive, but not statistically significant evidence that housing price responses were slightly more severe in Census blocks with higher percentages of black or African American households and lower income levels.

Our study contributes to several strands of literature. First, as alluded to above, we build on a robust literature that examines the economic consequences of natural disasters (Gallagher, 2014; Gallagher and Hartley, 2017; Deryugina et al., 2018; Gibson et al., 2019; Beatty et al., 2019). Flint is unique from these previous studies in that the events considered here were due to human error. This difference provides a unique opportunity to study the consequences of a significant public policy failure in which trust in government plays an important role.

Second, we build on a large literature that uses hedonic and averting expenditure methods to estimate social benefits from local environmental quality improvements (Chay and Greenstone, 2005; Greenstone and Gallagher, 2008; Neidell, 2008, 2009; Bayer et al., 2009; Deschenes et al., 2013; Currie et al., 2015; Ito and Zhang, 2016; Phaneuf and Williams, 2016; Keiser and Shapiro, 2019). A key empirical challenge in this literature involves properly characterizing the extent to which consumers are informed about pollution risk (Shimshack et al., 2007; Pope, 2008; Davis, 2011; Barwick et al., 2019). Our setting provides a unique opportunity to study a pollution event where we observe both averting behavior and housing market conditions over two distinct periods. During the switch period, households were uncertain about the city's water quality and received conflicting information about their pollution risk and exposure. The risks became much more clear after the emergency declaration. Our results suggest that even limited signals of pollution risk can trigger sustained averting expenditures and corresponding responses in housing prices. However, costlier averting behaviors and the largest housing market impacts are observed only after the emergency declaration. Our contribution is unique in that we examine averting behaviors alongside housing market responses. We show that the level and types of avoidance behavior that residents engage in depend on their knowledge of their pollution exposure and that these responses interact with impacts observed in the housing market. Under certain assumptions, we find that expected future averting expenditures could account for a significant fraction, up to 64%, of total estimated damages.

Third, we contribute to a large literature studying health and economic damages from lead pollution, and a growing literature examining the causes and consequences of the Flint crisis. It is not surprising that Flint households have undertaken costly investments to avoid lead exposure. Lead exposure, particularly in early childhood, has been shown to increase suspensions and juvenile detentions in schools (Aizer and Currie, 2018), lower test scores (Aizer et al., 2018; Hollingsworth and Rudik, 2019), increase violent criminal behavior (Feigenbaum and Muller, 2016), decrease fertility (Clay et al., 2018), and increase mortality (Clay et al., 2014; Hollingsworth and Rudik, 2019). Researchers have already found convincing evidence of acute health impacts from the Flint crisis due to lead and legionella exposure (Grossman and Slusky, 2017; Zahran et al., 2017; Jenkin and Danagoulian, 2018). Our avoidance

[2] For example, Grossman and Slusky (2017) state that the delay in the emergency declaration "reduced the scope of an avoidance behavioral response to the water crisis." Our results suggest this was not the case.

behavior results suggests that these impacts were likely mitigated as households increased bottled water use well before the emergency declaration.[2] Further, our estimated housing market impacts demonstrate that the economic damages extend beyond direct human health impacts. These results contribute to a growing hedonics literature that has estimated significant benefits from lead pipe replacement (Theising, 2019) and lead paint remediation (Billings and Schnepel, 2017; Gazze, 2019).

Finally, we contribute to a growing literature on the importance and value of safe drinking water infrastructure. In the U.S., this work has focused on the health impacts of providing basic treatment (Cutler and Miller, 2005; Alsan and Goldin, 2019; Anderson et al., 2018), perceptions of risk and avoidance behavior (Graff-Zivin et al., 2011; Wrenn et al., 2016), and public water system behavior (Bennear and Olmstead, 2008; Bennear et al., 2009; Allaire et al., 2018). Our work contributes in at least two important ways to these studies. First, our results are important for developing comprehensive estimates of the economic benefits of providing safe, clean water to communities today. These benefit estimates are crucial to informing the value of maintaining and reinvesting in this infrastructure. Evidence on these values is thin, and costs are large (Keiser and Shapiro, 2018). We are not aware of any available benefits estimates that consider the benefit of avoiding a system-wide contamination crisis. Second, our averting behavior estimates provide a unique setting to explore how these behaviors respond to conflicting information signals over a long period. These results are important for informing both benefit estimates of providing clean water as well as the potential health consequences of drinking contaminated water.

The paper proceeds as follows. We first provide some historical context for our study and discuss key events leading up to, during, and after the Flint water crisis (Section 2). Next, we briefly discuss a conceptual framework that we use to interpret our subsequent hedonic damage estimates (Section 3). We then discuss our estimation strategy (Section 4) and data (Section 5). Section 6 presents our averting expenditure and housing market results, and Section 7 uses the results to quantify economic damages due to the Flint crisis. We then discuss the implications of our study regarding the value of safe drinking water and water infrastructure and conclude (Section 8).

2 Background

2.1 Economic Conditions in Flint

Flint, MI was among America's first and foremost automobile towns. General Motors was founded in the city in 1908, and Flint had one of the highest per capita incomes in the U.S. in the early twentieth-century (Clark, 2018). Both the wealth and population of the city grew rapidly through the 1950s along with the demand for automobiles. Since 1960, the city has experienced large population losses mainly due to the closure of manufacturing plants in the 1980s and 1990s. Along with the large population decreases, economic conditions in Flint have deteriorated dramatically since the 1980s. Personal income estimates as reported in the city's annual financial reports suggest that aggregate income declined from $3.5 billion in the late 1990s to less than $500 million in 2010. During the same period, Flint's population declined by about 20%, from about 122,000 to just over 100,000.[3]

Economic conditions in Flint deteriorated further with the Great Recession. Unemployment rates increased from between 8% and 10% in the mid-2000s to a high of 16.9% in July 2009. Between 2007 and 2010, employment levels fell from 195,000 to around 160,000. Unemployment gradually declined from post-recession highs during 2011 and 2012 but remained between 8.3% and 11% through 2013.[4] The percent of residents below the poverty level during this period exceeded 40%.

A 2011 Michigan Treasury Department review of Flint's ability to meet its short-term financial obligations revealed severe structural deficits in the city's finances. In response, the Governor placed Flint in financial receivership in November 2011, appointing Michael Brown as the city's emergency manager. Under Michigan law, emergency managers have broad power to make unilateral decisions regarding city finances. The system was initially established to resolve systemic financial deficits accrued by cities. Emergency managers' powers were broadened in 1990 and again in 2011 so that they could handle all financial matters of cities placed under receivership.[5] Between 2011 and 2014, the governor appointed four successive emergency managers. All had broad authority to, for example, lay off government workers and renegotiate city labor contracts to stabilize cities' finances. They also had the power to alter municipal utility operations and bills.

2.2 The Flint Water Crisis

From the 1960s until 2014, Flint received treated drinking water from the Detroit Water and Sewer Department (DWSD). In March 2013, the Flint city council and emergency manager Ed Kurtz approved a plan to terminate the city's contract with DWSD and switch to the

[3] See `https://www.census.gov/quickfacts/geo/chart/flintcitymichigan/PST045217`.

[4] See `https://www.bls.gov/eag/eag.mi_flint_msa.htm`.

[5] 2011 was not the first time Flint was assigned an emergency financial manager. Flint was also appointed an emergency financial manager from 2002 to 2004 following a debt crisis in the early 2000s.

Karegnondi Water Authority (KWA). The move was prompted by the city's high cost of providing water. Flint's water rates were, and remain, among the highest in the country due to the high costs of maintaining the city's aging water system, increasing costs of acquiring water from DWSD, and a declining population (Highsmith, 2015). Moving to the KWA was projected to save the city around $200 Million over 25 years (Kurtz, 2013). The move, however, would require using the city's mothballed water treatment plant from the 1960s.[6] The city faced a one-year gap between the end of its contract with the DWSD and the completion of the KWA pipeline project. In the summer of 2013, rather than renew its contract with DWSD, as another cost-saving measure, the city decided to temporarily treat water from the Flint River until water from KWA became available. In April 2014, despite warnings from county officials that the plant was not ready to treat water from the Flint River (Fleming, 2018), the city closed off the water supply from DWSD and turned on its water treatment plant.

Soon after the switch, residents began to complain of the color, taste, and smell of their water. By early June 2014, residents reported that they were supplementing their drinking water with bottled water (Clark, 2018). Despite complaints throughout the summer of 2014, local officials told residents that their tap water was safe to drink.[7] Despite these reassurances, Flint residents continued to see ominous signals. In August 2014, the city issued a six-day boil advisory for part of the city due to elevated fecal coliform levels in the drinking water (Fonger, 2014d). A second and third boil advisory came in early September (Fonger, 2014b). In October, a local GM plant announced it would switch its water supply to the neighboring Flint Township because increased corrosion from Flint's water caused rust to form on engine parts (Fonger, 2014c). The move reduced water pressure and increased the time water stayed in the city's water mains before reaching households, worsening lead concentrations in households' tap water (Clark, 2018).

These events and reports of additional violations for exceeding allowable levels of a disinfectant byproduct from the Michigan Department of Environmental Quality (MDEQ) precipitated a raucous city hall meeting in January 2015. Residents brought with them orange, discolored water from their home taps, demanding the city return to DWSD water. Jerry Ambrose, the emergency manager at the time, insisted that the move would be too costly and MDEQ officials assured residents that the water was safe (Fonger, 2015d). Limited

[6]Flint treated water from the Flint River until the 1960s when the city first signed a contract to receive treated water from DWSD due to growing population growth and industrial demand. The city kept the treatment plant as an emergency backup system until 2014 (Clark, 2018).

[7]For example, in an interview in June 2014, Mayor Dayne Walling was quoted as saying 'I think people are wasting their precious money buying bottled water' (Fonger, 2014a).

lead testing began in February 2015. Water fountains at the University of Michigan, Flint revealed high lead levels (Clark, 2018). LeeAnne Walters, a Flint resident with particularly acute water quality problems, expressed health concerns for her children. City officials tested Walters' water and found that lead levels were more than seven times greater than maximum contaminant levels set by the U.S. Environmental Protection Agency (EPA) (Clark, 2018). An official at the EPA expressed concern over these results, while local and state officials dismissed these concerns, stating that the issues were confined to a single home. Nonetheless, the city continued a limited testing program.

In August 2015, an extensive, independent lead testing effort led by Dr. Marc Edwards of Virginia Tech University was underway. Results revealed much higher in-home lead levels than had been previously reported. In September, a local pediatrician, Dr. Mona Hanna-Attish, released a report showing increased incidences of children with elevated blood lead levels in Flint (Fonger, 2015a). In response to these events, local officials declared a public health emergency on October 1, 2015 (Genesee County Board of Commissioners, 2015). The city reconnected to the DWSD system shortly after. However, Flint's water supply continued to contain elevated lead levels. In January 2016, Michigan Governor Rick Snyder and President Obama issued subsequent states of emergency, authorizing state and federal aid for the city (Egan and Spangler, 2016).

Since the crisis declarations, local, state, and federal authorities, as well as private citizens and non-governmental organizations, have mobilized tremendous resources to minimize public health impacts of the crisis and restore Flint's water supply. The state of Michigan and the federal government provided free bottled water, water filters, and filter cartridges to Flint residents for nearly two and a half years (Chavez, 2018). In 2018, the Michigan Department of Environmental Quality estimated the cost of its bottled water program alone to be $22,000 per day (Fonger, 2018). The state of Michigan allocated $97 million to excavate and inspect over 18,000 service lines, and replace those that contain lead and galvanized steel as part of a March 2017 settlement (Smith, 2018).[8] In total, the state of Michigan has appropriated $350M to Flint to help deal with the crisis, in addition to $100M that the EPA has provided to aid the city with drinking water upgrades.[9] The city has excavated and inspected over 21,000 lines to date, replacing upwards of 8,000 lead lines (Renwick, 2019). While the water in the city is now deemed to be safe for human consumption, the costs of restoring Flint's water infrastructure system to a state that re-establishes public trust in the city's ability to provide safe services for its citizens remains unknown.

[8] The settlement calls for the state to pay $87 million to replace these lines. An additional $10 million will be held in reserve if replacement costs runs higher.

[9] See https://www.michigan.gov/flintwater/.

A series of institutional failures and federal regulatory violations caused and worsened the Flint water crisis (USEPA, 2018). First, the city failed to implement a corrosion control program when it switched to the Flint River.[10] The city did not implement a proper corrosion control program until August 31, 2015. Second, the city failed to adequately monitor water lead levels in accordance with EPA's Lead and Copper Rule (LCR). The LCR requires in-home drinking water sampling to be conducted by the Michigan Department of Environmental Quality (MDEQ). An independent task force found that MDEQ guidance and the city's water monitoring efforts were deeply flawed (Davis et al., 2016). Nearly 80 lawsuits have since been filed against the state, and fifteen individuals were charged in criminal cases (WNEM, 2019).[11]

3 Conceptual Framework

We study changes in multiple markets to evaluate the impacts of the Flint water crisis over time, quantifying the effects of the crisis on averting expenditures and housing markets. We hypothesize that short-run avoidance behaviors impacted these markets after the switch, while longer-run shifts in water safety expectations impacted them after the emergency declaration. While we argue that our empirical strategy, detailed below, provides valid estimates of these impacts, using them to quantify the welfare consequences of the crisis requires further assumptions.

Our evaluation of the housing market response to water quality changes in Flint relies on Rosen's hedonic model (1974). The model provides an empirical basis for evaluating the implicit price function for housing characteristics using observed transactions and has been used extensively by environmental and urban economists. A well-known drawback is that the second stage of Rosen's approach, which is required to value non-marginal changes, is difficult to implement due to simultaneity concerns (Bartik, 1987; Epple, 1987; Ekeland et al., 2004).

[10] All community water systems are subject to corrosion control requirements under the Optimal Corrosion Control Treatment (OCCT) provision of the Safe Drinking Water Act (SDWA). However, the Michigan Department of Water Quality misinterpreted their compliance requirements and made corrosion control dependent on a six-month monitoring period for lead and copper in homes (Davis et al., 2016). At the end of the monitoring period, the 90th percentile lead test was six parts per billion (ppb), disqualifying Flint from the (previously misinterpreted) exemption from the OCCT (City of Flint Water Plant, 2014). However, the Michigan Department of Environmental Quality failed to advise the Water Treatment Plant of their obligation at that time.

[11] In June 2019, all remaining criminal cases were abruptly dismissed due to problems with the investigations. Future cases may still be brought by the Michigan Attorney General's Office (Egan, 2019).

Because many if not all applications of the hedonic method to pollution problems study non-marginal changes, researchers are often limited in their ability to identify the welfare consequences of significant policy or environmental changes (Greenstone and Gallagher, 2008; Currie et al., 2015). Recent papers have addressed the simultaneity concern using preference inversion or repeat observations of housing transactions made by the same household (Bajari and Benkard, 2005; Bishop and Timmins, 2018).

Applying the hedonic method to the Flint water crisis requires confronting many of these same challenges. The water crisis involved a large, discrete shift in the drinking water quality in Flint. Several concerns arise. First, the composition and supply of homes may shift as a result of the crisis, leading to the classical concerns regarding Rosen's second stage. Second, residents may migrate, with individuals sorting onto and off of the Flint water distribution network based on their relative lead risk aversion or overall response to the crisis. Third, the Flint water crisis was one of the most important national news stories in 2015 and 2016. The coverage and revelation of similar problems in other cities may have impacted housing markets or avoidance behaviors across the U.S.

Several recent studies have discussed welfare interpretations of quasi-experimental empirical results in settings with similar features to our own (e.g., Kuminoff and Pope (2014)). Banzhaf (2018) shows that when there are unobserved changes in the types of buyers in a market, even well-identified hedonic estimates reflect exact willingness to pay for an environmental amenity only under highly restrictive assumptions. When changes in buyers' (unobserved) incomes and preferences correlate with changes in the amenities of interest, hedonic estimates instead identify a lower bound on the Hicksian equivalent surplus, plus the change in profits, associated with the amenity improvements.[12] In Section 6, we discuss these issues further. In the Appendix, we explore the extent of migration induced by the crisis, changes in the characteristics of buyers, and the supply response in Flint's housing market. We rely on these analyses for interpretation of our estimates. Because we can't rule out changes in the unobserved characteristics of buyers, we assume that our housing market estimates provide a lower bound on the welfare effects of the crisis.

4 Empirical Strategy

Flint is distinct from most U.S. cities. The city stands out for its high proportion of low-income households as well as high poverty rates, crime, and percentage of the population

[12] In simulations, Banzhaf (2018) shows that this bound is on the order of 10% of the true equivalent surplus. Even though Banzhaf (2018) uses a difference-in-differences approach, his result generalizes across a large class of empirical models that satisfy a conditional independence assumption.

that is black or African American. Similar to other papers studying the impacts of disasters in unique cities (e.g., Deryugina et al. (2018)), we use a matched difference-in-differences strategy to estimate the effects of the Flint water crisis on our economic outcomes of interest.

4.1 Control Group Construction

We collect population, labor force, and demographic data from the U.S. Census and American Community Survey to construct our control groups (Ruggles et al., 2015). We limit our list of potential control cities to those whose 2010 population is greater than 50,000 and less than 200,000 so that matched cities are similar in size to Flint. We match cities based on the level and long-run changes in key economic characteristics. From the 2010 Census, we match cities on population, percent of vacant homes, and the percent black or African American population. From the 2012 ACS, we match on median household income and the unemployment rate. We also match on changes in median household income and population from 1970 to 2012.[13]

Our analysis uses the top five matched cities from this exercise. The cities are, in order of best match: Youngstown, OH; Pontiac, MI; Camden, NJ; Gary, IN; and Dayton, OH. All cities share, to varying extents, a history of post-war economic prosperity due to large growth in manufacturing. All have experienced substantial population declines since 1970 with only modest income growth. In 2012, when Flint was placed into financial receivership, all cities shared low median incomes, high unemployment rates, a large share of vacant houses, and high population shares that were black or African American (Table A.1).

4.2 Estimation Strategy

Having defined the sample of control cities, our main estimation strategy is the following difference-in-differences model:

$$\begin{aligned} y_{ijt} = & \gamma_1 \left[\text{Receiver}_t \times \text{Flint}_i\right] + \gamma_2 \left[\text{Switch}_t \times \text{Flint}_i\right] + \gamma_3 \left[\text{Emergency}_t \times \text{Flint}_i\right] + \\ & \mu_1[\text{Receiver}_t] + \mu_2[\text{Switch}_t] + \mu_3[\text{Emergency}_t] + \mathbf{X}'_{ijt}\beta + \delta_{j(\tau)} + \epsilon_{ijt}. \end{aligned} \tag{1}$$

Our outcome of interest, y_{ijt}, for observation i on date t includes measures of avoidance behavior (store-level sales of bottled water and water filters) and individual housing prices. The variables Receiver_t, Switch_t, and Emergency_t are indicators that equal one if date t is

[13] Appendix A details our matching procedure, variables, and summary statistics for the matched cities.

after Flint was placed in financial receivership, the city switched its water supply to the Flint River, and the city's first emergency declaration, respectively. While our matched control cities are similar to Flint along many observable dimensions, time-varying differences likely remain and impact our estimated impacts of the water crisis. As such, we also include a host of spatial and temporal fixed effects, $\delta_{j(\tau)}$, and controls, $\mathbf{X}_{ijt}$. We discuss the specific fixed effects and controls used when we present our results.

Our coefficients of interest are γ_2 and γ_3. The coefficients measure the average change in outcome y_{ijt} in Flint relative to control cities. We include Receiver_t in all specifications to control for possible differential conditions in Flint just before the switch. The water supply switch was, in part, precipitated by deteriorating economic conditions in the city. Thus, we also interpret the coefficient γ_1 as an indirect test of differential pre-trends in Flint versus our control cities.

We also estimate an event study difference-in-differences model, comparing outcomes of interest to those of our control cities over time as:

$$y_{ijt} = \sum_{\tau} \mu_\tau \mathbf{1}[t = \tau] + \sum_{\tau} \gamma_\tau \left(\mathbf{1}[t = \tau] \times \text{Flint}_i\right) + \mathbf{X}'_{jt}\beta + \delta_{j(\tau)} + \epsilon_{ijt}. \tag{2}$$

$\mathbf{1}[t = \tau]$ is an indicator for whether date t falls in year-quarter τ, and Flint_i is an indicator for whether observation i is in Flint. All other variables are defined as before.

We specify all outcomes in natural logarithms. Thus, we interpret our estimated impacts as the percentage change in the value of y_{ijt} relative to the omitted reference group and period. For equation (2), our coefficients of interest are γ_τ, the percentage difference in y_{ijt} in each year-quarter for observations in Flint relative to control cities. These coefficients are informative for two purposes. First, they flexibly estimate the evolution of y_{ijt} over time for observations in Flint relative to those in control cities. This allows us to compare our findings to the events described in Section 2. Second, examining the path of γ_τ's in the period before the water crisis provides a second indirect test of no differential pre-trends between Flint and our control cities.

5 Data and Summary Statistics

5.1 Data Sources

5.1.1 Product Sales

We use Nielsen Retail Scanner and Consumer Panel data from the Kilts Center for Marketing at the University of Chicago to estimate the impact of the water crisis on household expenditures. The Retail Scanner data include UPC-level, weekly volume, price, and product characteristic data from more than 35,000 grocery, drug, and mass merchandising stores from January 2006 to December 2016.[14] The data cover more than half the total sales volume of grocery and drug stores in the U.S. The Consumer Panel data consist of a representative, longitudinal panel of U.S. households that report product-level purchase and price data for all shopping trips over their participation in the program. The panel includes 40,000 to 60,000 households per year.

We compile monthly, store-level sales volume and value (e.g., revenue) data for several products from the Retail Scanner data. Bottled water and in-home water filter sales serve as our primary variables of interest. Bottled water includes branded (e.g., Dasani) and generic non-flavored water. In addition to total sales, we distinguish bottled water by price-per-ounce and unit-size quartiles to track the types of bottled water that households purchase (e.g., 6-packs versus 30-packs). We include all faucet-mounted Brita and Pur water filter systems and cartridges. These filters are approved to remove lead by NSF International, a public health standards and certifications company, and were the filter systems that state and federal officials distributed to Flint residents after the emergency declarations.[15] We also separately track Pur and Brita filter system and cartridge sales. While the state of Michigan and NSF International designated both Pur and Brita filters as safe to use,[16] amid the confusion in 2015 a rumor spread on social media that Brita filters did not remove lead from water (Schuch, 2015). The empirical analysis explores potential differential impacts on these brands.

The finest geographic unit available in the Retail Scanner data is county and three-digit zip code. The Consumer Panel data identifies households' five-digit zip code. We take advantage of this feature of the Consumer Panel data to refine our definitions of treatment and control stores. We designate a store as being in Flint if it is located in Flint's three-digit zip code and if any household living in a Flint five-digit zip code shopped at that store between 2004 and 2016. We observe 79 households in Flint zip codes make 23,438 shopping

[14]Kilts releases all data with a one-year lag. Sales from 2017 will be incorporated into the analysis once it is released and processed.

[15]NSF International also approves a ZeroWater's dispenser. However, we observe few sales of the product, particularly in early years, and exclude these filter sales.

[16]See `https://www.michigan.gov/flintwater/0,6092,7-345-75251_75315---,00.html`.

[17]We observe water filter sales in 23 of the 25 'Flint' stores and bottled water sales in all 25 stores.

[18]Defining treated stores by county does not appreciably affect our results (Table B.1).

[19]The Nielsen Consumer Panel data are representative for broader U.S. regions. Therefore, we do not use the Consumer Panel to infer Flint-level outcomes.

trips to 25 stores in our retail panel over this period.[17] In our control markets, we observe 581 households make 178,777 trips to 173 stores.[18,19]

5.1.2 Housing Sales Data

We use transaction-level housing price and characteristic data covering the universe of transactions in Flint and our control cities from 2006 through June 2017 from the Zillow Transactions and Assessment Dataset (ZTRAX).[20] Zillow aggregates these data from several sources, including county assessor offices.[21] All prices are adjusted to 2009 dollars using the U.S. Bureau of Labor Statistics' Home Consumer Price Index. We restrict the transactions data in several ways. First, we follow Currie et al. (2015) and restrict our sample to homes that sold for between $25,000 and $10 million.[22] Second, we remove intra-family transfers and tax-exempt transactions. Third, we remove transactions for multi-family properties, undeveloped land, and mixed-use or commercial properties. Last, we removed all transaction types that do not involve deed transfers (e.g. assessments, easements, affidavits of trust).

5.1.3 Water Infrastructure and Lead Test Data

Before October 2015, the Flint Department of Public Works stored drinking water service line information on around 45,000 index cards (Fonger, 2015b). Beginning in November 2015, a team led by the University of Michigan, Flint digitized these data and published parcel-level lead service line maps to help prioritize line replacement efforts.[23] The data, first published in February 2016 identify the service line composition (e.g., lead, galvanized iron, copper) for many homes in Flint. We match these data to our ZTRAX transactions, indicating whether homes have lead/galvanized iron service lines, non-lead service lines, or whether the service line type is unknown.[24] Lead and galvanized iron service lines were

[20] We restrict our data to June 2017 since data past this date are currently incomplete for many cities.

[21] ZTRAX data are available at: `https://www.zillow.com/research/ztrax/`.

[22] Flint has a large number of vacant homes and lots. Many are purchased for very low prices by neighboring property owners or land banks. This is apparent in our raw data. Before restricting the data, the lowest non-zero transaction price in the data is $83; 25% of transactions sell for less than $5,500; and the median home sold for $15,000 (2009$). In Appendix Table B.8, we consider the impact of the water crisis on these low-priced homes.

[23] See `https://www.umflint.edu/gis`.

[24] The Department of Public Works did not document many homes' service lines types. For these homes, a definitive determination must be made by excavating the line and visually inspecting the connections between the city water main at the edge of a property line and a property's interior plumbing.

found to be leading causes of elevated lead levels in Flint homes. Without proper corrosion control, the more corrosive Flint River caused lead to leach from these lines.[25] Figure 1a maps the spatial distribution of lead and galvanized service lines within and across Flint. Lead service lines are distributed relatively evenly throughout the city, with only areas on some outer-parts of the city showing little presence of lead lines.

The state of Michigan also made a concerted effort to release lead risk and exposure information after the emergency declaration. The state created an online database of aggregate blood test results, lead and copper test results at several Flint water main locations and schools, and residential and establishment-level lead test results data.[26] We observe around 30,000 in-home lead test results, covering a large portion of Flint's housing stock. The data include the date the sample was submitted, the address of the home, the amount of lead and copper (ppb) detected in a one-liter sample, and the date the results were released online. We use the data to construct several spatial measures of lead concentrations that we match to our ZTRAX data. Figure 1b maps the lead test results. Tests that violate EPA safe drinking water standards are shown as red squares, while those with low lead levels are blue circles. Areas with missing tests are mainly non-residential areas. There is no clear visual evidence of "hot spots." However, some pockets with and without violations stand out. For example, areas in the northwest corner of the city have few violations. The western part of Flint has fewer, but more clustered, violations. Both are more affluent neighborhoods.

5.1.4 Economic Controls and Weather Data

U.S. Bureau of Labor Statistics monthly labor force data serves as an additional control variable in some specifications. The data are meant to control for residual, time-varying economic conditions in Flint relative to control cities. We also include county average monthly temperature and precipitation data from PRISM Climate Data to control for seasonal and weather differences across control and treatment cities.

5.2 Summary Statistics

Table 1 presents baseline summary statistics for Flint and compares Flint to the Top 3 control cities (column 2), Top 5 control cities (column 3), and to other towns in Genesee

[25]Galvanized iron pipes were often found coated with lead that, as rust crumbled from the pipes, increased concentrations (Fonger, 2015c).

[26]See https://www.michigan.gov/flintwater/.

County, the county in which Flint resides (column 4).[27] Panel A shows city-level demographic statistics from the 1970 and 2010 Census and the 2010-2012 American Community Survey (Ruggles et al., 2015). Flint's population in 2010 was just over 102,000, down 91,000 from 1970. Flint's median income in 2010 was just $26,000 and grew by only $9,000 since 1970. Recent housing vacancy and unemployment rates both exceed 20%, and the city has a large African American population, nearly 60% of all residents. Panel B shows ZTRAX housing market characteristics from 2006 to 2013. The average (median) priced home in our sample sold for $71,000 ($60,000).[28] Panel C shows that, on average, stores in Flint sold 206,000 bottle-equivalent units of water per month from 2006 to 2013 and nearly 2,800 filter system units per month.

Our matched control cities are similar to Flint along many of these dimensions. Top 3 control cities are smaller on average. Cities in both matched control groups lost population from 1970 to 2010, though their losses were not as dramatic as those in Flint. Median incomes are roughly the same in the two control samples as in Flint, with slightly better income growth since 1970. Vacancy and unemployment rates, as well as population demographics, are very similar. Average and median home prices in control cities are higher than in Flint, while average grocery sales of bottled water and filters are higher in our control cities. Column (4) shows why we do not compare outcomes in Flint to other nearby towns (e.g., use a border discontinuity design). Flint is different in almost all dimensions compared to towns in Genesee County. Cities in Genesee are, on average, smaller, more affluent, have lower housing vacancy and unemployment rates, and are primarily white. Housing prices are 75% higher on average, while grocery sales are lower.

Figure 2 graphs housing prices, lead tests, bottled water sales, and water filter sales over our study period.[29] Housing prices in both Flint and our control cities show a steady decline from 2006 through 2014-15 (Figure 2a). Since 2015, Flint shows little to no improvement in its average home price while prices in other cities increased.[30] Neither average or median housing prices in Flint collapsed after either the switch to the Flint River or the emergency declaration. Higher quantiles (75th and 90th) show modest increases following the public health emergency declaration, pulling average prices higher than median home prices. This

[27] Columns 2 to 4 present coefficients from separate regressions of each outcome on an indicator for the relevant control group. We use quantile regression to estimate differences in median home prices.

[28] Recall that we restrict our ample to homes that sold for between $25,000 and $10 million.

[29] We smooth house prices, bottled water sales, and water filter sales using a two-quarter moving average, limiting the influence of seasonality and better illustrating long-term trends in the data.

[30] These increases in control cities are not an isolated trend. In both the United States as a whole and the state of Michigan, median home prices have increased steadily since the Great Recession.

feature of the data is important for interpreting the impact of the water crisis. A negative estimated impact suggests that Flint home prices would have experienced similar growth in the absence of the crisis, not that housing prices collapsed in the city.

Figure 2b shows the increase in in-home lead testing after the emergency declaration at the end of 2015. Limited testing began in early 2015, led primarily by researchers at Virginia Tech. Early testing revealed dangerously high lead levels, above 60 ppb on average, suggesting the homes tested early on had particularly acute water quality problems. The number of lead tests in Flint increased from just a handful to around 30,000 in the months following the emergency declaration. Average test results remain near or above EPA health standards (15 ppb) even after testing expanded. A non-negligible number of test results showed lead violations.

Figures 2c and 2d graph quarterly bottled water and filter sales at stores in Flint and our control cities. Bottled water sales in Flint and the control cities increase at around the same rate from 2008 to 2014. Flint sales spike in 2015Q1, well before the emergency declaration. Sales remain high through 2016Q2 after which they fall to 2006 levels as the state began distributing free bottled water to all Flint residents. Water filter sales in Flint and the control cities decreased from 2010 through 2014. The trend continued even after the switch to the Flint River. Sales spiked in the quarter of the emergency declaration and remain elevated for two subsequent quarters despite water filters being freely available to residents at the time. We also see a delayed but notable increase in filter sales in the Top 3 and Top 5 control cities, suggesting that the events in Flint may have increased demand for filters in other cities.

6 Results

We first examine the impact of the water crisis on household avoidance behavior, focusing on bottled water and water filter purchases. We then explore the effects of the crisis on home prices in Flint. Next, we explore heterogeneous impacts of the water crisis using demographic data from the 2010 Census and our service line and lead test data.

[31] Water filter sales include both water filter systems and cartridges. Appendix B reports separate results for each.

6.1 Avoidance Behavior

Table 2 presents our results from estimating equation (1) using the log volume of bottled water sales (Panel A) and water filter sales (Panel B) as our dependent variables.[31] In both panels, columns (1) and (2) present results using the Top 3 and Top 5 control groups, respectively. In Panel A, columns (3) and (4) limit the bottled water sample to products in the largest unit-size quartile and cheapest price-per-ounce quartile.[32] Columns (3) and (4) of Panel B report results for Pur and Brita water filters. All specifications include store, year, and month-of-year fixed effects, as well as labor market and weather controls.[33]

We find a significant, 16% to 25%, increase in bottled water sales after the switch to the Flint River and before the emergency declaration. After the public health emergency declaration, sales collapsed by over 70%, corresponding to the tremendous effort by public, private, and non-profit entities to provide free bottled water to Flint residents. The largest unit-size and cheapest bottled water were impacted most by the crisis, consistent with households purchasing water in bulk in response to the crisis. We see no evidence of increased water filter sales after the switch, suggesting that households' avoidance behavior was initially limited to bottled water. After the emergency declaration, filter sales increased by 17%. When we separate Pur and Brita filters, we see that the increase was driven by a 28% increase in Pur water filter sales, while Brita filter sales did not increase. At the time, several stories shared through social media wrongly reported that Brita filters did not remove lead (Schuch, 2015).[34]

Figures 3a-3d graph our event study estimates. We see no differential pre-trends in bottled water sales leading up to or after the receivership period, providing some reassurance that our identifying assumptions are satisfied. Sales of all bottled water did not significantly increase until 2015Q1 (Figure 3a) after public outcries followed several boil advisories. However, Figure 3b shows that sales of the largest bottled water units increased steadily after the switch and leveled off around 2015Q1. Sales remain elevated until the quarter after the emergency declaration. After the emergency declaration, sales of bottled water fell precipitously.

[32] Appendix B reports estimates for all other price- and size-quartiles. We also explore the sensitivity of the results to including alternative controls and samples and using the sales value rather than volume as our dependent variable.

[33] We use the log of the labor force to control for differential labor market conditions and quadratics of average temperature and precipitation. Both controls vary by county and month.

[34] In Appendix B, we show that the increase in Pur sales was likely driven by water filter system purchases and not cartridges, suggesting that households were either purchasing their first filter system or supplementing their existing filter systems.

Figures 3c and 3d plot results for all filters and Pur filters, respectively. Across all filters, we see a gradual uptick in sales in Flint versus our control cities from 2006 through 2009. However, these differential sales level off by 2010 and remain stable up until the emergency declaration. We then see a jump in the quarter of the emergency declaration of approximately 30% for all filters. Differences in pre-trends leading up to the switch are less evident in the case of Pur filters (Figure 3c) and we find little evidence of increased sales following the switch. However, when the public health emergency was declared, sales increased by 70% relative to the quarter of the switch. Sales quickly fell back to pre-crisis levels as water filters became freely available.

6.2 Housing Market Impacts

Table 3 presents our housing market results. The dependent variable is the log of the sales price (2009 $) for home i in Census Block Group j on date t. Columns (1) to (3) present results using the Top 3 control cities, and columns (4) to (6) present results using the Top 5 control cities. All specifications include year and month-of-year fixed effects and weather controls. Specifications (1), (2), (4), and (5) use all homes in our sample, and include Census Block Group fixed effects to control for time-invariant local characteristics of neighborhoods in each city.[35] Specifications (2), (3), (5), and (6) include controls for time-varying labor market differences across cities. We estimate specifications (3) and (6) using the sub-sample of homes for which we observe at least one repeat transaction over our sample and include property fixed effects in these specifications.

Across all specifications, we find a decline in home prices following the water supply switch with a further reduction after the emergency declaration. Coefficients on the 'Receivership X Flint' indicator are positive and significant for the Top 3 sample when we omit our time-varying economic controls and for the Top 5 sample when we include all homes, suggesting a violation of our 'no differential pre-trends' assumption.[36] Thus, we view specifications (2) and (3), the Top 3 sample with economic controls, as our most credible. Columns (2) shows a 9% decline in home values after the water supply switch, with a further 20% decrease after

[35]Census Block Groups contain between 600 and 3,000 people. There are 133 Census Block Groups in Flint.

[36]Figure 2a highlights the reason for this result – average home prices in Flint increased just after the receivership while prices in control cities were steady or declining. We find similar results if we specify our control group as other financially distressed cities in Michigan, cities just outside the Flint water distribution line, or cities in Genesee County (Table B.6). This highlights the importance (and challenge) of identifying valid control cities for Flint and including time-varying, city-level controls for differential economic conditions.

the emergency declaration. Column (3) suggests slightly different results. We find that home values decreased 25% after the switch and a further 13% after the emergency. While the property fixed effect model controls for time-invariant unobservable variables, the sample size is substantially smaller.[37]

Figures 4a and 4b plot our event study estimates from specifications (2) and (5). Figure 4a shows a modest decline in home prices after the switch. However, most year-quarter effects are not statistically significant. An exception is 2015Q2. The decline becomes more apparent after the emergency declaration. We see an uptick in prices in 2017Q1, around the time that a settlement was reached to replace lead service lines within three years and an additional $100M in federal funds was allocated by the EPA to aid in infrastructure upgrades. The uptick may reflect improved confidence that the crisis would be resolved, which may have improved home values since the settlement included funds to replace lead service lines. However, the increase was only temporary. The coefficient on the last quarter, 2017Q2, shows a 40% price decline relative to the quarter the city switched to the Flint River. Figure 4b shows similar declines after each event when we use the Top 5 sample. However, the increase in home values in Flint relative to the control cities during the receivership period suggests the control group may be less ideal than the Top 3 sample.

Appendix B presents several robustness checks. Results are similar, though still sensitive to including time-varying, city-level controls when we vary whether we use the Top 1 or Top 10 matched cities, and the relative importance of the switch increases in many cases. We find very similar results when we include year-by-month fixed effects and larger impacts when we include city-specific time trends. We also explore alternative price restrictions. We find larger percentage declines in very low-value homes ($500 to $25,000) after the switch, with smaller, though in most cases still significant, reductions after the emergency declaration. Results are similar to our main specifications if we narrow our price range ($25,000 to $1 million), and are larger when we broaden the price range ($500 to $10 million).

Changes in the composition of buyers and sellers in Flint due to the crisis would affect the interpretation of our hedonic estimates (Banzhaf, 2018). We explore whether sales volumes and buyer, owner and renter characteristics changed in Flint in Appendices C and D. Compared to the Top 3 control cities, we find a small, but statistically significant, decline in home sales after the switch, but no difference in home sales after the emergency. We find evidence of an increase in mortgage applications from high-income households after 2014.

[37] We observe 312 transactions in Flint after the switch and a further 340 after the emergency declaration when we include all sales, but just 107 after the switch and 114 after the emergency declaration in our property fixed effects model.

However, we find no other significant departures from underlying trends in the characteristics of individuals applying for mortgages. We see only a slight decrease in the probability that renters and owners move from Flint after the emergency declaration. These results suggest that there were not large, sudden changes in the composition of households in Flint due to the switch and subsequent crisis. Housing prices fell sharply while other aspects of the market remained (relatively) stable.

6.3 Housing Market Impacts: Heterogeneity

We use a triple difference estimator to examine heterogeneous responses to the crisis within Flint. Specifically, we interact each of the Flint indicators in equation (1) with indicators for within-Flint characteristics. We first explore heterogeneity within Flint based on socio-demographic attributes of Census Block Groups using data from the 2010 Census. We then explore differential impacts based on variation in lead risk using service line type and lead test data.

Demographic Characteristics. We explore heterogeneity among Census Block Groups in Flint in two ways. First, we examine heterogeneity across Block Groups with above and below median incomes. Second, we explore heterogeneity across Block Groups with above and below average African American population. Flint exhibits substantial differences across neighborhoods in both categories. The lowest income Block Group has a median income of \$2,500 while the highest earning Block Group has a median income of over \$120,000.[38] The distribution of African American population across Census Block Groups in Flint is bi-modal. The median (mean) Block Group has an 8% (20%) African American population, while the 90th percentile Block Group has an African American population of 65%.

Table 4 presents results. Except for specification (6), homes that sold in higher income areas and areas with higher black or African American populations experienced the same decline in home values after the switch. However, we find suggestive evidence that the emergency had a smaller impact on higher income Block Groups and a larger impact on Block Groups with larger black or African American populations. In column (2), homes in both above and below median income Block Groups fell by approximately 8% after the switch. After the emergency, home values in low-income Block Groups fell by 22% while home values in high-income block groups fell by 18%, though the difference is not significant. We find the opposite when we compare Block Groups with high versus low African American

[38]The 25th, 50th, and 75th percentile Census block groups have median incomes of \$25,000, \$48,500, and \$64,000 respectively.

population in all but the property fixed effects model. In column (5), while housing prices in Block Groups with above and below median African American populations fell at similar rates after the switch, values in below median Block Groups fell by 17% on average while those in above median Block Groups fell by over 23%. Again, the difference is not statistically significant.

Lead Risk. Next, we explore heterogeneity by lead risk. We first interact all Flint indicators with an indicator for whether the property has a lead or galvanized service line (SL). The reference category is homes with non-lead or unknown service lines. Next, we use local lead test data to explore differential impacts based on whether a transaction occurs in an area with high lead test concentrations. For every purchase after February 2015, we calculate the average lead test result for all tests that occurred up to the date of sale and within a 1 KM radius of the home.[39] We exclude homes after February 2015 with no lead tests within 1 KM.[40] We then interact all Flint indicators with an indicator for whether the matched average test results were above the EPA safe drinking water standard (> EPA MGL).

Table 5 presents our results. When we include all homes in the sample, homes with lead service lines show little differential response to the switch compared to homes with lead or unknown service lines. The emergency impacted homes with lead service lines less. The result may be due to expectations that the city would replace the service lines. However, the difference is not significant in any specification and the result is sensitive to including property fixed effects. Results are again sensitive to specification when we explore the impacts of local lead tests on home values. In the Block Group fixed effects model, home values in areas with high lead tests saw large declines after the water supply switch, due were largely unaffected by the emergency. The opposite conclusion emerges in the repeat sales model.

In all cases, our estimated heterogeneous impacts are imprecise as a result of several contributing factors. First, our statistical power is limited by small sample sizes when we distinguish Flint homes by their characteristics. Second, while lead lines and local lead test results may seem to be useful measures of lead risk, determining the true lead levels and mitigation costs for a particular home is challenging. Chojnacki et al. (2017) show that a range of household characteristics (including service line type) only weakly predict in-home lead test results.

[39]Testing began in Flint in late February 2015.

[40]This drops only 40 sales. We exclude these homes since a zero average lead test result does not reflect a zero lead risk.

7 Damages from the Flint Water Crisis

In this section, we discuss our estimated hedonic damages and place them in the context of our estimated averting expenditures. We also discuss the role of state and federal spending in Flint.

Using specification (1) of Table 2, bottled water expenditures after the switch to the Flint River and before the emergency declaration increased by \$3.7 million (SE=\$3.9 million), or \$94 per household (SE=\$97).[41] After the emergency declaration, bottled water sales decreased by \$9.9 million (SE=\$2.2 million), or \$248 per household (SE=\$56). Water filters sales were less affected by the switch. Expenditures increased by \$0.01 million (SE=\$1.1 million), or \$0.21 per household. After the emergency declaration, spending on filters and systems increased by \$1.9 million (SE=\$1.2 million), or \$47 per household (SE=\$30).

To understand total averting expenditures, these figures need to be considered in the context of additional state and federal spending. The state of Michigan tracks public spending on the Flint crisis and reports expenditures for various categories.[42] Through 2016, the state reported spending \$6.7 million on bottled water and \$6.1 million on residential filters.[43] Considering that outside donations of bottled water were well-documented, we assume the \$9.9 million drop in bottled water sales after the crisis equals state and private donations to the city. Adding this to private expenditures before the crisis, we estimate that at least \$13.6 million has been spent on bottled water since the switch to the Flint River. For filters, the event study estimates show no displacement of spending before the switch. We aggregate the \$1.9 million spent by households since the switch with the \$6.1 million spent by the state to obtain an estimate of \$8 million spent on filters. Thus, private and public spending on averting behaviors since the switch to the Flint River totals at least \$21.6 million.[44]

We now consider the hedonic estimates using our preferred specification from Table 3 column (2). This estimate indicates that average home prices in Flint declined by \$4,790 after

[41]For this and all other calculations, we re-estimate equation (1) using the value of stores' monthly bottled water sales as the dependent variable. We multiply the relevant Flint-by-event coefficient by the number of stores in Flint (25 for bottled water, 23 for water filters and filter systems) and the number of months over which the event took place (18 between the switch and the emergency declaration and 15 between the emergency declaration and the end of our sample). Per household estimates divide the expenditure estimates by 39,780 households in Flint from the Census Bureau 2012-2017 ACS.

[42]This information can be found at https://www.michigan.gov/flintwater/.

[43]We exclude spending on shower filters, distribution and storage costs, filters at locations specified as non-residential, and filters grouped with other services such as water sample testing.

[44]Our estimate is \$16.5 million if we use our Nielsen estimates for pre-switch private spending and reported state expenditures for post-emergency spending.

the switch to the Flint River (SE=$2,360) and a further $15,550 (SE=$4,550) after the emergency crisis declaration.[45] Summing the two, prices declined by over $20,340 (SE=$4,830) through June 2017. According to Neighborhood Scout, a real estate data company, Flint has 31,370 single family homes.[46] We eliminate 46% of transactions in our raw ZTRAX data when we exclude homes that sold for less than $25,000. Assuming the proportion is representative, we extrapolate our damages to all single-family homes valued over $25,000 and estimate that the Flint crisis resulted in a $345 million (SE=$82 million; 2009 $) loss in the value of the housing stock. If we include nearly all single-family homes in Flint by expanding the price range to include all transactions from $500 to $10 million (Table B.8), then total damages amount to $488 million (SE=$55 million).[47] Interpreting these impacts in the spirit of Banzhaf (2018), the damage estimates represent a lower bound on Hicksian equivalent surplus.

As with averting expenditures, our hedonic estimates need to be considered within the context of additional state and federal spending. Up through the end of our study period, approximately $350 million in state and federal funds had been appropriated for the crisis.[48] Theoretically, our hedonic estimates should already reflect these investments. If this is the case, total damages of the crisis are several hundred million dollars larger than the estimated decrease in the value of the housing stock. Summing these two figures yields damages of $688 million to $831 million.

In addition to recovering total damage estimates, our paper provides a unique opportunity to examine the interaction between hedonic and averting behavior responses. However, this analysis requires that we move into more speculative territory. Theoretically, these averting expenditures should be reflected in the housing price response. After the switch but before the emergency declaration, households spent around $63 more on bottled water and filters annually. At the same time, the average home value declined by $4,790 as households saw their water quality rapidly deteriorate but were unaware of the full extent of the crisis. If we

[45] We re-estimate each specification using the level of CPI-adjusted home values to estimate damages in 2009 $.

[46] See https://www.neighborhoodscout.com/mi/flint/real-estate. Detached single-family homes make up 79% of housing units in Flint.

[47] Corresponding damages using our preferred price range and household fixed effects model, column (3) of Table 3, are $29,330/home (SE=$4,520) or $497 million (SE=$77 million).

[48] As of the end of 2016, this figure includes $243 million in state appropriated funds (https://www.michigan.gov/flintwater/) and $100 million in federal funds awarded by US EPA for infrastructure upgrades in Flint. Of the state funds, approximately $74 million was allocated to safe drinking water, $42 million for water bill credits, and the remainder to categories including Food and Nutrition, Social Development and Well Being, Physical Well Being, and Economic Development.

assume that households believed the water quality shock was permanent, the present value of averting expenditures costs is around \$2,095 using a 3% discount rate or \$1,257 using a 5% rate. In this case, anticipated averting expenditure costs would contribute at most 40% of our estimated housing price response. The remaining damages could be attributed to other impacts from the switch including anticipated remediation costs, the disutility associated with substituting bottled water for tap water, health concerns, beliefs that damages were more severe than public officials led the public to believe, risk aversion, or erosion of public trust in local government to provide public services.

The extent of the crisis became more evident after the emergency declarations. Assuming households anticipated a permanent shock and that the free bottled water and filter programs were temporary, we calculate the present value of averting expenditures to be around \$12,972/household using a 3% discount rate (\$7,783 using a 5% discount rate).[49] By comparison, our hedonic damages increased to \$20,340. Thus, averting expenditures makeup at most 64% of estimated damages. This suggests that non-averting expenditure damages (including the disutility associated with the substitution of bottled water for tap water) also comprise a significant fraction of the housing response. After the crisis, households learned that the switch to the Flint River not only damaged the service lines but also damaged pipes and appliances. State and federal funds have been allocated to pay for service line replacements, but do not cover damaged appliances or pipes within homes. According to GOOD Money Magazine, replacing in-home pipes and fixtures will cost an average homeowner around \$7,200 (Talty, 2017).[50] If we add this kind of additional expense to our averting expenditure estimates, they would account for nearly 100% of estimated damages. However, these calculations rely on several assumptions, including a strong assumption that households believed they would have to pay for these expenditures in perpetuity after federal and state support was no longer available.

Are damages from the Flint crisis permanent? Several popular press articles detail frustration and mistrust of government officials to ever solve the crisis. However, it is unrealistic to assume that the entire decline in housing values is permanent. Housing values may increase in the long-run, especially as the city completes its extensive abatement programs.

[49] After the emergency declaration, average bottled water expenditures fell by \$16.5/household/month relative to the pre-switch period while filter expenditures increased by \$3.15/household/month. If we add additional state and federal spending on filters, this figure increases to \$15.93/household/month for filters and \$32.43/household/month for all averting expenditures. These figures assume current consumption levels would remain fixed in the absence of state and federal spending.

[50] The estimate includes \$4,000 to \$5,000 to replace pipes in an average single-story home, and \$2,200 to replace fixtures – water heaters, dishwashers, and washing machines – that were likely damaged by the corrosive water.

Nonetheless, even as significant remediation efforts were underway and large settlements were reached to replace lead lines and improve water quality, we see no evidence of the market rebounding as of mid-2017. The lack of improvement in housing values may reflect long-term damage to public trust as residents continue to question the safety of the public water supply (Smith et al., 2019).

Last, we find it helpful to consider these damage estimates relative to other hedonic responses in the literature. Our preferred estimates suggest a decline of 29% in housing values since the switch. This is larger than a 22% decrease for a toxic algae bloom (Wolf and Klaiber, 2017), a 14 to 16% decline for a cancer cluster (Davis, 2004), 15% increase for brownfield remediation (Haninger et al., 2017), 14% for the siting of a well pad for shale gas (Muehlenbachs et al., 2015), 11% decrease for the opening of a toxic plant (Currie et al., 2015), and 8% for the discovery of a hazardous waste (Mendelsohn et al., 1992). One exception is that our estimates are slighty smaller than a recent study of the value of lead paint remediation. Billings and Schnepel (2017) estimate a 32% increase in home values from remediation, though the authors note a significant fraction may be due to other property improvements associated with remediation.

8 Discussion and Conclusions

This paper presents results from a study of the economic impacts of the Flint water crisis. We find evidence of substantial averting expenditures well before local officials announced that the water was not safe to drink. One striking finding is that our estimated private averting expenditures before the crisis were as large as the expected public savings from switching to the Flint River.[51] One silver lining of our finding is that citizens' early avoidance behavior likely prevented larger human health impacts. Large decreases in bottled water sales after the crisis suggest that private expenditures would have been much larger in the absence of the city's free bottled water program. We estimate that the average house lost approximately 29% of its value, translating to a $345 to $497 million decrease in the value of Flint's housing stock. This decrease occurred despite $350 million in state and federal spending over this same period.

What happens when a critical public good like safe drinking water is no longer available? Our analysis suggests that the impacts are substantial. Both averting expenditures and

[51]This compares an expected savings of $2.5 million per year with $2.5 million per year in averting expenditures.

housing markets show stark responses as the crisis unfolded, and remained evident even after significant remediation efforts were underway. The impact's magnitude naturally begs the question as to what, if any, changes should be made to the way we provide and regulate public services like safe drinking water? On the one hand, one could argue that regulations in place are sufficient since the crisis was caused by failures to adhere to existing rules. Perhaps all that is needed are more significant safeguards to prevent similar cases of wrongdoing on the part of state and local officials. On the other hand, it is clear that the rule did not account for the possibility of system-wide failures.

The original Lead and Copper rule of 1991 placed a heavy emphasis on corrosion control, which had favorable benefit to cost ratios. This seems rational on first glance. If Flint had adhered to the rule, the switch likely would not have triggered a crisis. However, the crisis occurred in part because of the existence of lead service lines and plumbing throughout the city. The EPA did not include a program to replace lead service lines in the 1991 regulation because the benefit-cost ratios of a nationwide program were perceived to be very unfavorable (Lead and Copper Rule, 1991). The benefits of such a program, however, were based on studies that estimated health benefits using expected lead exposure before and after service line replacement. This type of cost-benefit analysis does not account for potential system-wide losses in drinking water distribution networks. While it is difficult, if not impossible, to accurately gauge the likelihood of an event like the Flint water crisis, our study highlights a key limitation of the current framework used by regulators in assessing benefits of critical infrastructure investment programs.

Moving forward, the EPA is considering revising the Lead and Copper Rule. While admirably discussing the need for "clear and enforceable requirements", a white paper released by EPA suggests benefits will be similarly calculated. For example, in discussing the possibility of revisiting the need to replace lead service lines, EPA writes "[b]enefits will be estimated based upon avoided effects of lead exposure such as IQ loss in developing children. EPA will evaluate how much additional lead exposure reduction can be achieved in removing LSLs from water systems with optimized corrosion control" (USEPA, 2016). It is not clear that the possibility of a large, non-marginal, change in the quality of public drinking water has been considered in the EPA cost-benefit analyses.

The Flint water crisis resulted from a series of institutional failures and violations of federal regulatory requirements, making the economic damages from the Flint crisis relevant for understanding the benefits of compliance with federal drinking water regulations such as the Safe Drinking Water Act and the Lead and Copper Rule. Our results suggest the need to revisit how these rules account for the possibility of major, system-wide impacts that can have widespread economic consequences.

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Table 1: Summary Statistics: Baseline Characteristics

	(1) Flint	(2) Flint vs. Top 3	(3) Flint vs. Top 5	(4) Flint vs. Genesee
Panel A: City Demographics				
Population (2010)	102,434	-34,490.67	-12,511.00	-90,457.85
		(10,339.40)	(36,652.98)	(9,572.78)
Population Change (1970-2010)	-90,883.00	49,630.00	23,380.00	93,550.36
		(31,536.64)	(44,852.98)	(5,059.77)
Med. Income (2012)	26,339.00	311.33	1,566.80	24,653.07
		(2,543.24)	(2,704.15)	(12,362.63)
Med. Income Change (1970-2012)	9,158.00	4,523.33	4,868.80	18,459.36
		(3,859.84)	(3,057.98)	(9,993.38)
Housing Vacancy Rate (%, 2010)	0.21	-0.04	-0.03	-0.13
		(0.03)	(0.03)	(0.02)
Unemployment Rate (%, 2012)	0.25	-0.04	-0.06	-0.12
		(0.03)	(0.03)	(0.04)
African American Population (%, 2010)	0.57	-0.08	-0.05	-0.51
		(0.04)	(0.12)	(0.09)
Panel B: Housing Market (2006-2013)				
Average Home Price ($2009)	71,075.34	13,073.54	33,534.14	53,864.05
		(3,938.69)	(4,952.56)	(5,099.62)
Median Home Price ($2009)	61,472.17	11,592.91	19,282.90	44,594.83
		(716.46)	(711.36)	(799.50)
Panel C: Grocery Sales (2006-2013)				
Bottled Water Sales (1000 bottles/month)	206.32	100.41	223.92	-90.10
		(66.07)	(62.36)	(56.30)
Filter (units/month)	2,775.43	1467.72	1503.62	-558.22
		(1,517.59)	(1,296.93)	(1,330.85)

Notes: The table presents statistics for the city of Flint in the first column and coefficients from a regression of the outcome on an indicator for three control groups (Top 3 control cities, Top 5 control cities, and cities in Genesee County). Panel A presents statistics from the 1970 and 2010 Census and 2010-2012 American Community Survey. Panel B presents average and median home prices ($ 2009). The latter estimates a quantile regression model. Panel C presents statistics from Nielsen's Retail Scanner data. Standard errors are clustered at the Census Block Group in Panel B and the store-level in Panel C.

Table 2: Flint Avoidance Behavior Impacts

Panel A: Bottled Water				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Size-Quartile 4	Price-Quartile 1
Emergency X Flint	-0.749	-0.724	-0.499	-0.802
	(0.099)	(0.097)	(0.090)	(0.100)
Water Supply Switch X Flint	0.161	0.249	0.340	0.193
	(0.082)	(0.076)	(0.077)	(0.084)
Receivership X Flint	0.041	0.028	-0.008	0.071
	(0.065)	(0.057)	(0.116)	(0.076)
Observations	11,282	22,730	11,137	10,991
N (Stores)	96	201	96	96
Panel B: Water Filters				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Pur	Brita
Emergency X Flint	0.170	0.156	0.280	0.051
	(0.090)	(0.085)	(0.108)	(0.098)
Water Supply Switch X Flint	-0.057	-0.005	0.034	-0.105
	(0.081)	(0.067)	(0.085)	(0.087)
Receivership X Flint	0.130	0.114	0.096	0.112
	(0.109)	(0.103)	(0.073)	(0.114)
Observations	9,507	19,171	6,189	8,769
N (Stores)	93	197	86	93
Control Sample	Top 3	Top 5	Top 3	Top 3
Store FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of the volume of bottled water sales or water filter sales at stores in Flint versus control cities from January 2006 to December 2016. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the store level.

Table 3: Flint Housing Price Impacts

	(1)	(2)	(3)	(4)	(5)	(6)
Emergency X Flint	-0.201	-0.198	-0.126	-0.160	-0.160	-0.062
	(0.037)	(0.037)	(0.069)	(0.036)	(0.036)	(0.067)
Water Supply Switch X Flint	-0.106	-0.087	-0.247	-0.167	-0.163	-0.297
	(0.034)	(0.034)	(0.062)	(0.033)	(0.033)	(0.059)
Receivership X Flint	0.112	0.037	0.049	0.108	0.093	0.004
	(0.031)	(0.030)	(0.053)	(0.030)	(0.030)	(0.050)
Control Sample	Top 3	Top 3	Top 3	Top 5	Top 5	Top 5
Observations	33,367	33,367	16,015	91,136	91,136	48,365
N (Houses)	24,120	24,120	6,768	62,966	62,966	20,195
Property FE	No	No	Yes	No	No	Yes
Census Block Group FE	Yes	Yes	No	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	No	Yes	Yes	No	Yes	Yes

Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 $). All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Table 4: Flint Housing Price Impacts
Heterogeneous Impacts by 2010 Census Block Group Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
Emergency X Flint	-0.223	-0.220	-0.134	-0.174	-0.171	-0.096
	(0.064)	(0.064)	(0.134)	(0.042)	(0.042)	(0.078)
X High Income	0.045	0.044	0.022			
	(0.074)	(0.074)	(0.156)			
X High Black %				-0.062	-0.062	-0.110
				(0.065)	(0.065)	(0.123)
Water Supply Switch X Flint	-0.101	-0.083	-0.197	-0.106	-0.087	-0.155
	(0.039)	(0.039)	(0.112)	(0.046)	(0.046)	(0.068)
X High Income	-0.009	-0.008	-0.069			
	(0.062)	(0.062)	(0.128)			
X High Black %				0.001	-0.001	-0.197
				(0.063)	(0.063)	(0.118)
Receivership X Flint	0.163	0.086	0.113	0.117	0.044	-0.010
	(0.049)	(0.049)	(0.090)	(0.039)	(0.035)	(0.047)
X High Income	-0.097	-0.091	-0.110			
	(0.056)	(0.055)	(0.101)			
X High Black %				-0.011	-0.014	0.125
				(0.058)	(0.056)	(0.101)
Control Sample	Top 3	Top 3	Top 3	Top 3	Top 3	Top 3
Observations	33,367	33,367	16,015	33,367	33,367	16,015
N (Houses)	24,120	24,120	6,768	24,120	24,120	6,768
Property FE	No	No	Yes	No	No	Yes
Census Block Group FE	Yes	Yes	No	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	No	Yes	Yes	No	Yes	Yes

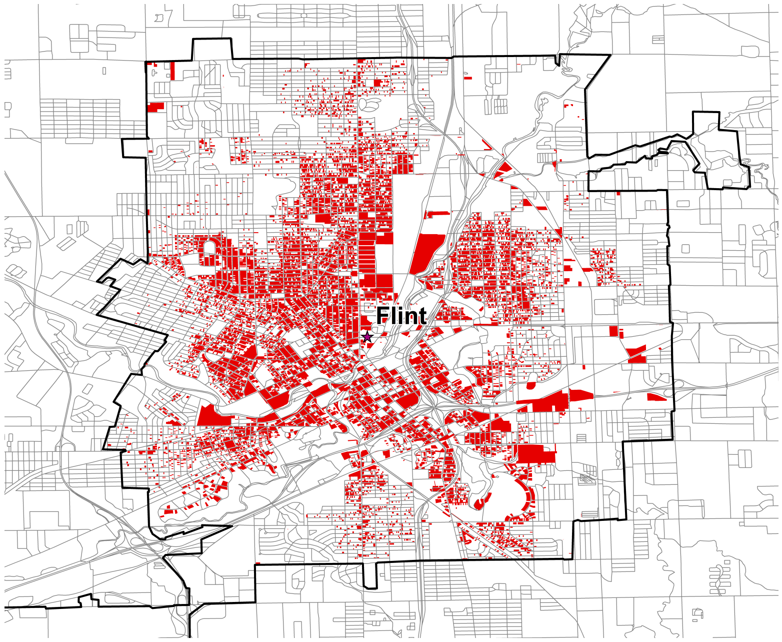
Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 \$). "X High Income" refers to Flint homes in Census Block Groups with above median incomes according to the 2010 Census. "X High Black %" refers to Flint homes in Census Block Groups with above median Black or African American populations according to the 2010 Census. All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Table 5: Flint Housing Price Impacts
Heterogeneous Impacts by Lead Exposure

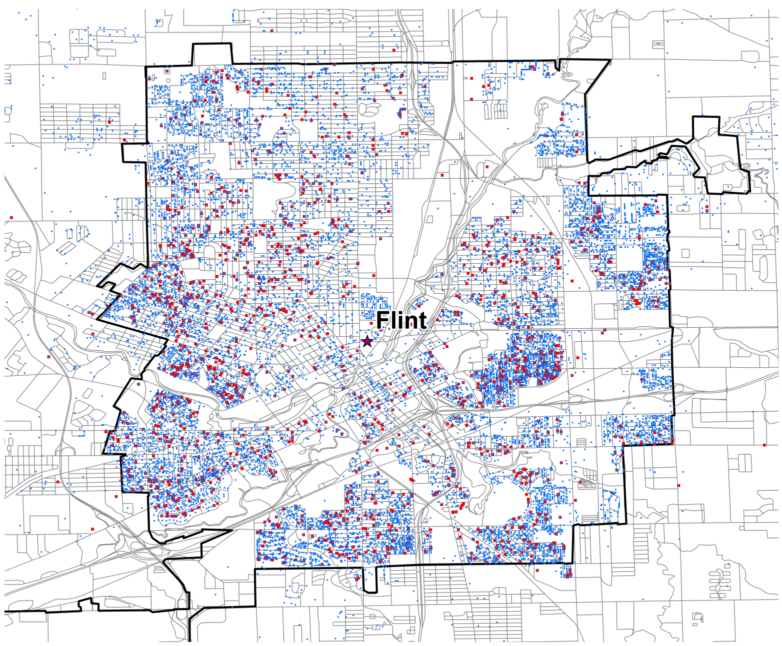
	(1)	(2)	(3)	(4)	(5)	(6)
Emergency X Flint	-0.214	-0.210	-0.115	-0.237	-0.235	-0.203
	(0.040)	(0.040)	(0.075)	(0.049)	(0.049)	(0.105)
X Lead SL	0.071	0.069	-0.056			
	(0.091)	(0.092)	(0.085)			
X (>EPA MGL)				0.211	0.226	-0.062
				(0.135)	(0.136)	(0.181)
Water Supply Switch X Flint	-0.112	-0.094	-0.278	-0.080	-0.061	-0.210
	(0.036)	(0.036)	(0.065)	(0.035)	(0.035)	(0.070)
X Lead SL	0.026	0.028	0.139			
	(0.054)	(0.053)	(0.120)			
X (>EPA MGL)				-0.190	-0.201	0.197
				(0.083)	(0.083)	(0.118)
Receivership X Flint	0.122	0.048	0.065	0.112	0.038	0.040
	(0.029)	(0.028)	(0.047)	(0.031)	(0.030)	(0.054)
X Lead SL	-0.052	-0.051	-0.070			
	(0.035)	(0.035)	(0.095)			
Control Sample	Top 3	Top 3	Top 3	Top 3	Top 3	Top 3
Observations	33,367	33,367	16,015	33,323	33,323	15,979
N (Houses)	24,120	24,120	6,768	24,096	24,096	6,752
Property FE	No	No	Yes	No	No	Yes
Census Block Group FE	Yes	Yes	No	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	No	Yes	Yes	No	Yes	Yes

Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 $). "X Non-Lead SL" indicates homes with non-lead service lines (omitted category lead/unknown service lines). "X >EPA MGL)" indicates homes that, at the time of sale, lived in an area where average lead tests of all homes in a 1KM radius were above EPA standards. All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Figure 1: Flint Service Lines and Lead Tests



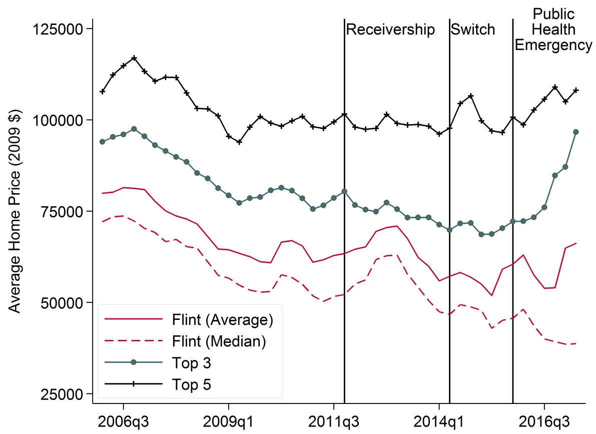
(a) Service Lines



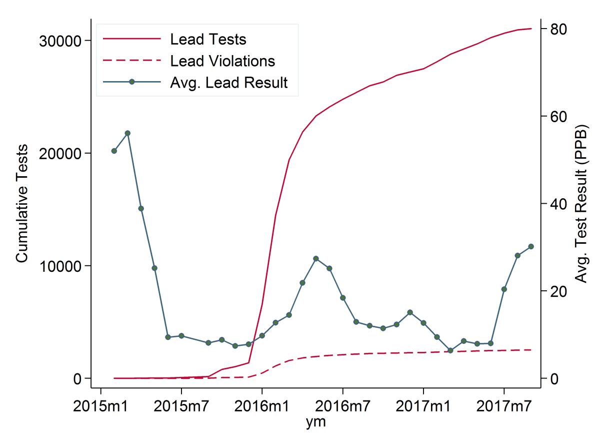
(b) Lead Test Results

Notes: Figure 1a displays the location of lead services lines in Flint. Red parcels indicate a home with a lead service line. Figure 1b presents lead testing results in and around the city. Results violating safe drinking water standards are shown as red squares, and those below safe drinking water standards are blue circles. The City of Flint boundary is delineated by a dark black line. Census Block Groups are delineated by grey lines. The maps exclude the Flint airport in the southwestern section of the city.

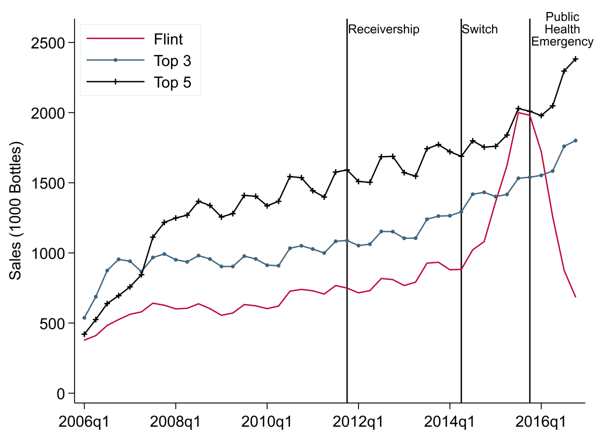
Figure 2: Housing Markets Summary Statistics



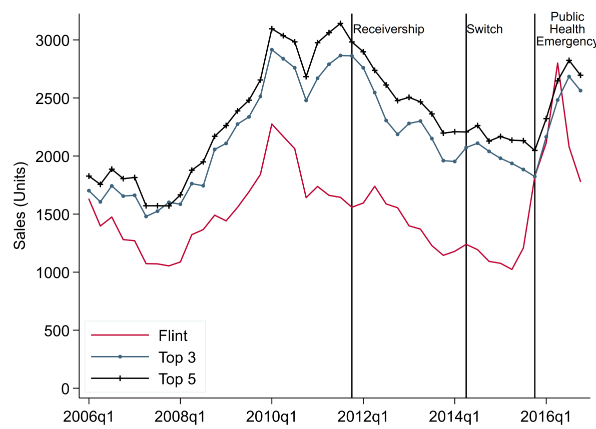
(a) Home Prices by Sample



(b) Flint Lead Tests



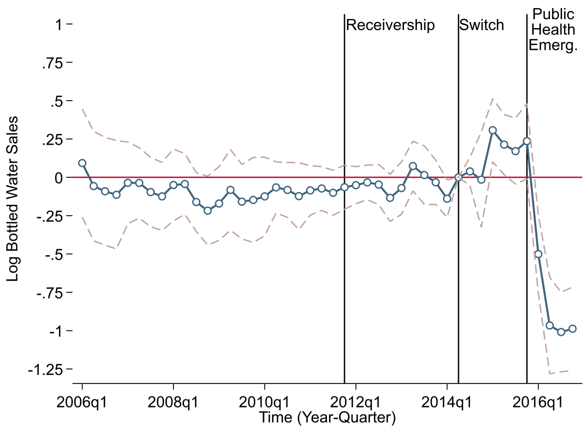
(c) Bottled Water Sales



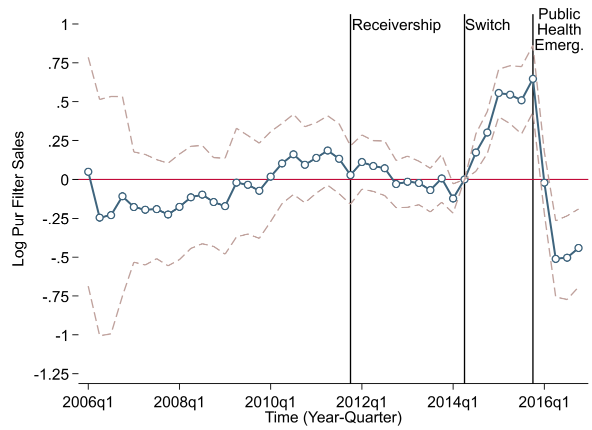
(d) Water Filter Sales

Notes: Figure 2a graphs smoothed average housing prices in Flint, the Top 3 control group cities, and the Top 5 control group cities. Figure 2b graphs the cumulative number of lead tests and tests where lead concentrations violated EPA health standards over time (left axis), as well as the average lead test result in homes (right axis). Figures 2c and 2d graph smoothed bottled water and water filter sales over time in Flint and the Top 3 and Top 5 control group cities.

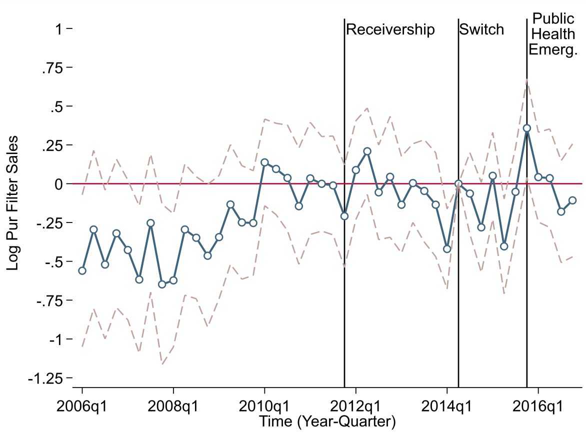
Figure 3: Avoidance Behavior Event Studies: Flint versus Top 3 Control Cities



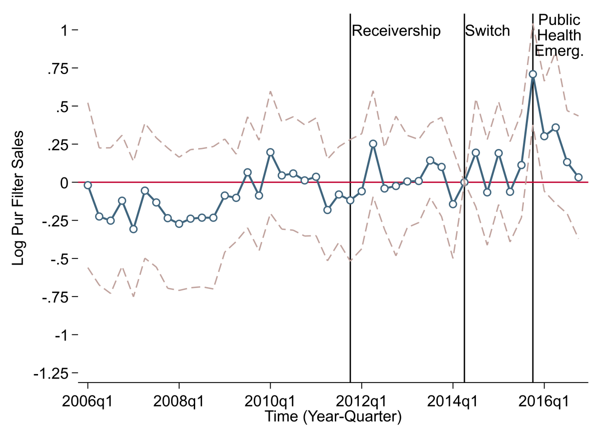
(a) Bottled Water Sales



(b) Bottled Water Sales: Largest Quartile



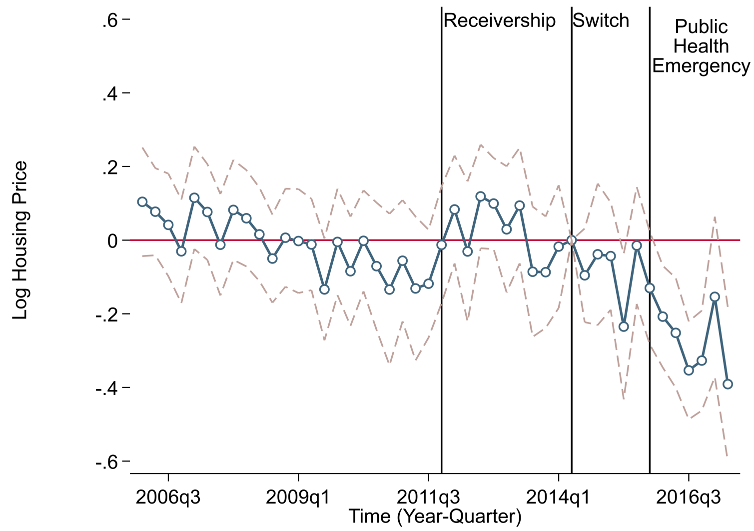
(c) Water Filter Sales



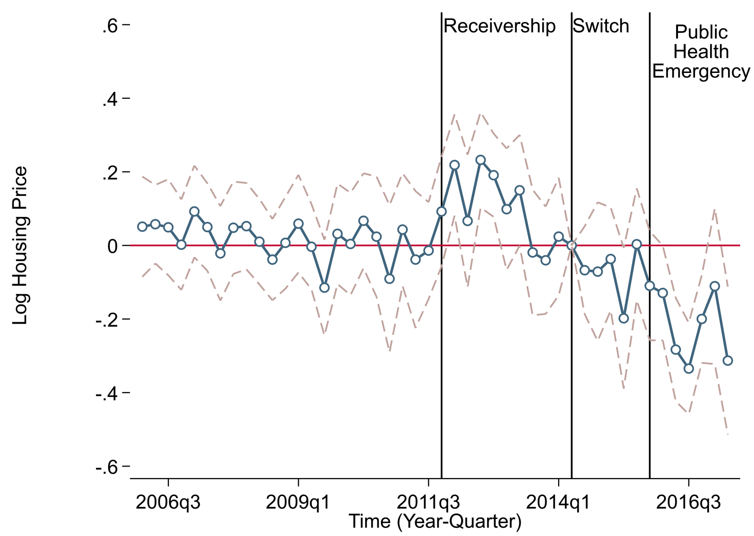
(d) Pur Water Filter Sales

Notes: The figures graph event study coefficients from estimating equation (2) using the log of monthly bottled water sales and water filter sales at stores shopped at by consumers that live in Flint and the Top 3 control cities. Dashed lines show 95 % confidence intervals. Figure 3a graphs results using all bottled water sales. Figure 3b includes only the largest bottled water size quartile. Figure 3c includes all water filters in our sample. Figure 3d includes only Pur filters. Each specification includes weather and economic controls as well as store fixed effects.

Figure 4: Home Price Event Studies



(a) Flint versus Top 3 Control Cities



(b) Flint versus Top 5 Control Cities

Notes: These figures graph event study coefficients from estimating equation (2) using housing transactions in Flint and the Top 3 and Top 5 control cities. Dashed lines show 95 % confidence intervals. Each specification includes weather and economic controls as well as Census Block Group fixed effects.

Online Appendix for
Economic Effects of Environmental Crises: Evidence from Flint, Michigan

Peter Christensen, David A. Keiser, and Gabriel E. Lade

June 20, 2019

A Matching Details

We collect city-level population, labor force, and demographic data from the U.S. Census and American Community Survey to construct our matched control groups (Ruggles et al., 2015). We limit the data to cities with populations greater than 50,000 and less than 200,000 to ensure our sample is composed of cities similar in size to Flint. We choose several city-level statistics to construct our matched control group. From the 2010 Census, we match on city population, the percent of vacant households, and the percent of the population that is black or African American. From the 2012 ACS, we match on median household income and the unemployment rate. We also construct variables to capture changes in city demographics over time to ensure our control sample cities experienced similar economic declines as Flint since the mid-20th century. We create variables for the difference in median household income from 1970 to 2012, and the population change from 1970 to 2010.

We define the distance between the vector of other cities' and Flint's covariates as the vector norm of the covariate differences, $||\mathbf{z}-\mathbf{x}|| = [(\mathbf{z}-\mathbf{x})'V(\mathbf{z}-\mathbf{x})]^{\frac{1}{2}}$, where V is specified as the diagonal of the inverse variances for each element in $(\mathbf{z}-\mathbf{x})$. After computing the differences in pre-treatment covariates, we construct our matched control samples using the top 3 and top 5 city matches. As a robustness check, we also consider the top 10 city matches.

Table A.1 reports the match distance (normalized between zero and one) and statistics for Flint and our control cities. Youngstown, OH, Pontiac, MI and Camden, NJ make up our Top 3 control cities, and Gary, IN and Dayton, OH are included in our Top 5 sample. All cities have seen significant population declines since the 1970s, have low median incomes with only modest income growth rates over time, and have high unemployment and black populations. As expected, matched cities are less comparable to Flint on our baseline characteristics as we include more cities in the sample.

Table A.1: Matched Sample

City	Match Distance	Population (2010)	Population Δ (1970-2010)	Med. Income (2012)	Med. Income Δ (1970-2012)	Vacant Houses (%, 2010)	Unemploy. Rate 2012	Black Population (%, 2010)
Flint, MI	–	102,434	-90,883	26,339	9,158	0.211	0.255	0.566
Youngstown, OH	0.304	66,971	-72,788	24,421	10,981	0.190	0.195	0.452
Pontiac, MI	0.396	59,515	-25,764	28,825	12,643	0.180	0.214	0.521
Camden, NJ	0.396	77,344	-25,207	26,705	17,420	0.137	0.238	0.481
Calumet (Gary), IN	0.413	104,258	-111,682	30,983	12,554	0.178	0.170	0.696
Dayton, OH	0.470	141,527	-102,074	28,595	16,536	0.211	0.172	0.429
Hartford, CT	0.602	124,775	-33,242	28,931	17,418	0.129	0.193	0.387
Trenton, NJ	0.697	84,913	-19,725	36,727	24,545	0.135	0.179	0.520
Portage, IN	0.825	93,063	-36,210	33,791	18,524	0.149	0.167	0.262
Wayne, IN	0.964	103,803	-45,713	32,951	17,816	0.154	0.150	0.225
East Orange, NJ	1	64,270	-11,201	38,910	25,533	0.134	0.194	0.885

B Sensitivity Analyses and Robustness Checks

B.1 Avoidance Behavior

Bottled Water and Water Filter: County Results Table B.1 presents results using all stores in Genesee County and the Top 3 control cities' respective counties. We find around a 20% increase in bottled water sales in Genesee County after the switch across all specifications, comparable to the 16% to 25% we find in Table 2. After the emergency, water sales decreased by 57% to 58%, a smaller decrease than we observe in our preferred store sample. We see a 6% to 8% decrease in water filter sales after the switch and no statistically significant increase in sales after the emergency. We still find that Pur sales increased after each event, but the estimates are noisier.

Bottled Water Purchases: Additional Results. Table B.2 presents results using alternative controls and samples. The dependent variable in every column is the log of all bottled water sales. Results are nearly identical to those in Table 2 if we use year-by-month fixed effects (columns 2 and 4), and are robust to excluding the economic and weather controls (columns 1 and 3). Table B.3 presents results for every unit-size quartile (Panel A) and price-per-ounce quartile (Panel B). After the switch, sales of the smallest sized units increased by 15%, sales of the second and third quartiles remained largely the same or even decreased, and sales of the largest sized units increased by 34%. Sales of all product sizes decreased after the emergency declaration, with the largest impacts again being seen for the smallest and largest quartiles. The story is clearer when we divide our sample by price-per-ounce. Both the largest increases (post switch) and decreases (post emergency declaration) in sales volumes are seen for the cheapest water bottles on a per-ounce basis. The results suggest that as consumers faced uncertainty regarding the quality of their tap water, they began purchasing water in bulk.

Bottled Water and Water Filter: Sales Value Our primary specification studies the volume of bottled water (ounces) and water filter (unit) sales. A natural question is whether the crisis impacted sales values. This would be impacted by two factors: (i) changing composition of the types of items people purchase (e.g., shifting from high-cost to low-cost, bulk bottled water as we show likely occurred above); and (ii) retailers changing their prices (e.g., increasing prices when demand increased after the switch to the Flint River or decreasing prices when free bottled water and filters were readily available in the community). Table B.4 presents our results using the same specifications as in Table 2 but using the log of sales value as the dependent variable. Bottled water sales value increased by 11% to 19%

following the switch to the Flint River, and decreased around 62% following the emergency declaration. The estimates are smaller than those when we use the sales volume as our dependent variable, consistent with consumers shifting towards lower-priced bottled water. Water filters continue to show no response after the switch to the Flint River, while the sales value impact is higher after the emergency declaration when we use sales value instead of sales volume. As shown in Table B.5, this is consistent with consumers purchasing Pur water filter systems, which are more expensive than cartridges. As before we see no impact of the emergency declaration on demand for Brita filters.

Water Filters: Systems and Cartridges. Table B.5 presents results separately for water filter systems (e.g., on-tap or pitcher water filter systems) and water filter cartridges (replaceable filters). Most water filter systems come with one or more cartridges. As in Table 2, we present results for all approved brands, Pur, and Brita and use the Top 3 controls in all columns. We see no significant change in water filters sales after the switch. Both water systems and cartridge sales increased after the crisis, and the result is driven by large increases in Pur systems (26%) and Pur cartridges (20%). Brita sales were unaffected by the crisis. Pur filter system sales increased by more than cartridge sales, suggesting that households needed either new (e.g., multiple on-tap systems) or their first water filter system. The last finding may also be due to the availability of free water filter cartridges after the emergency.

Table B.1: Flint Bottled Water Purchase Impacts - County Stores

Panel A: Bottled Water				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Size-Quartile 4	Price-Quartile 1
Emergency X Flint	-0.583	-0.566	-0.421	-0.634
	(0.062)	(0.061)	(0.047)	(0.062)
Water Supply Switch X Flint	0.186	0.204	0.224	0.220
	(0.053)	(0.052)	(0.052)	(0.053)
Receivership X Flint	0.071	0.007	-0.045	0.128
	(0.044)	(0.041)	(0.065)	(0.052)
Observations	42,610	64,000	42,033	40,945
N (Stores)	390	597	389	386
Panel B: Water Filters				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Pur	Brita
Emergency X Flint	0.010	0.027	0.089	0.021
	(0.051)	(0.050)	(0.067)	(0.056)
Water Supply Switch X Flint	-0.080	-0.062	0.056	-0.139
	(0.045)	(0.043)	(0.052)	(0.051)
Receivership X Flint	0.052	0.071	-0.010	0.058
	(0.066)	(0.065)	(0.051)	(0.066)
Observations	29,939	42,273	19,470	27,829
N (Stores)	312	459	280	312
Control Sample	Top 3	Top 5	Top 3	Top 3
Store FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of the volume of bottled water sales or water filter sales at stores in Flint versus control cities from January 2006 to December 2016. Economic controls include the unemployment rate. Standard errors are clustered at the store level.

Table B.2: Bottled Water Impacts: Alternative Controls and Samples

	(1)	(2)	(3)	(4)
Emergency X Flint	-0.750	-0.752	-0.729	-0.727
	(0.099)	(0.099)	(0.096)	(0.097)
Water Supply Switch X Flint	0.153	0.162	0.246	0.249
	(0.083)	(0.083)	(0.077)	(0.077)
Receivership X Flint	0.067	0.040	0.039	0.026
	(0.073)	(0.066)	(0.060)	(0.058)
Control Sample	Top 3	Top 3	Top 5	Top 5
Observations	11,282	11,282	22,730	22,730
N (Stores)	96	96	201	201
Store FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No
Month FE	Yes	No	Yes	No
Year-Month FE	No	Yes	No	Yes
Economic Controls	No	Yes	No	Yes
Weather Controls	No	Yes	No	Yes

Notes: The dependent variable is the log of the volume of bottled water sales at stores in Flint versus control cities from January 2006 to December 2016. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the store level.

Table B.3: Bottled Water Impacts: Additional Results

	(1)	(2)	(3)	(4)
Panel A: Product Size Quartiles				
Emergency X Flint	-0.849	-0.253	-0.337	-0.499
	(0.113)	(0.082)	(0.083)	(0.090)
Water Supply Switch X Flint	0.149	-0.105	0.002	0.340
	(0.089)	(0.070)	(0.067)	(0.077)
Receivership X Flint	0.105	0.083	0.195	-0.008
	(0.099)	(0.131)	(0.089)	(0.116)
Quartile	1	2	3	4
Observations	11,230	11,242	10,258	11,137
N (Stores)	96	96	95	96
Panel B: Product Price Quartiles				
Emergency X Flint	-0.802	-0.322	-0.346	-0.291
	(0.100)	(0.073)	(0.121)	(0.059)
Water Supply Switch X Flint	0.193	0.081	0.060	-0.080
	(0.084)	(0.084)	(0.058)	(0.058)
Receivership X Flint	0.071	-0.061	-0.312	-0.027
	(0.076)	(0.099)	(0.102)	(0.069)
Quartile	1	2	3	4
Observations	10991	11229	10868	11217
N (Stores)	96	96	93	96
Store FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of the volume of bottled water sales at stores in Flint versus control cities from January 2006 to December 2016. Product size and price quartiles are based on UPC unit size and price per ounce, respectively, and represent the total monthly volume of UPC sales in each quartile. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the store level.

Table B.4: Avoidance Behavior Impacts: Sales Value

Panel A: Bottled Water				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Size-Quartile 4	Price-Quartile 4
Emergency X Flint	-0.635	-0.620	-0.635	-0.635
	(0.079)	(0.077)	(0.079)	(0.079)
Water Supply Switch X Flint	0.117	0.187	0.117	0.117
	(0.061)	(0.057)	(0.061)	(0.061)
Receivership X Flint	0.012	-0.001	0.012	0.012
	(0.052)	(0.048)	(0.052)	(0.052)
Observations	11,282	22,730	11,282	11,282
N (Stores)	96	201	96	96
Panel B: Water Filters				
	(1)	(2)	(3)	(4)
Dep. Variable	All	All	Pur	Brita
Emergency X Flint	0.250	0.235	0.355	0.002
	(0.082)	(0.077)	(0.091)	(0.107)
Water Supply Switch X Flint	0.006	0.008	0.065	-0.081
	(0.071)	(0.060)	(0.085)	(0.077)
Receivership X Flint	0.091	0.110	0.110	0.014
	(0.084)	(0.081)	(0.084)	(0.096)
Observations	9,507	19,171	6,189	8,769
N (Stores)	93	197	86	93
Control Sample	Top 3	Top 5	Top 3	Top 3
Store FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of the value of bottled water and water filter sales at stores in Flint versus control cities from January 2006 to December 2016. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the store level.

Table B.5: Water Filter Purchases: Systems and Cartridges

Dep. Variable	(1) All (System)	(2) All (Cartridge)	(3) Pur (System)	(4) Pur (Cartridge)	(5) Brita (System)	(6) Brita (Cartridge)
Emergency X Flint	0.111	0.120	0.261	0.195	-0.050	0.030
	(0.112)	(0.089)	(0.149)	(0.104)	(0.155)	(0.096)
Water Supply Switch X Flint	0.059	-0.097	-0.031	0.030	0.076	-0.101
	(0.067)	(0.083)	(0.067)	(0.083)	(0.134)	(0.087)
Receivership X Flint	-0.104	0.134	-0.111	0.070	-0.207	0.104
	(0.149)	(0.110)	(0.180)	(0.078)	(0.163)	(0.117)
Control Sample	Top 3	Top 3	Top 3	Top 3	Top 3	Top 3
Observations	4,744	9,215	3,415	5,592	2,828	8,543
N (Stores)	90	93	82	85	87	93
Store FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of the volume of monthly water filter sales at stores in Flint versus control cities from January 2006 to December 2016. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the store level.

B.2 Housing Market Impacts

Alternative Control Cities: Table B.6 shows results using alternative control groups. Panel A presents results using different ranked samples (Top 1 and Top 10 cities) and all cities in Genesee County. Columns 1 and 2 present the full-control specifications with and without property fixed effects, respectively, using only our top matched control city, Youngstown, OH. Results are similar to our corresponding estimates in Table 3. When we consider our Top 10 sample, the coefficient on the switch (emergency) increases (decreases) slightly in the all homes sample, and the results remain sensitive across all homes and repeat sales models. Columns 5 and 6 of Panel A and all columns in Panel B show why we do not pursue a local control group. When we include housing transactions from all of Genesee County or cities 1 to 5 miles outside Flint, we find a significant, differentially positive impact of receivership on Flint housing prices, suggesting that the controls exhibit differential pre-trends.

Alternative Control Variables: Table B.7 presents results using the same samples as Table 3 but with alternative control variables. Panel A presents the results for the Top 3 controls, and Panel B presents results using the Top 5 control. Columns 1 and 2 include only Census Block Group and property fixed effects, respectively. We find similar results in both cases, however, in all but the Top 5 city property fixed effects model, the coefficient on receivership is large and statistically significant. Columns 3 and 4 have the same controls as in columns 2 and 3 of Table 3 but use year-by-month fixed effects instead of year and month-of-year fixed effects. Results are very similar. Columns 5 and 6 allow for city-level, yearly trends. Results are larger than in our preferred specifications, suggesting that city-specific, time-varying unobserved factors may attenuate our results.

Alternative Price Restrictions: Our main specifications follow Currie et al. (2015) and restrict our sample to houses that sold between \$25,000 and \$10,000,000 (2009 \$). Table B.8 presents results using alternative price-ranges. Each panel includes the same sequence of controls and samples, as in Table 3. Panel A presents results for low-priced homes that sold for between \$500 and \$25,000 in each city. Low-valued homes did substantially worse in the receivership period in Flint than homes in control cities. With the caveat that low-valued homes appear to violate our differential pre-trends assumption, we find that these homes experienced larger (proportional) losses after the switch and smaller losses after the emergency. The result may be due to home values 'bottoming out' after years of decline or

[52] After dropping all intra-family transfers, tax-exempt purchases, lot sales, and observations with missing prices, we still observe roughly 1,400 homes that transacted for \$0. Zero-valued transactions may be explained by several factors that we do not see in our data. For example, some of these homes may have outstanding property taxes due that exceed the property's value.

because we limit our sample at $500 since even this low bound is binding.[52] Panel B considers homes that transacted for $25,000 to $1,000,000 to ensure outlier observations do not drive our results. Results are insensitive to this exclusion. Panel C considers the broadest range of home prices, $500 to $10,000,000. Results for the emergency declaration are similar to our main results. However, the water supply switch impact is larger, though the coefficient on receivership suggests differential pre-trends exist in the sample.

Table B.6: Flint Housing Price Impacts: Alternative Control Cities

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Top 1, Top 10, and Genesee County						
Emergency X Flint	-0.218	-0.167	-0.140	-0.060	-0.189	-0.112
	(0.038)	(0.070)	(0.035)	(0.066)	(0.036)	(0.063)
Water Supply Switch X Flint	-0.120	-0.295	-0.181	-0.338	-0.272	-0.467
	(0.034)	(0.061)	(0.032)	(0.058)	(0.034)	(0.057)
Receivership X Flint	0.051	0.076	0.074	-0.018	0.129	0.217
	(0.028)	(0.051)	(0.031)	(0.049)	(0.032)	(0.051)
Control Sample	Top 1	Top 1	Top 10	Top 10	Genesee	Genesee
Observations	19,512	9,039	91,136	48,365	12,513	6,804
N (Houses)	14,313	3,840	62,966	20,195	8,530	2,821
Panel B: Local Sales						
Emergency X Flint	-0.192	-0.221	-0.176	-0.182	-0.181	-0.114
	(0.041)	(0.095)	(0.040)	(0.085)	(0.038)	(0.068)
Water Supply Switch X Flint	-0.212	-0.302	-0.214	-0.345	-0.255	-0.450
	(0.041)	(0.081)	(0.038)	(0.074)	(0.034)	(0.063)
Receivership X Flint	0.221	0.363	0.190	0.313	0.158	0.292
	(0.040)	(0.067)	(0.035)	(0.059)	(0.033)	(0.056)
Control Sample	1 Mile	1 Mile	2 Miles	2 Miles	5 Miles	5 Miles
Observations	8,216	3,920	10,954	5,547	23,397	12,720
N (Houses)	5,957	1,661	7,729	2,322	16,005	5,328
Property FE	No	Yes	No	Yes	No	Yes
Census Block Group FE	Yes	No	Yes	No	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 \$). All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Table B.7: Flint Housing Price Impacts: Alternative Control Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Top 3 Control Sample						
Emergency X Flint	-0.201	-0.118	-0.199	-0.138	-0.296	-0.227
	(0.036)	(0.075)	(0.038)	(0.076)	(0.038)	(0.074)
Water Supply Switch X Flint	-0.109	-0.258	-0.085	-0.240	-0.219	-0.413
	(0.034)	(0.060)	(0.034)	(0.063)	(0.036)	(0.064)
Receivership X Flint	0.107	0.126	0.037	0.048	-0.065	0.039
	(0.030)	(0.051)	(0.030)	(0.053)	(0.035)	(0.057)
Control Sample	Top 3	Top 3	Top 3	Top 3	Top 3	Top 3
Observations	33,367	16,015	33,367	16,015	33,367	16,015
N (Houses)	24,120	6,768	24,120	6,768	24,120	6,768
Property FE	No	Yes	No	Yes	No	Yes
Census Block Group FE	Yes	No	Yes	No	Yes	No
Year FE	No	No	No	No	No	No
Month FE	No	No	No	No	Yes	Yes
Year-Month FE	No	No	Yes	Yes	No	No
City$\times$Year Trend	No	No	No	No	Yes	Yes
Economic Controls	No	No	Yes	Yes	Yes	Yes
Panel B: Top 5 Control Sample						
Emergency X Flint	-0.164	-0.065	-0.159	-0.069	-0.166	-0.085
	(0.035)	(0.072)	(0.036)	(0.068)	(0.036)	(0.069)
Water Supply Switch X Flint	-0.171	-0.303	-0.160	-0.292	-0.204	-0.405
	(0.033)	(0.058)	(0.033)	(0.058)	(0.034)	(0.062)
Receivership X Flint	0.106	0.040	0.090	-0.002	0.146	0.245
	(0.028)	(0.047)	(0.030)	(0.049)	(0.037)	(0.059)
Control Sample	Top 5	Top 5	Top 5	Top 5	Top 5	Top 5
Observations	91,136	48,365	91,136	48,365	91,136	48,365
N (Houses)	62,966	20,195	62,966	20,195	62,966	20,195
Property FE	No	Yes	No	Yes	No	Yes
Census Block Group FE	Yes	No	Yes	No	Yes	No
Year FE	No	No	No	No	No	No
Month FE	No	No	No	No	Yes	Yes
Year-Month FE	No	No	Yes	Yes	No	No
City$\times$Year Trend	No	No	No	No	Yes	Yes
Economic Controls	No	No	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 $). Columns (1)-(2) include only the indicated fixed effects. Columns (3)-(6) include weather controls and the specified fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Table B.8: Flint Housing Price Impacts: Alternative Price Restrictions

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Home Prices $500 to $25,000						
Emergency X Flint	-0.069	-0.069	-0.072	-0.106	-0.106	-0.118
	(0.037)	(0.037)	(0.064)	(0.033)	(0.033)	(0.059)
Water Supply Switch X Flint	-0.222	-0.231	-0.328	-0.117	-0.120	-0.214
	(0.037)	(0.036)	(0.066)	(0.030)	(0.031)	(0.057)
Receivership X Flint	-0.198	-0.134	0.020	-0.232	-0.216	-0.061
	(0.030)	(0.033)	(0.057)	(0.026)	(0.028)	(0.049)
Control Sample	Top 3	Top 3	Top 3	Top 5	Top 5	Top 5
Observations	21,542	21,542	9,556	37,307	37,307	18,093
N (Houses)	16,168	16,168	4,182	26,952	26,952	7,738
Panel B: Home Prices $25,000 to $1,000,000						
Emergency X Flint	-0.208	-0.205	-0.125	-0.170	-0.170	-0.062
	(0.037)	(0.037)	(0.069)	(0.035)	(0.035)	(0.067)
Water Supply Switch X Flint	-0.107	-0.089	-0.247	-0.168	-0.164	-0.297
	(0.034)	(0.034)	(0.062)	(0.033)	(0.033)	(0.059)
Receivership X Flint	0.112	0.038	0.050	0.108	0.094	0.003
	(0.031)	(0.030)	(0.053)	(0.030)	(0.030)	(0.050)
Control Sample	Top 3	Top 3	Top 3	Top 5	Top 5	Top 5
Observations	33,361	33,361	16,011	91,105	91,105	48,343
N (Houses)	24,116	24,116	6,766	62,946	62,946	20,184
Panel C: Home Prices $500 to $10,000,000						
Emergency X Flint	-0.221	-0.220	-0.229	-0.223	-0.223	-0.238
	(0.040)	(0.040)	(0.062)	(0.037)	(0.037)	(0.058)
Water Supply Switch X Flint	-0.321	-0.314	-0.484	-0.262	-0.256	-0.376
	(0.039)	(0.040)	(0.064)	(0.036)	(0.036)	(0.058)
Receivership X Flint	-0.293	-0.330	-0.293	-0.408	-0.433	-0.555
	(0.033)	(0.034)	(0.054)	(0.027)	(0.028)	(0.044)
Control Sample	Top 3	Top 3	Top 3	Top 5	Top 5	Top 5
Observations	54,935	54,935	35,484	128,497	128,497	82,842
N (Houses)	33,659	33,659	14,208	78,590	78,590	32,935
Property FE	No	No	Yes	No	No	Yes
Census Block Group FE	Yes	Yes	No	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	No	Yes	Yes	No	Yes	Yes

Notes: The dependent variable is the log of home sales prices in Flint and the specified control cities from January 2006 to June 2017 (2009 $). All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

C Home Sales

The crisis may have impacted both the supply and composition of homes sold in Flint, affecting welfare interpretations of our damage estimates (Banzhaf, 2018). Figures C.1a and C.1b graph smoothed quarterly housing sales in Flint and the Top 3 control cities. Flint saw a large decline in housing sales from 2006 through the end of our sample, with only a brief respite at the beginning of the receivership period. Our control cities show similar trends, suggesting that declining sales are not specific to Flint and occurred in cities with similar economic conditions. The decline in the Top 3 control cities bottomed out in 2011 and showed slight improvements in 2015. Top 5 city sales show similar patterns but saw a larger uptick in mid-2016.

Figure C.2 breaks out Flint sales by home type. Figure C.2a shows that most of the decline in sales since 2006 were high-valued homes. Sales of below-median priced homes saw relatively small decreases from 2006 to 2012 and were stable from 2012 to 2014. Low-priced homes were steady through the Flint crisis, while homes in the second price quartile declined after the switch. Figure C.2b shows larger declines for homes with unknown or non-lead service lines relatively to homes with lead service lines. We observe few home sales with lead service lines after the receivership period, but sales of homes with lead service lines did not change substantively after the switch or emergency declarations. Figures C.2c and C.2d show sales across Census Block Groups with above and below incomes and percentage of their population that is black or African American. Sales in low-income Census Block Groups saw larger declines from 2006 to 2012 but remain on-par with above median income Census Block Groups from 2012 to mid-2014. Since the public health emergency, we see higher sales volumes from higher income Census Block Groups. We do not observe notable differences across Census Block Groups with above and below median African American populations.

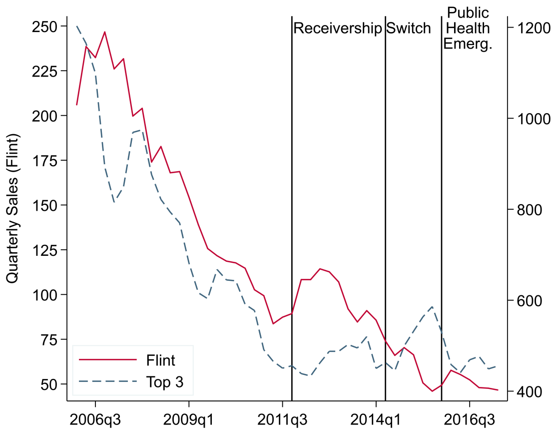
We test whether the switch or crisis had an impact on sales in Flint by creating a balanced panel of housing sales for every Census Block Group in every city and year-month. When we do this, the outcome variable is discrete, ranging between zero and 18, with many zero observations. Given this, we convert the outcome variable to an indicator for whether any sale occurred in a particular Census Block Group and month and estimate a linear probability model similar to equation (1). Table C.1 presents our regression results. In the specifications with full controls, columns (3) and (6), we find no differential pre-trends leading up to the switch, and a 5% to 8% decrease in the probability of a sale in Flint Census Block Groups after the switch. When we use our Top 3 control sample, we see no further decline in sales probabilities in Flint after the emergency but see a further 4% decline in the likelihood of a sale in a Flint Census Block Group in our Top 5 sample. Overall, while we observe changes in the probability of sales in Flint, the change in sales after the switch is smaller than observed historical declines from 2006 through 2012, and these aggregate trends are also present in our control cities. Further, our summary statistics show some changes in the composition of homes sold in Flint, though again the relative changes are small.

Table C.1: Flint Housing Sales Impacts - Linear Probability Model

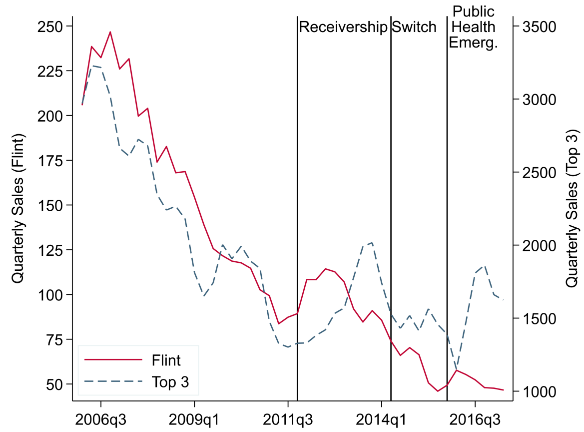
	(1)	(2)	(3)	(4)	(5)	(6)
Emergency X Flint	0.013	0.013	0.014	-0.040	-0.039	-0.039
	(0.011)	(0.011)	(0.011)	(0.010)	(0.010)	(0.010)
Water Supply Switch X Flint	-0.093	-0.093	-0.081	-0.038	-0.043	-0.045
	(0.013)	(0.013)	(0.013)	(0.012)	(0.011)	(0.012)
Receivership X Flint	-0.161	0.021	-0.026	-0.191	0.005	0.011
	(0.023)	(0.012)	(0.017)	(0.020)	(0.010)	(0.013)
Control Sample	Top 3	Top 3	Top 3	Top 5	Top 5	Top 5
Observations	58,098	58,098	58,098	115,644	115,644	115,644
Census Block Group FE	No	Yes	Yes	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Economic Controls	No	No	Yes	No	No	Yes

Notes: The dependent variable is an indicator for whether a sale occurred within a Census Block-Group in a year-month combination in Flint and the specified control cities from January 2006 to June 2017. All regressions include weather controls, year fixed effects, and month fixed effects. Economic controls include the log of each city's monthly labor force. Standard errors are clustered at the Census Block Group.

Figure C.1: Home Sales: Flint versus Control Cities



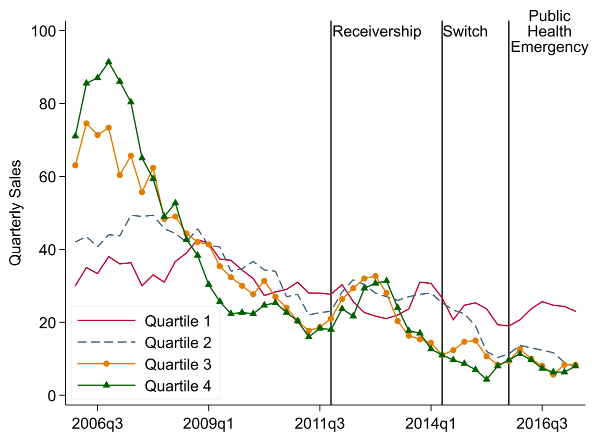
(a) Flint vs. Top 3



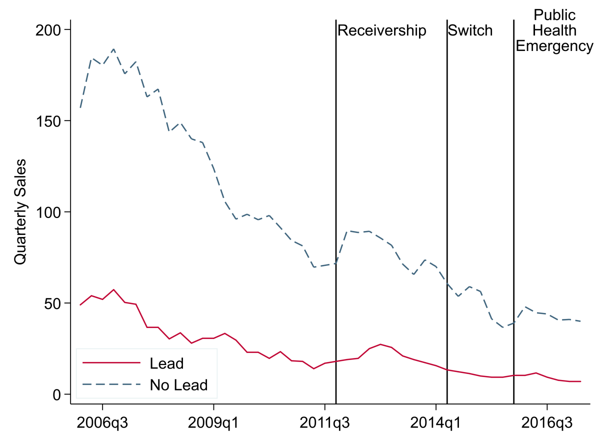
(b) Flint vs. Top 5

Notes: Figures C.1a and C.1b graph quarterly sales volumes for Flint (left axis) and the Top 3 and Top 5 control cities (right axis), respectively. All sales are smoothed using a moving average including the previous two quarters to smooth seasonal fluctuations in home sales.

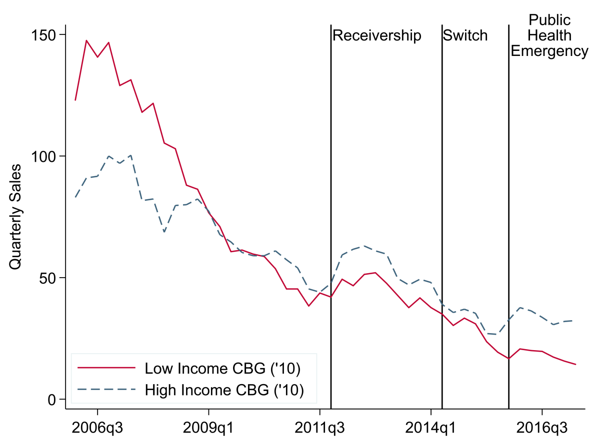
Figure C.2: Home Sales: Within Flint Heterogeneity



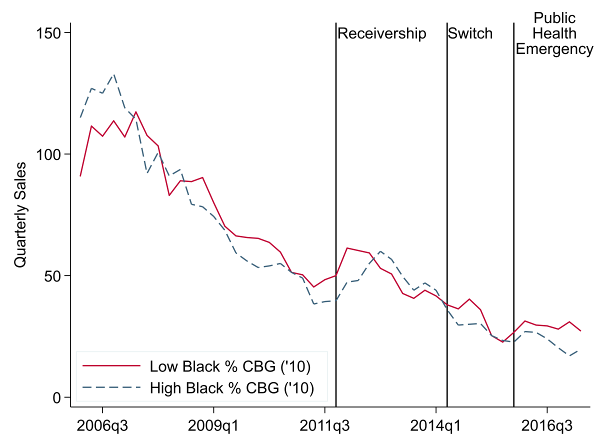
(a) Home Price Quartiles



(b) Homes with Lead vs. Non-Lead/Unknown Service Lines



(c) Above vs. Below Median Income Census Block Group



(d) Above vs. Below Median % Black CBG

Notes: All sales are smoothed using a moving average including the previous two quarters to smooth seasonal fluctuations in home sales.

D Buyer, Owner, and Renter Characteristics

D.1 Changes in Buyer Characteristics

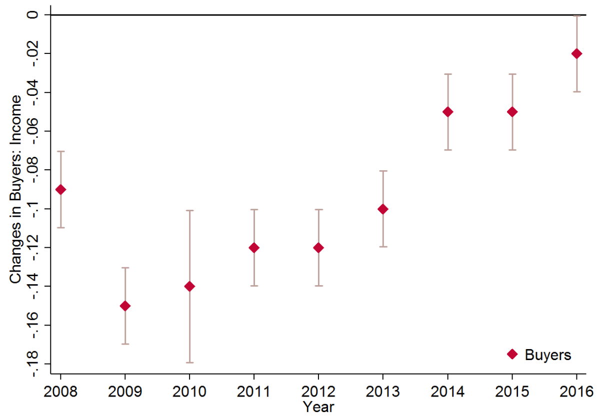
We combine the ZTRAX data with information on individual mortgages from the Home Mortgage Disclosure Act (HMDA) to explore the impacts of the crisis on buyer characteristics in Flint. HMDA data report the data on borrowers and loans initialized from 2007 to 2016. We observe approximately 30,500 new loans initialized in Flint during our study period. Figure D.1 graphs changes in buyer characteristics for homeowners who applied for a home loan in Flint from 2008 to 2016. All estimates report differences relative to the first year, 2007. Buyers' incomes decreased by 10% to 15% in the two years following the financial crisis, but mostly recovered by 2014 and improved slightly from 2015 to 2016. We see changes over time in other characteristics as well (probability of a co-applicant, denial rates, race, and gender). However, in all cases, we see little change in an outcome from 2014 to 2016, suggesting a limited role of the Flint crisis in buyer characteristics.

D.2 Out-Migration from Flint

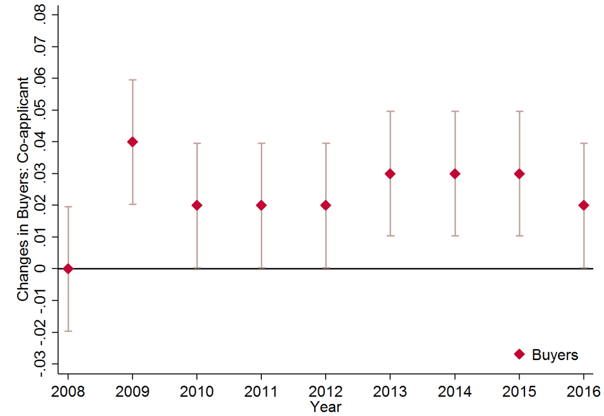
We use data from InfoUSA to identify patterns of out-migration of homeowners and renters in Flint and our control cities. InfoUSA collects household-level address history data covering 2006 to 2017. The data include indicators for whether households rent or own their home, as well as unique identifiers that allow us to construct Flint and control city cohorts over time.[53] Figure D.2 plots changes in moving behavior of owners and renters using the 2012 household cohort. To create the figure, we follow all households living in Flint and our top 3 control cities in 2012 and estimate the likelihood that Flint households move in 2013 to 2016 relative to control households. We define a move as a change of address to a location outside of their original city. We find small declines in the likelihood of Flint households moving in 2014 and 2015. However, the coefficient is largest among renters. Homeowners are nearly as likely to move as our base year, 2012. The 2016 coefficients are almost the same as our base year. Thus, out-migration does not appear to be a significant issue in our sample, particularly for homeowners.

[53] InfoUSA tracks movers using a combination of utility data, deed transfers (homeowners), a Fair Credit Reporting Act compliant magazine, and credit sources. The entire database contains information on around 120 million households (292 million individuals) in the U.S. InfoUSA validates the database every 12 to 24 months, and the company records approximately 1 million moves per month. The company identifies 90% to 95% of movers from deed transfers. The data include information on ownership status, household head ethnicity, estimated household income, age, marital status, and the presence and number of children in the home.

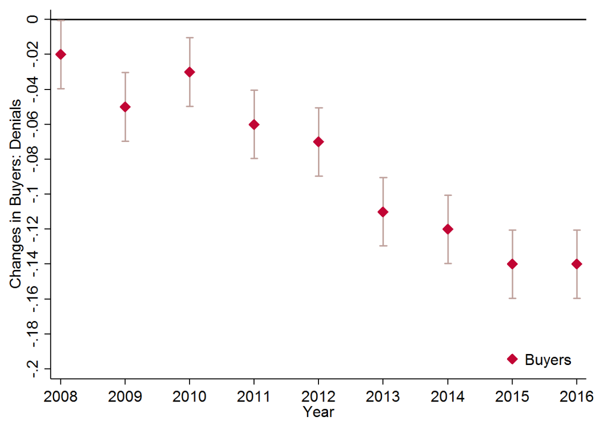
Figure D.1: Changes in Mortgage Applicants



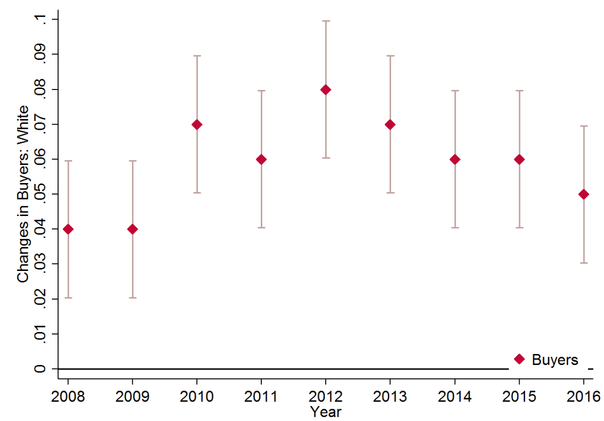
(a) Income of Applicants



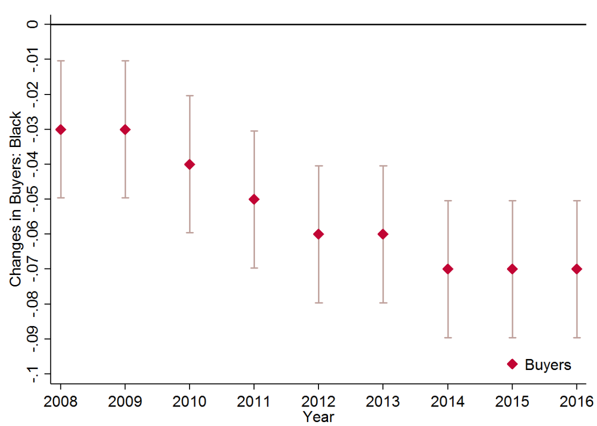
(b) Applications with Co-applicants



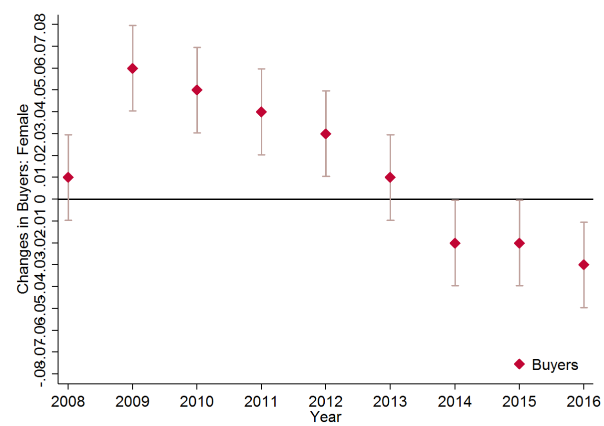
(c) Application Denials



(d) White Applicants



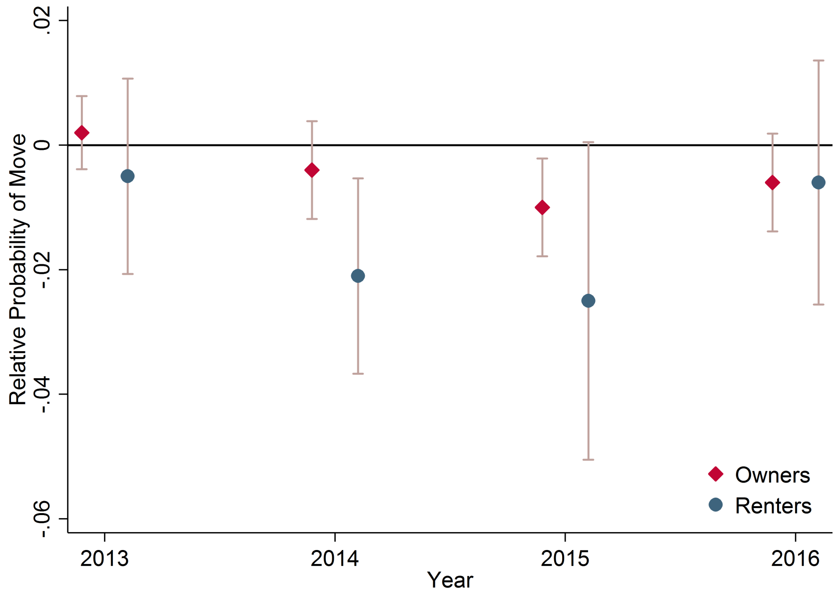
(e) Black Applicants



(f) Female Applicants

Notes: The figure reports estimates from a model of annual changes in the loan applicants characteristics reported by financial institutions as part of the Home Mortgage Disclosure Act (HMDA). All figures report estimates of changes relative to the base year, 2007.

Figure D.3: Migration: Flint versus Top 3 Control Cities



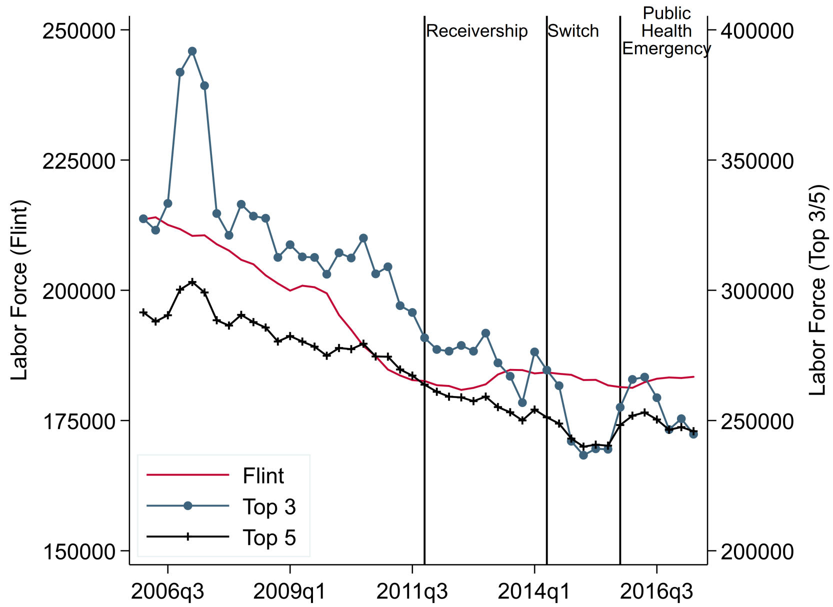
Notes: The figure plots estimates from a panel model of the 2012 cohort in InfoUSA. Estimates represent differences in the probability of a move for Flint households relative to households in our control cities. All models includes controls for household estimated income, household marital status, number of children in the household and household wealth. Error bars report standard errors.

E Labor Market Conditions

We use labor force data in many of our specifications to control for time-varying economic conditions in Flint and our control cities. We implicitly assume that labor markets were unaffected by the Flint water crisis. Figure E.2 provides graphical evidence to support this assertion. Labor forces in all cities declined over time (Figure E.2).[54] Top 3 cities see a decline in the labor force around the time of the switch to the Flint River, but the labor force in Flint remained stable through the switch and public health emergency. Although we don't use them as additional controls, we find similar trends in unemployment levels and mean wages in Flint and our control cities over time.

[54]The Figure graphs smoothed times series for the labor market force in Flint and our control cities using a two-quarter moving average to limit the influence of seasonality in the data and better show long-term trends around each event.

Figure E.2: Labor Force



Notes: Figure E.2 graphs smoothed labor force variables from the U.S. Bureau of Labor Statistics for Flint, the Top 3 control group cities, and the Top 5 control group cities.