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The Effect of an Increase in Lead in the Water System on Fertility and Birth Outcomes: The Case of Flint, Michigan

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Abstract

Flint changed its public water source in April 2014, increasing lead exposure. The effects of lead in water on fertility and birth outcomes are not well established. Exploiting variation in the timing of births we find fertility rates decreased by 12%, fetal death rates increased by 58% (a selection effect from a culling of the least healthy fetuses), and overall health at birth decreased (from scarring), compared to other cities in Michigan. Given recent efforts to establish a registry of residents exposed, these results suggests women who miscarried, had a stillbirth or had a newborn with health complications should register.

Keywords: Women's Health; Birth Rate; Fertility Rate; Birth Outcomes; Lead; Environmental Regulation; Michigan

JEL Codes: H75, I12, I18, J13, Q53, Q58

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"We were drinking contaminated water in a city that is literally in the middle of the Great Lakes, in the middle of the largest source of fresh water in the world. This corrosive, untreated water created a perfect storm for lead to leach out of our plumbing and into the bodies of our children." - Dr. Mona Hanna-Attisha

1. Introduction

A recently released budget plan calls for extensive cuts to the EPA workforce and budget, including compliance monitoring such as testing for lead and other water pollutants (Davis 2017).[1] There is overwhelming evidence that lead in water contributes to higher rates of lead in the blood, and is related to eventual developmental problems in children (Edwards, Triantafyllidou, and Best 2009; Hanna-Attisha et al. 2016). However, testing for lead in infants is not routinely performed, despite the fact that a separate large literature underscores the importance of in utero health on long-term health and human capital development (see e.g., Almond and Currie 2011).

In this paper, we estimate the effect of the higher lead content of water sourced from the Flint River on fertility and birth outcomes. Importantly, during the period in which water was sourced from the Flint River (beginning on April 25, 2014), local and state officials continually reassured residents that the water was safe. Officials did not issue a lead advisory until September 2015, just a few weeks before switching off Flint River water for good (Fonger 2015a). This reduced the scope of an avoidance behavioral response to the water crisis (see e.g. Neidell 2009).[2] Flint had previously used the Flint River as its water source until 1967, switching due to concerns about historic pollution from the dwindling auto industry. The state of Michigan passed a law in 2000 expanding the state's Department of Environmental Quality's oversight over the river. When

[1] The proposed cuts also entail curbing funding for the EPA Lead Renovation, Repair, and Painting Program.

[2] When individuals change their behaviors in response to environmental or health information, the estimated effect contains both a biological and individual response, which are difficult for the econometrician to separate.

the city switched back to it for their water source in 2014, many residents and officials hoped cleanup efforts of the river had been successful (Carmody 2016).

High lead content in the blood affects nearly all organ systems and is associated with cardiovascular problems, high blood pressure, and developmental impairment affecting sexual maturity and the nervous system (Agency for Toxic Substances and Disease Registry; Zhu et al. 2010). Recent studies have linked maternal lead exposure to fetal death, prenatal growth abnormalities, reduced gestational period, and reduced birth weight (Edwards 2014; Zhu et al. 2010; Taylor, Golding, and Emond 2014); while historically lead is associated with increased fetal death and infant mortality rates (Clay, Troesken, & Haines 2014), and the poisoning of many adults as well (Troesken 2006). Maternal lead crosses the placenta providing a potential direct link for lead poisoning of the fetus (Taylor, Golding, and Emond 2014, Lin et al. 1998).

We leverage the fact that only the city of Flint switched their water source at this time, while the rest of Michigan did not. These areas provide a natural control group for Flint in that they are economically similar areas and, with the exception of the change in water supply, followed similar trends in fertility and birth outcomes over this time period.

We use the universe of live births and fetal deaths in Michigan from 2008 to 2015 to estimate the effect of a change in the water supply in Flint on fertility and health. Our results suggest that women in Flint following the water change had a general fertility rate (GFR) of approximately 7.5 live births per 1,000 women aged 15-49 fewer than control women of the same age group, or a 12.0 percent decrease. Because the higher lead content of the new water supply was unknown at the time, this decrease in GFR is likely a reflection of an increase in fetal deaths and miscarriages and not a behavior change in sexual behavior related to conception like contraceptive use. Indeed we find that fetal death rates increase by 0.1 deaths in Flint per 1,000 women aged 15-49 compared to control areas, a 58 percent increase. Additionally, the ratio of male to female live births decreases by 0.9 percentage points in Flint compared to surrounding areas. Finally, we present suggestive evidence that behavioral changes are unlikely to drive our results.

Estimates of birth outcomes are less precise and at times contradictory. Birthweight, estimated gestational age, and in utero growth rate all decreased as a result of the water crisis, but these results are small and not consistently statistically signficant. On the other hand, abnormal conditions also decreased by approximately 13.4 percent in Flint following the water switch compared to controls.[3]

This study contributes to the large literature on fetal origins hypothesis. In his seminal work, Almond (2006) discusses how in utero shocks may affect health. The sign of the effect of these shocks is ambiguous due to two countervailing mechanisms. First, these shocks may lead to "selective attrition," or the culling of weaker fetuses through miscarriage or fetal death. Thus, the less healthy fetuses would not be born, leaving only the healthier fetuses, or a potentially positive effect on population health. Alternatively, although not mutually exclusively, higher rates of lead may shift the overall health distribution of infants affected in utero. In this case, the shift in the entire health distribution towards infants being more unhealthy would lead to worse health outcomes for those affected by the shock. The two effects (selection and scarring) could even approximately cancel each other out for surivors (Bozzoli, Deaton, and Quintana-Domeque 2009). For example, in the case of the Great Chinese Famine, taller children were more likely to survive

[3] Abnormal conditions include assisted ventilation, NICU admission, receipt of surfactant replacement therapy, antibiotic receipt to treat neonatal sepsis, seizure, and significant birth injury.

but then were stunted, resulting in a minimal change in height for the affected cohort but their unscarred children being taller (Gørgens, Meng, and Vaithianathan 2012).

Given that it has only been a few years since the natural experiment in Flint, and because of the potential long term effects of lead on cognitive development (e.g., see Aizer et al. 2016), we cannot make any definitive statement about whether babies born represent individuals with a higher future health stock compared to control cohorts or if latent health for this group is actually worse. We can however estimate the selection effect by focusing on the birth rate, and investigate infant health of the surviving children to estimate the magnitute of the offsetting scarring effect on survivors.

In section 2 we describe the timeline of events around the Flint water changes. We present a literature review of health conditions associated with lead in Section 3. Section 4 describes our data. We present our empirical methods in section 5 and our results in section 6. In Section 7 we describe numerous robustness checks and then discuss our results in Section 8. Section 9 concludes.

2. Background on Flint

Flint is an old manufactuirng city and the birthplace of General Motors (GM) (Scorsone and Bateson 2011). The city has been shedding residents for many years, with its contraction coinciding with GM closing several plants in and around Flint.[4]

Through 1967, the city sourced its drinking water from the Flint River. In 1967, Flint switched its water source away from the Flint River because of concerns about serving a growing

[4] The number of inhabitants employed by GM decreased from 80,000 in 1978 to approximately 30,000 in the late 1990s to well under 10,000 today (Scorsone and Bateson 2011).

population (Carmody 2016). They signed a deal to receive Lake Huron water via pipeline from the Detroit Water and Sewerage Department (DWSD).

In 2011 the Governor of Michigan installed an Emergency Manager in the city who would make all fiscal decisions and "rule local government," based on the city's precarious economic health (Longley 2011). This changed the political economy of Flint and essentially meant that citizens and elected officials would have little recourse to fight decisions made by the Emergency Manager. At the same time, DWSD water rates were rising (Zahran, McElmurry, and Sadler 2017). To cut costs, the Emergency Manager together with other Genesee County officials pursued a project to build a pipeline directly to Lake Huron through the Karegnondi Water Authority (KWA) in March 2013 (City of Flint 2015; Walsh 2014). This project would provide untreated water directly to Flint and the rest of Genesee County upon its projected completion at the end of 2016, more than two years away. When Flint announced this project, DWSD terminated the current agreeement, in place since 1967, to sell water to Flint but left open the possibility of a new agreement in the interim (Fonger 2013; Carmody 2016). Instead, Flint decided to use water from the Flint River to source its drinking water between April 2014 and the completion of the KWA pipeline, while Genesee County continued to receive water from DWSD.

Flint had to treat the new water source and while they used some of the same products as the DWSD , like free chlorine, they did not use anti-corrosive inhibitors such as orthophosphate (Pieper et al. 2017, Olson et al. 2017). After switching to Flint River water, Flint citizens began complaining about the color and smell of their water but were continually assured that the water was safe to drink (City of Flint 2015a,b). The first sign of trouble came in August 2014 when a boil advisory was announced for part of the city due to a positive fecal coliform test, although the city minimized this adverse result claiming it was an "abnormal test" caused by a "sampling error"

(Fonger 2014a; Adams 2014). Less than a month later a second boil adivisory was announced for a similar issue leading the city to increase chlorine levels in the water (Fonger 2014b). Then in October 2014, GM announced they would switch off of Flint River water in its Flint plant because the water was too corrosive for its engine parts (Fonger 2014c). The city confirmed the GM switch was best for engine parts but that the water was safe for human consumption. In late December 2014, Flint received an EPA violation for excess trihalomethanes (TTHM) in the water, likely caused by the chemicals used to treat the water (Fonger 2015b).[5]

Throughout early 2015, Flint held public meetings to assure citizens the water was safe and that the TTHM violation would be fixed soon (City of Flint 2015a,b). During this time, the Emergency Manager commissioned a report on the safety of the water and rebuffed an offer from DWSD to return Flint to Lake Huron water. A team from Virginia Tech, led by Mark Edwards began independently testing Flint consumers' water in August 2015 and reported much higher levels of lead than previously reported, noting that Flint River water was many times more corrosive than the DWSD water (http://flintwaterstudy.org/wp-content/uploads/2015/10/Flint-Corrosion-Presentation-final.pdf). Mona Hanna-Attish, a Flint pediatrician and researcher, held a press conference September 24, 2015 to report a substantial increase in blood lead levels in children following the water switch (Fonger 2015c; Hanna-Attish et al. 2016). While the city initially attacked the results of this study, the resulting public outcry finally led the city to switch back to Lake Huron water on October 16, 2015 (Emery 2015). The crisis continues as those

[5] Because of these additional contaminants found in Flint drinking water after the water switch, we cannot attribute all health effects to changes in lead. However, because of the well-established pathways through which lead effects health, including fetal health, described in more detail in the next section, we focus on lead in this paper. To the extent that these other contaminants are present in the water, our estimates would be an upper bound on the effect of lead on fertility and birth outcomes.

exposed to lead face potential life-long problems.[6] As of July 2017, the state Attorney General had filed indictments against 15 individuals for their roles in the Flint water crisis (Egan 2017).

3. Background on Lead

Lead is a heavy metal that is associated with health problems in children and adults. It occurs naturally both in the earth's crust and the environment. But, human activities, including burning fossil fuels and other chemical reactions from industry, cause the majority of lead emission into the environment (Agency for Toxic Substances and Disease Registry (ATSDR) 2007). The US banned lead paint in the 1970s and reduced leaded-gasoline throughout the 1980s before banning it in 1996. These actions have decreased the incidence of lead emissions and the concentration of lead in the blood dramatically over the past 40 years (CDC 2005, Zhu et al. 2010).

High lead content in water leads to increases in lead content in the blood (Edwards, Triantafyllidou, and Best 2009; Hanna-Attischa et al. 2016), which is associated with cardiovascular problems, high blood pressure, and developmental impairment affecting sexual maturity and the nervous system (ATSDR 2007; Zhu et al. 2010). Lead crosses the placenta (Amaral et al. 2010, Schell et al. 2003, Rudge et al. 2009, Lin et al. 1998) and is correlated with mental health issues, prenatal growth abnormalities, reduced gestational period, and reduced birth weight (Hu et al. 2006; Zhu et al. 2010; Taylor, Golding, and Emond 2014). Edwards (2014) finds that fetal death rates increased and birth rates decreased following the increase of lead in the water in Washington, DC from 2000 to 2003. Similarly, Clay, Portnykh, and Severnini (2017), using variation in lead exposure from the introduction of the Interstate Highway System and the Clean

[6] https://www.washingtonpost.com/national/grant-to-create-registry-of-flint-residents-exposed-to-lead/2017/08/01/78c8fa66-7707-11e7-8c17-533c52b2f014_story.html?utm_term=.f89d3f64e273

Air Act, find that exposure to lead in the air resulted in reductions in the birth rate and a worsening of birth outcomes.

While previous studies have used exact measures of lead in the blood (see e.g. Taylor, Golding, and Emond 2014; Zhu et al. 2010), these study designs do not include exogenous variation in lead supply and thus cannot rule out that these worse birth outcomes are actually associated with an omitted variable (or some other environmental factor that is associated with both birth outcomes and lead concentration). Beyond the change in water supply per se, lead increased in the Flint water supply because of improper water treatment. Officials did not treat the Flint River water using corrosion inhibitors, while simultaneously using ferric chloride (to combat infectious bacteria in the water) which increased the likelihood of corrosion (Clark et al. 2015, Pieper, Tang, and Edwards 2017). Corrosion inhibitors aid in creating protective corrosion scales within pipes, reducing the amoung of lead leached from the pipes (Pieper, Tang, and Edwards 2017; Olson et al. 2017).

The change in the water source in Flint may affect health through several channels, including selection into fertility, direct health effects, and indirect health effects. As discussed above, fetal insults may reduce the overall fertility rate by reducing the number of viable fetuses. Clay, Troesken, and Haines (2014) find evidence of higher rates of fetal deaths in cities with more lead service pipes and more acidic water. The expected direction of this effect on overall health is ambiguous depending on which part of the fertility distribution it affects. If lead only effects health by causing women to miscarry the weakest fetuses, we would expect the remaining births to be healthier. However, if lead also shifts the health distribution of births then we would expect either no change in overall health if selection and scarring effects perfectly counterbalance each other or a decrease in health if the scarring effect dominates the selection effect. Behavioral selection into pregnancy may occur if women decide not to get pregnant because of worries about their future child's health. Dehejia and Lleras-Muney (2005) document non-random selection into pregnancy in response to changing labor market conditions while Clay, Portnykh, and Severnini (2017) provide evidence of more educated women reducing fertility in response to lead exposure. However, women would need to be aware of the water crisis in advance for this explanation to affect our analysis. While women were aware of several issues with Flint water following the change, they had no way of knowing about the lead content in the water until nearly the end of the Flint River water regime (see Figure 2 below for support of this).

Additionally, lead may effect health through indirect channels including by decreasing latent health of those infants carried to term. Latent health will be difficult to measure and may not manifest until much later in life (Barker 1995; Schultz 2010; Almond and Currie 2011). Previous studies have found that changes in lead levels have a perverse effect on mental health and criminality (Reyes 2007, 2015), educational outcomes (Aizer et al. 2016), and school suspensions (Aizer and Currie 2017, Billings and Schnepel 2017). However, Billings and Schnepel (2017) find that lead remediation can moderate the negative effects of those exposed to lead. Taken together these studies suggest that exposure to lead in utero and in infancy may only represent a lower bound on the overall effect of lead on health and human capital development.

4. Data

We use vital statistics data for the state of Michigan from 2008 to 2015. These data contain detailed information on every birth in the state including health at birth and background information on the mother and father which includes race, ethnicity, education, marital status, as well as prenatal care and whether the mother smoked or drank alcohol during her pregnancy. We calculate the date of conception for a woman from the clinical gestational estimate and exact date of birth. Vital records data also contain the census block on which a mother resided at the time of birth, which we exploit to create a more exact measure of lead intensity. We define Flint per the census tract-level (University of Michigan-Flint GIS Center 2017) data on lead pipes[7], and then use HUD census tract to ZIP code matching[8] and SAS ZIP code to city matching[9] for the 15 largest non-Flint cities (i.e., Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming).[10]

Using population data from the American Community Survey[11], we calculate general fertility rate (GFR) as:

$$GFR_{ct} = 12 * 1000 * \frac{Total\ Births_{ct}}{Population\ Aged\ 15{-}49_{ct}} \quad (1)$$

where c indexes the city, and t the month and year. Total births are the exact number of births occurring in the area for a given conception month, while population is a measure of the female population of childbearing age.[12] We multiply by 12 to make this an annual measure.

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[7] In our primary analysis we therefore exclude the very small remainder of Flint that did not have lead pipes. Our county-level analysis in Appendix B shows that our results are robust to this choice.

[8] https://www.huduser.gov/portal/datasets/usps_crosswalk.html#data

[9] https://support.sas.com/downloads/download.htm?did=104285#

[10] In Appendix B, we compare Flint to the largest counties in Michigan and to all Michigan counties.

[11] https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_1YR_S0101&prodType=table – "State 040," "Place 160"

[12] Our analysis sample covers 95 months from May 2007 through March 2015. Because we use conception date, our 2008-2015 data contains complete date of conception data from approximately April 2007 through March 2015. We drop April 2007 data because the number of births from 2008 conceived in that month was substantially lower than all other 2007 months. This is likely due to births that occurred before 2008, which are not captured by our data set.

5. Methods

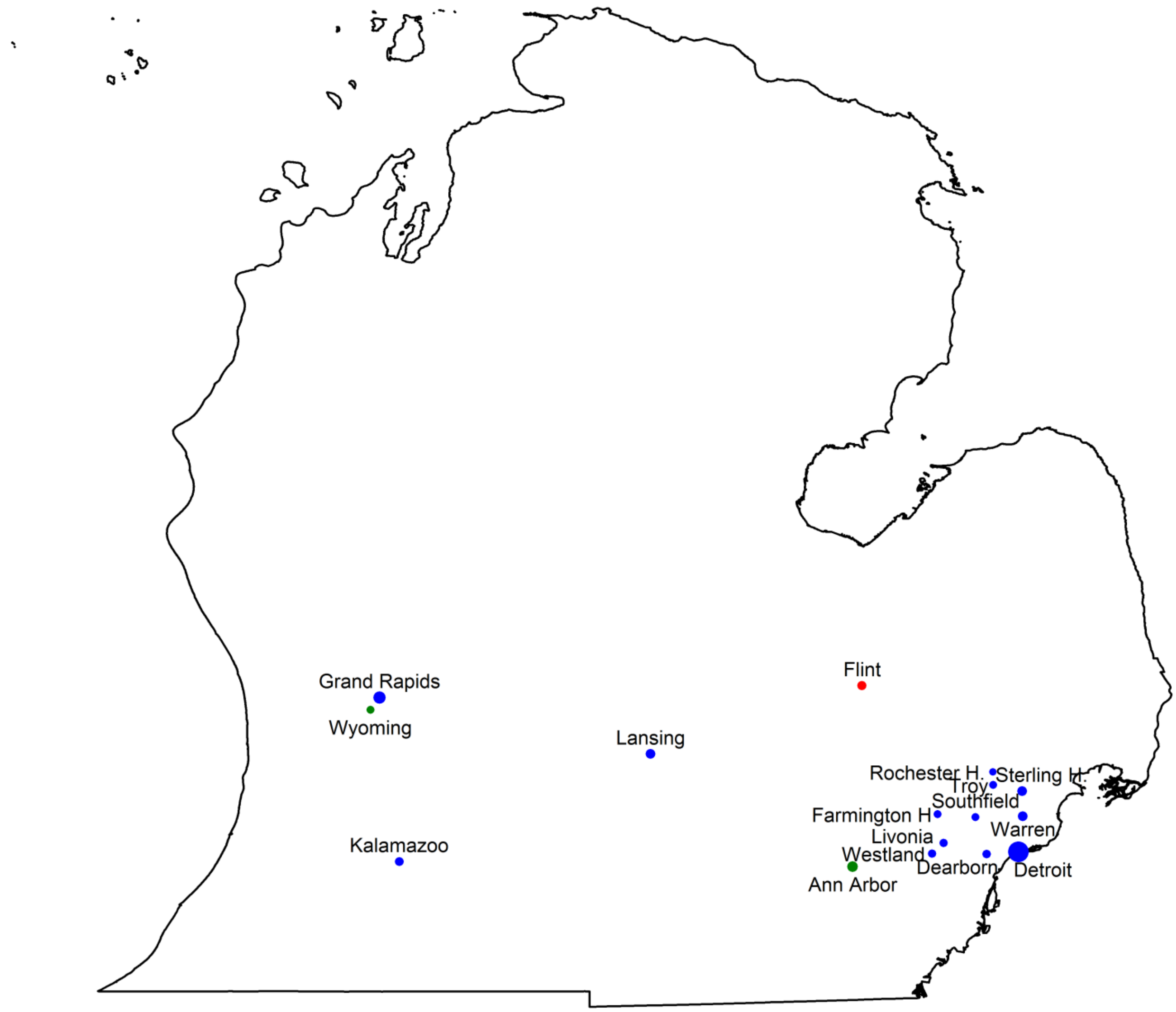
To assess the relationship between water source and fertility outcomes, we use a difference-in-differences model to compare areas that received the new source to areas that did not change their water source but were trending similarly in the pre-period. The difference-in-differences model takes the form of the following:

$$Outcome_{ct} = a + \beta_1 Water_{ct} + \alpha_c + \delta_t + \varepsilon_{ct} \quad (2)$$

Where c indexes the city, and t the month and year. *Outcome* includes measures of *GFR* and male to female sex ratio (sex ratio).[13] *GFR* is a measure of the number of births conceived in a month given the total female population aged 15-49 of the city, as defined in equation (1) above, and as shown below in Figure 1.

[13] Our results are robust to using alternative specifications, including the natural log of the count of births and a nonlinear Poisson specification of the count of births. See Appendix Tables B3-B4, and note that the coefficients are in log points, which for this range are approximately numerically the same as percentage points.

Figure 1: Comparison Cities



Note: Comparison cities are in blue, Flint in red, and cities with outlier GFR in green. Point size is proportional to the population of women age 15-49 in that city in 2014.

Water is a binary variable indicating whether the date of conception of the child occurred after the water supply changed and whether the mother lived in Flint. We define being in utero during the new water regime as a birth being conceived in November 2013 or later, which would mean that at least one trimester of the pregnancy was affected by the water change. We include city fixed effects, α_c, to control for time-invariant characteristics of the city. δ_t is a vector of month and year fixed effects. City and time fixed effects subsume the main effects of living in Flint and being in utero during the new water regime, respectively.

For birth outcomes, we estimate the following model:

$$Birthoutcome_{ict} = a + \beta_1 Water_{ct} + \beta_2 X_{ict} + \gamma_{cen} + \delta_t + \varepsilon_{ict} \quad (3)$$

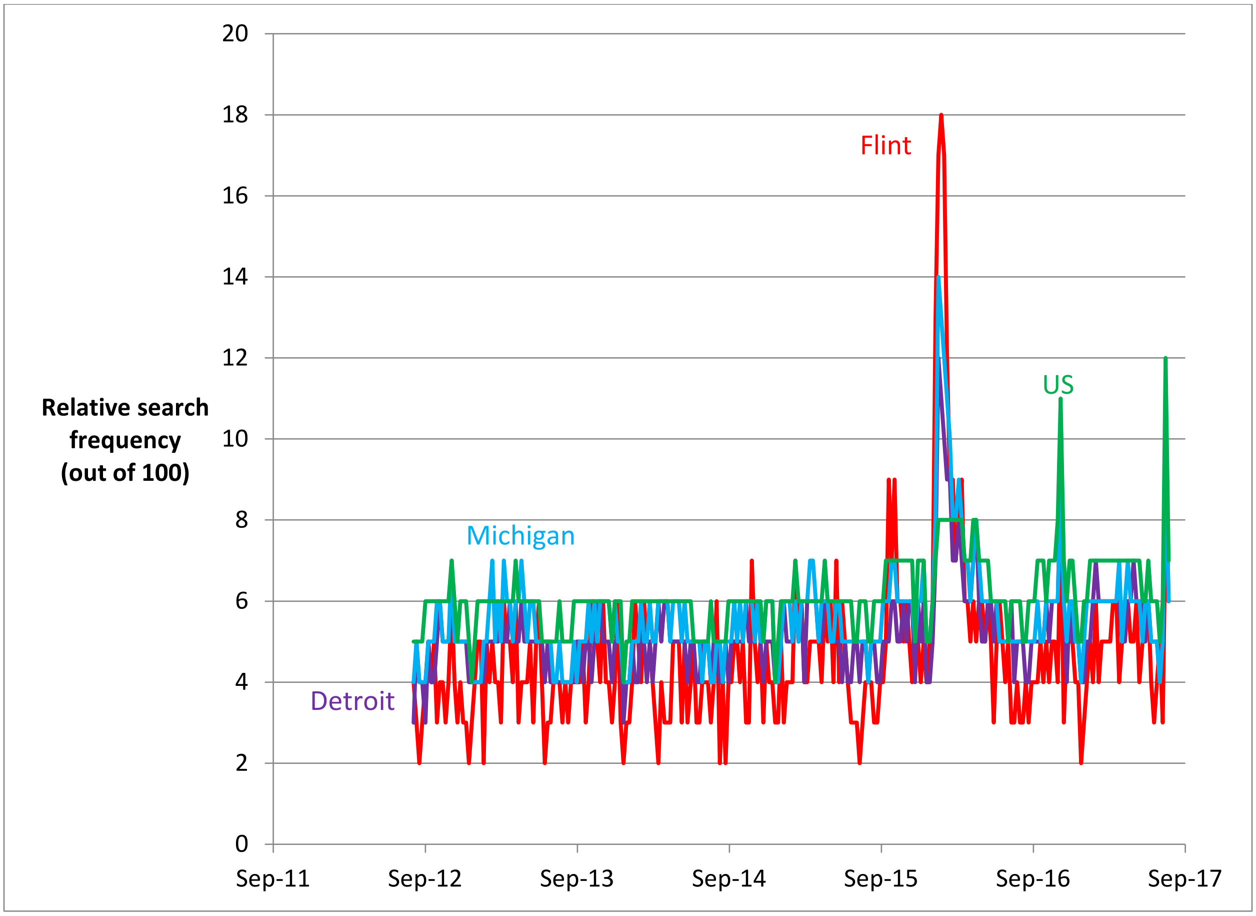
where i indexes the individual, c the city, and t the month. *Birthoutcome* includes a binary variable for any abnormal condition and a continuous variable for birthweight in grams, estimated time of gestation in weeks, or fetal growth rate, defined as the birth weight divided by weeks in gestation. *Water* is a binary variable indicating whether the date of conception of the child occurred after the water supply changed and whether the mother lived in Flint. X_{ict} is a vector of variables capturing individual level socioeconomic characteristics of the mother and child including gender of the child, race, ethnicity, marital status, and educational attainment of the mother, which come from birth records. We include census tract fixed effects, γ_{cen}, to control for time-invariant characteristics of the direct neighborhood of the mother. δ_t is a vector of month and year fixed effects, which control for seasonality of births and a general trend in birth outcomes across Michigan over time. ε is an error term clustered at the city level.

The strengths of our study are that it exploits a natural experiment in the exposure of women to lead caused by an exogenous change in the water supply. Any time a policy shift occurs that potentially causes an exogenous change, economists worry about policy endogeneity, or the idea that this policy change occurred in response to conditions that were already changing or in response to public pressure which would suggest additional factors unobservable to the econometrician were present.

In this situation, the change we study is a change in the water supply for a municipality that was decided by an unelected official, the Emergency Manager, appointed by the state Governor.[14] Furthemore, government officials continued to insist that the water was safe. An EPA memo citing lead concerns was leaked to the public only in July, 2015, and confirmed by other researchers in September, 2015 (Robbins 2016). Using Google Trends, in Figure 2 we confirm an increase in concern about lead did not occur until September 2015, followed by a large spike in searches in January 2016, when the national media began to pick up this story. This likely greatly reduces the possibility of policy endogeneity in that the actual residents of the municipality had little to no say in the matter and almost no recourse to make known any displeasure they may have had with the change in water supply. We compare areas from the same city and from adjacent counties who received water from the same supply source up until the supply changed for Flint in April 2014. Conceivably, this change in water supply is the only change that occurred at this time so any differences in fertility and birth outcomes between Flint and similar counties over this time period can be attributed to the change in the water supply.

[14] The water change was enacted to increase revenues in Flint and to reduce payments to the Detroit Water and Sewer Department while the city awaited the completion of a new pipeline (Fonger 2014d).

Figure 2. Google Trend Data on Searches for Lead



Source: Google Trends

6. Results

Table 1 presents summary statistics of fertility rates and birth outcomes by time period in Michigan. Columns (1) and (2) present means of births to individuals who did not reside in Flint before and after the water change, respectively. Descriptive statistics for mothers who lived in Flint at the time of birth before the water change are presented in Column (3) while results for Flint mothers who gave birth after the water change are presented in Column (4). In general, we consider a birth as occurring after the water change if the mother conceived in November 2013 or later.[15]

Mothers who gave birth outside of Flint were older (27.6 years compared to 24.7 years) in the pre-period. However, we find no differential change in age between the periods. Women in Flint also had lower educational attainment. They were much more likely not to have a high school diploma and less likely to have obtained a college degree. While the proportion of mothers who did not receive a high school diploma decreased by approximately 2.5 percentage points for both Flint and non-Flint mothers following the water change, Flint mothers were more likely to receive a high school diploma and non-Flint mothers were more likely to complete some college or a college degree.

The general fertility rate in Flint was nearly 8.5 births per 1000 women aged 15-49 lower in Flint following the water change compared to control areas. Fetal death rates increased in Flint but did not change substantially in other areas following the water change. The sex ratio of babies born in Flint skewed more female following the water change, a decrease of 0.74 percentage points. Babies born in Flint were nearly 150 grams lighter than in other areas, were born ½ a week earlier and gained 5 grams per week less than babies in other areas in the preperiod. The unadjusted difference-in-differences for these variables was a decrease of 15 grams, 0.12 weeks of gestational age and 0.27 grams per week in growth rate.

[15] This allows for a mother to be considered "treated" if she lived under the new water regime for at least one trimester of her pregnancy.

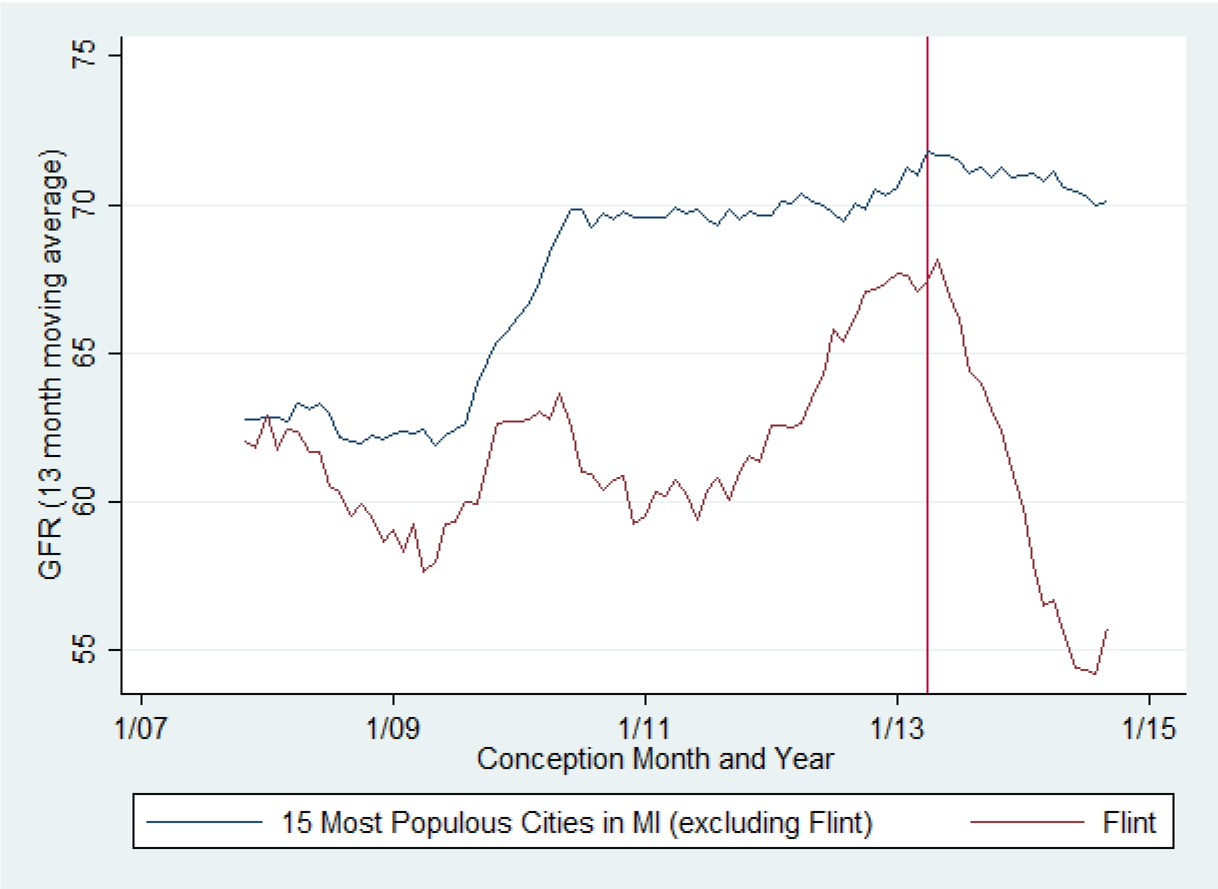
Table 1: Summary Statistics

	(1)	(2)	(3)	(4)	(5)
	Non-Flint Births		Flint Births		
	Pre-Water Change (N=269,151)	Post-Water Change (N=59,057)	Pre-Water Change (N=10,623)	Post-Water Change (N=2,010)	Difference in Differences
Demographic variables:					
Mother's age (years)	27.68 (6.04)	28.27 (5.75)	24.66 (5.60)	25.17 (5.37)	-0.07
Mother no high school	0.177	0.145	0.294	0.271	0.010
Mother high school grad	0.259	0.255	0.317	0.343	0.043***
Mother some college	0.282	0.299	0.337	0.337	-0.021
Mother college grad	0.272	0.290	0.050	0.047	-0.02***
Outcome variables:					
General fertility rate	67.09 (5.01)	70.12 (2.87)	62.28 (6.81)	56.87 (6.76)	-8.45***
Fetal death rate	0.36 (0.99)	0.34 (0.13)	0.18 (0.34)	0.32 (0.43)	0.16
Male-Female Sex Ratio (percent male)	51.15 (0.77)	51.04 (1.24)	51.05 (4.59)	50.20 (3.06)	-0.74
Abnormal Conditions	0.093 (0.29)	0.110 (0.31)	0.185 (0.39)	0.177 (0.38)	-0.03***
Birth weight (grams)	3234 (628)	3,209 (641)	3,082 (632)	3,042 (651)	-15
Estimated gestational age (weeks)	38.52 (3.03)	38.39 (2.54)	38.10 (3.14)	37.89 (2.69)	-0.08
Gestational Growth (grams/week)	85.54 (14.58)	83.03 (14.51)	80.36 (14.36)	79.58 (14.48)	-0.27

Notes: For Columns (1)-(4), standard deviation for non-dummy variables in parenthesis. For Column (5), robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

6.2. Fertility Results

Figure 3: Moving Average Fertility Rate Over Time in Flint and Comparison Cities



Note: The red vertical line is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average.

In Figure 3 we present trends in GFR for Flint and the rest of Michigan separately. We calculated a 13 month moving average (+/- 6 months) to remove both seasonality and idiosyncratic noise.[16] While births in Flint are still slightly more volatile due to the smaller base sample in the area, the graph demonstrates a substantial decrease in fertility rates in Flint for births conceived around October 2013, which persisted through the end of 2015. Flint switched its water source in

[16] We present unadjusted fertility rates in Appendix Figure B1.

April 2014, meaning these births would have been exposed to this new water for a substantial period in utero (i.e., at least one trimester). Given the moving average, the vertical line is for April 2013, which is the last conception date for which no affected birth rates are included in the moving average.

Table 2: Lead in Water on General Fertility Rate

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.451*** (0.786)	-7.451*** (0.791)	-7.451*** (0.791)	-8.450*** (1.993)	-8.450*** (1.640)	-8.467*** (1.746)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,520	1,520	1,520	190	190	190
Cities	16	16	16	16	16	16
R-squared	0.003	0.019	0.235	0.277	0.551	0.595
Mean	62.28	62.28	62.28	62.28	62.28	62.28

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 2 presents regression results for GFR by city. The main coefficient of interest is β_1, the parameter of $Water_{ct}$ calculated using equation (2) above. The unit of observation is city-month. Column 1 does not include any covariates. We estimate that women living in Flint following the water change gave birth to 7.5 fewer infants per 1,000 women aged 15-49 compared to control counties. These results are statistically significant at the 0.001 (0.01%) level. This is on a base of 62 births per 1000 women aged 15-49, or a 12.0 percent decrease in births in Flint. In Column 2 we include conception month fixed effects and conception year fixed effects and in

Column 3 we additionally include city fixed effects in equation 1. Estimates are nearly identical in these more saturated models. We also calculate GFR effects collapsing births in Flint and all other areas in Michigan in columns 4-6. This reduces our sample size substantially as instead of 29 comparison counties, we now have just 1 comparison group. However, our estimate of GFR for Flint following the water change is both quantitatively and qualitatively similar.

Next, we investigate how much of this decrease in general fertility rate can be explained by changes in fetal death rates in Table 3. Fetal deaths are reported by hospitals and are comprised of pregnancies lasting more than 20 weeks that do not result in a live birth.[17] Deaths are calculated analogously to the fertility rate, i.e., divided by the number of women 15-49 in the associated geographic area. They are assigned to a conception month using the available information on gestational age.

[17] Fetal deaths are likely an underestimate of total fetal deaths occurring in Michigan for several reasons: (1) they do not include abortions; (2) they do not include miscarriages that occur before 20 weeks of gestation; and (3) they are restricted to hospitals reporting these events.

Table 3: Fetal Death

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	0.107** (0.0372)	0.107** (0.0374)	0.107** (0.0374)	0.159 (0.114)	0.159 (0.112)	0.179* (0.104)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,520	1,520	1,520	190	190	190
Cities	16	16	16	16	16	16
R-squared	0.005	0.021	0.021	0.090	0.206	0.269
Mean	0.182	0.182	0.182	0.182	0.182	0.182

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results show that fetal death rates increased by 0.1 per 1000 women aged 15-49 in Flint after the water source was switched, as compared to other cities in Michigan. This is a 58% increase in fetal death rates.

Unfortunately, given how low the fetal death rate is overall, our results lose statistical significance when we move to the specification in Columns (4)-(6) where the rest of Michigan is collapsed into one control group. Yet, the point estimates are all positive and of a comparable, though slightly larger, magnitude.

Table 4: Fatal Death Added Back to Live Births

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.324*** (0.783)	-7.324*** (0.788)	-7.324*** (0.787)	-8.273*** (1.973)	-8.273*** (1.615)	-8.266*** (1.733)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,520	1,520	1,520	190	190	190
Cities	16	16	16	16	16	16
R-squared	0.003	0.019	0.235	0.284	0.560	0.604
Mean	62.47	62.47	62.47	62.47	62.47	62.47

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Adding fetal deaths to our live birth numerator, we calculate live births and fetal deaths per 1000 women aged 15 to 49 in Table 4. Our results are comparable to those of Table 2 (only live births) but the effect is about 2 percent smaller,[18] suggesting that only a small amount of the drop in the birth rate can be explained by the rise in recorded fetal deaths. Therefore, lower conception rates and higher miscarriage rates are likely driving the decrease in the birth rate.

In Table 5, we examine how the sex ratio of live births changed in Flint, given the medical literature that male fetuses are more susceptible to fetal insults (Trivers and Willard 1973, Sanders and Stoecker (2015).

[18] 1-(-7.324/-7.451) = 1.7%.

Table 5: Sex Ratios

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.00898**	-0.00898**	-0.00898**	-0.00727	-0.00727	-0.0105
	(0.00299)	(0.00301)	(0.00301)	(0.00953)	(0.00905)	(0.00980)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,330	1,330	1,330	190	190	190
Cities & Flint	16	16	16	16	16	16
R-squared	0.001	0.014	0.014	0.007	0.096	0.163
Mean	0.510	0.510	0.510	0.510	0.510	0.510

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

We find that sex ratios decrease by 0.9 percentage points (1.8 percent) in Flint, compared to other Michigan cities. Sanders and Stoecker (2015), investigating the health effects of the Clean Air Act, find that birth ratios skew more male following the implementation of the act. They argue this is consistent with an increase in health. While this increase in the proportion of births that are female likely represents a level of selection consistent with an increase in fetal deaths, it is also consistent with a decrease in health at the time of birth.

6.3. Birth Outcomes

The results in the section above provide direct support for the Flint water change causing a culling of the weakest fetuses. Next, we turn our focus to birth outcomes. If increased lead in the water only has a selective attrition effect then we would expect an increase in health among the births in Flint as the selection would remove only the weakest and leave the healthier fetuses to come to term. If, alternatively, a scarring effect also is present, then we would expect a decrease in health for those births that actually occurred.

We first investigate whether the change in water supply caused a change in abnormal conditions in Table 6.[19] Abnormal conditions decrease by 2.5 percentage points (13.5 percent) in Flint compared to the rest of Michigan after the switch to Flint River water, a positive health outcome. This result is statistically significant, although it is partially driven by the substantial decrease in abnormal conditions in other areas, which is unlikely to be attributable to the Flint water change. Adding census tract, month and year of conception fixed effects and additional covariates in columns 2-5 does not substantially change the coefficient on abnormal conditions.

Results for birthweight, gestational age and gestational growth rate are all negative but imprecisely measured. The magnitudes on the coefficients are all rather small, suggesting non-economically meaningful effect sizes. For birthweight, we find the water change decreased birthweight by between 12 and 22 grams. None of these estimates is statistically significant. Estimates of the effect of the water change on estimated weeks of gestation suggest that babies born in Flint after the water change were in utero for 0.1 weeks less than before the change compared to the rest of Michigan. This amounts to a reduction of less than 1 day in utero. Growth rate is calculated as an infant's birth weight divided by his or her gestational age. We find that those born in Flint after the water switch grew between 0.3 and 0.4 grams per week less.

[19] Abnormal conditions include assisted ventilation, NICU admission, receipt of surfactant replacement therapy, antibiotic receipt to treat neonatal sepsis, seizure, and significant birth injury.

Table 6: Lead in Water on Other Birth Outcomes

	(1)	(2)	(3)	(4)	(5)
Abnormal Conditions	-0.0254***	-0.0237**	-0.0236**	-0.0234**	-0.0249**
	(0.00970)	(0.00970)	(0.00968)	(0.00968)	(0.00970)
Birthweight (grams)	-15.24	-21.51	-20.21	-19.02	-11.52
	(13.61)	(14.62)	(14.44)	(14.74)	(14.59)
Gestational Age (weeks)	-0.0790	-0.102*	-0.0885	-0.0892	-0.0765
	(0.0591)	(0.0618)	(0.0601)	(0.0599)	(0.0601)
Gestational Growth (grams/week)	-0.271	-0.400	-0.381	-0.349	-0.173
	(0.306)	(0.327)	(0.324)	(0.333)	(0.331)
Census Tract Fixed Effects		X	X	X	X
Conception Month Fixed Effects			X	X	X
Conception Year Fixed Effects			X	X	X
Child Sex Control				X	X
Mom Controls					X

Notes: Robust standard errors clustered at the census tract level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

6.4. Behavioral Changes

One possible concern with lower conception rates having a role is that they are a result of behavioral changes (i.e., less sex) and not the physiological impacts of lead. Following Barreca, Deschenes, and Guldi (2016) we use the American Time Use Survey to investigate time spent engaged in sexual relations, proxied by any time spent in "personal or private activities".[20] Table 7 has the result of those analyses. Note that these analyses are at the county or CBSA-level and are thus not directly comparable to our main results as Flint comprises approximately ¼ of the

[20] I.e., "having sex, private activity (unspecified), making out, personal activity (unspecified), cuddling partner in bed, spouse gave me a massage."

population of Genesee County. Appendix Table B6 provides our main results treating all of Genesee County as treated, which should bias our results towards zero.

Table 7: Time Use Data on Sex

	(1)	(2)	(3)	(4)	(5)	(6)
	County-level			CBSA-level		
Water (β_1)	0.0148*** (0.00203)	0.0158*** (0.00133)	0.0157*** (0.00131)	0.0186*** (0.00229)	0.0206*** (0.00319)	0.0205*** (0.00310)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
CBSA Fixed Effects						X
Observations	861	861	861	745	745	745
Counties/CBSAs	16	16	16	13	13	13
R-squared	0.011	0.037	0.036	0.003	0.028	0.027

Notes: Robust standard errors clustered at the county or CBSA level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

We find that sexual activity *increased* in the post period, which would bias our main result of a decrease in the fertility rate toward zero.[21] While this is only suggestive evidence, together with our fetal death and sex ratio results, it supports our conclusion that the reduction in the conception rate is not driven by a reduction in sexual activity.[22]

[21] This is analogous to Barreca, Deschenes, and Guldi (2016) which also finds a statistically significant *increase* in time in the probability that individuals spend time on sex during environmental conditions that overall reduce fertility.

[22] As an extension of the CPS, the ATUS lacks city identifiers and only has county or CBSA ones. In Appendix Table B6, we repeat our results are the county level and show that while the inclusion of the rest of Genesee County (where Flint is located) as treated reduces the magnitude of our results, they are still directionally consistent and statistically significant in some specifications.

7. Robustness Checks

We perform a number of robustness checks to ensure our results are not sensitive to geographical definitions of our control group or of Flint, or functional form assumptions. First, in Appendix Table B1 and Appendix Figure B2 we omit the cities with the highest and lowest GFR in the sample and compare GFR in Flint to the 13 largest cities in Michigan. The reductions in GFR are between 8 and 9 births for this sample.

In Appendix Table B2, we limit our sample period to conceptions through September 2014. By shortening the time frame of our analysis, we reduce the likelihood of individuals changing their behavior in response to any concerns about the water in Flint. Our results are robust to this specification and the magnitudes even larger. This provides support for our claim that behavioral responses are unlikely to explain our results, given that all births in this sample would have to have been conceived before any boil advisories or EPA violations had occurred.

In Appendix Table B3 we estimate the effect of the water change on log births. We find between a 15 and 18 percent decrease in Flint following the water change, which is comparable to our 12 to 14 percent result in Table 2. In Appendix Table B4 we estimate a Poisson model and find a decrease in births of 0.15, which can be interpreted as similar to a 15 percent decrease in births in Flint.

We compare county level GFR rates in Appendix Table B5. The treatment in this table includes all of Genesee County, of which Flint comprises approximately ¼ of the population. The results are greatly reduced in this table, which is to be expected given that the treatment sample is contaminated with non-affected areas. However, GFR still decreases in a statistically significant way in Genesee County compared to other counties in Michigan following the Flint water change.

In Appendix Table B6 we investigate Flint compared to the rest of Genesee County. This model tests whether Flint and bordering areas within the same county differed in terms of fertility and birth outcomes following the water change. We find robust and consistent results for both GFR and sex ratio. Additionally, as a placebo analysis, we compare Genesee County, excluding Flint, to the rest of Michigan in Appendix Table B7 and find no change in GFR or sex ratios providing strong support for a change within Flint at the time of the water switch driving our results.

In Appendix C, we focus on Flint compared to counties in Michigan rather than cities. The results are largely robust to this alternative definition of control areas. The main difference between these results and our main city comparison results are that the effect of the water switch on fertility rates in Flint is slightly smaller than our main results, but birth outcome results are slightly larger. The magnitudes of these differences are still quite similar. However, because Flint is a city within a county and urban areas tend to have higher fertility rates, as is evidenced in Appendix Figure B1, we focus on the city results and simply state that our results are robust to other comparison groups.

Lastly, we perform an analysis of fertility rates using a synthetic control methods approach (Abadie, Diamond, and Hainmueller 2010; Cunningham and Shah 2017).[23] This method creates a weighted matched control group that more closely resembles the characteristics of Flint in the period before the water change on both level and trend of fertility rates. It also controls for demographic characteristics of mothers in the pre-period, including race/ethnicity, educational attainment, and gender of the child. Figure 4 presents the results of this method. Panel A displays GFR trends in Flint and its synthetic control group before and after the water switch, which is visualized as the vertical line at April 1, 2013, which is the last conception date for which no

[23] We describe this method in detail in Appendix A.

affected birth rates are included in the moving average. [24] Panel B shows the difference between each city systematically assigned to treatment and the synthetic version of the city for each month. Flint is denoted by the solid line. The average treatment effect in Flint compared to the synthetic control is a decrease of 5.9 births, presented in Panel C by the horizontal blue line. This effect size is very similar to that found above in Table 2. This graph presents the cumulative distribution function of average treatment effects from systematically assigning treatment to each potential control city. The average treatment effect in Flint is larger than the average treatment effect for all other cities, which provides an implied p-value of 0.07.

As an additional robustness check, we perform a synthetic control model matching on all GFR for the month of March in each year before the water change (2008, 2009, 2010, 2011, 2012, 2013).[25] The strength of this analysis is that it creates a better pre trend match on GFR, but the weakness is that it may over-fit on GFR and ignore other covariates (see Kaul et al. 2017). Our estimates are robust to this alternative specification and we present these results in Appendix Figure B3.

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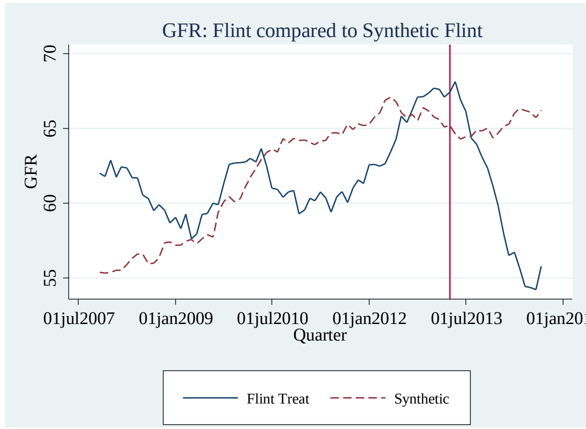
[24] We find similar effect sizes and inference interpretations using quarter of birth rather than month of birth (results available upon request).

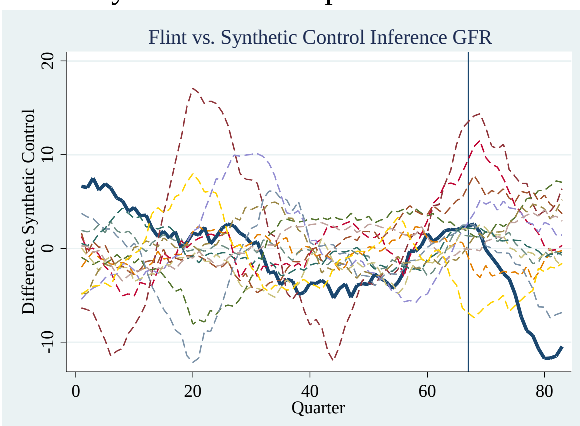
[25] We estimate a similar model matching on the 4th quarter GFR for each year before the water change (2007, 2008, 2009, 2010, 2011, 2012) and find comparable results (Available upon request).

Figure 4. Synthetic Control Results for General Fertility Rates

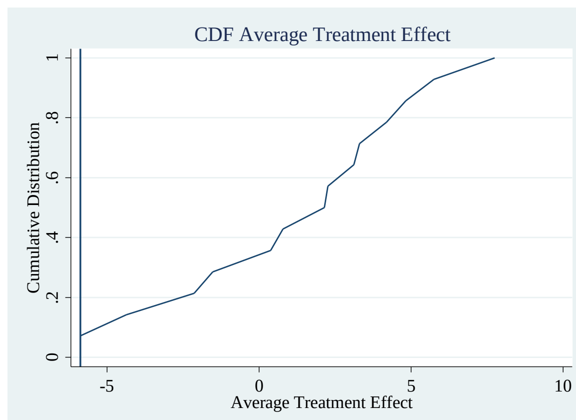
Panel A. Flint GFR compared to Synthetic Flint GFR



Panel B. Difference Between Each City and it's Synthetic Counterpart



Panel C. Inference using Average Treatment Effect



Note: The red vertical line in Panel A is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average. The blue solid line in Panel B represents the difference between GFR in Flint and "synthetic Flint." The horizontal blue line in Panel C displays the average treatment effect. It is the largest average treatment effect compared to assigning all areas to treatment, suggesting statistical significance.

8. Discussion

First of all, our results for the decrease in the fertility rate and the increase in the fetal death rate are plausible given the broader scientific literature on this topic. While the impact of drinking water with high concentrations of lead on fertility rates and fetal death rates has not been studied in the economics literature, there has been some work in the environmental science literature. Specifically, Edwards (2014) studies an increase in lead in drinking water in Washington, D.C. in the early 2000s, and using somewhat different methods finds a 12% decrease in the fertility rate and a 32-63% increase in the fetal death rate. The magnitude of the fertility rate decrease that we find is identical to Edwards's result, and our fetal death result (a 58% increase), while horrifyingly large, is within Edwards's range.

Secondly, we attempt to extrapolate the consequences of our results. The population of women aged 15-49 in Flint during our study period is approximately 26,000. The GFR dropped from 62 to 57, suggesting that over our study window of 17 months (births conceived from November 2013 through March 2015) between 198 and 276 more children would have been born had Flint not enacted the switch in water.[26] We consider this strong empirical support for the existence of a culling effect caused by increased lead in the water.[27] Our results on sex ratios suggest that among the live births that occurred in Flint following the change in water supply, an additional 18 female infants were born than expected.[28] While birth outcome results are not as definitive as our fertility results, they provide evidence that the effect we find is likely a combination of a selection and a scarring effect. In fact, even an effect size of zero for these birth outcomes provides evidence of scarring because had there only been a selection effect, we would expect the health effects to be positive. Because we find evidence of negative health effects in Flint following the water change, we conclude that in addition to reducing the number of expected births in the city, the water change also caused a decrease in overall health of those babies born.

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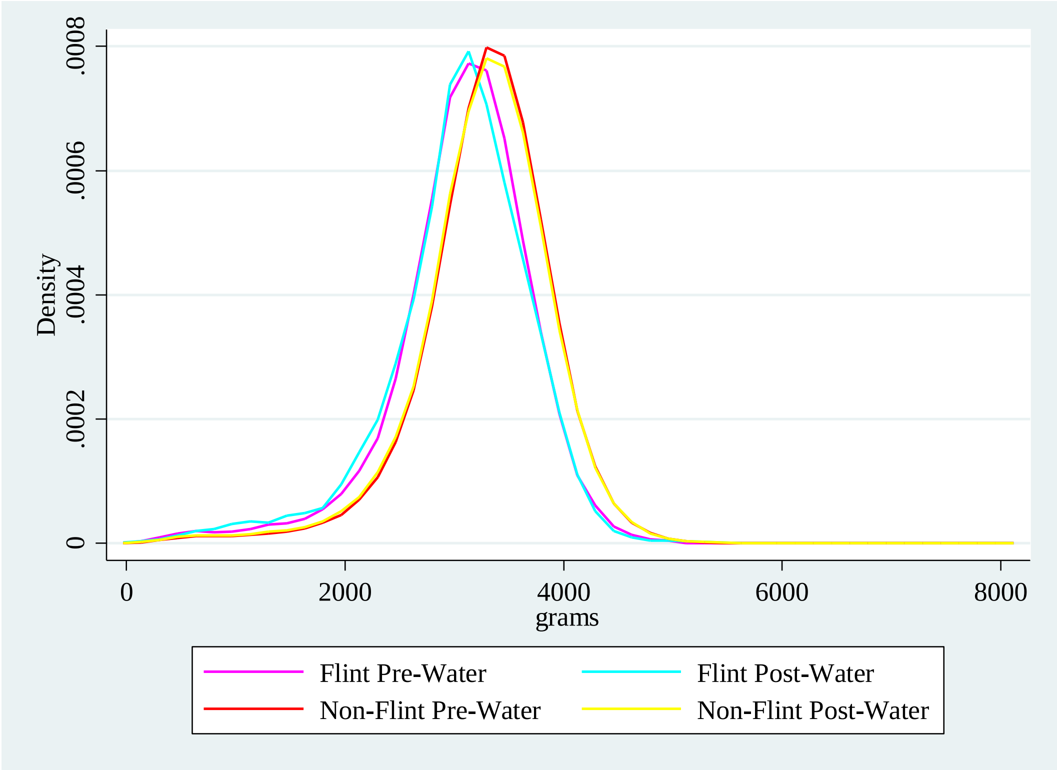
[26] We calculate this as the either the change in GFR in Flint only (62-57) or the difference-in-differences estimate (7.5) * population aged 15-49 in Flint (26,000) * the number of years affected (17/12) which gives us a range of 198 to 276.

[27] Using log births instead of GFR provides consistent results, as shown in Appendix Table B3.

[28] We multiply the change in sex ratio (0.009) * the number of post water change births (2,010) to get 18.

We perform an analysis in the spirit of Bozzoli, Deaton, and Quintana-Domeque (2009) to untangle scarring and selection. First, we assume that the pre-water change birthweight distibriution in Flint is normally distributed (see Figure 5) and has the mean (3082 g) and standard deviation (632 g) as in column 3 of Table 1. Using the 12.0 percent reduction in the live birth rate as found in Table 2, we assume that this reduction all came from the left tail of the birthweight distribution, as birthweight is often thought of as a proxy for infant health. Another way to think of this is that there is some minimal birthweight cutoff for live birth, and the selection shock of adding lead to the water shifted the entire distribution left such that the bottom 12.0 percent of birth weight did not survive.

Figure 5. Probability Density Function of Birthweight Before and After the Water Switch.



Using the standard formula for the mean of a truncated normal[29] we calculate that mean birthweight of the surviving newborns, without any scarring, would have been 3242 g. From here to the observed Flint mean birthweight in the post period (3042 g) is a decrease of 183 g. Removing the pre-post difference in the rest of Michigan (from Columns 1 and 2 of Table 1) reduces this by 25 g to a scarring effect of 158 g, which is a 4.9 percent decrease. This is much larger than the scarring effect found from ignoring how scarring and selection cancel each other out (as in Gørgens, Meng, and Vaithianathan 2012) and naïvely using the coefficient in Table 6. We consider this a bounding exercise for the full effect of scarring had no selective attrition occurred. As Figure 4 makes clear, despite the large amount of selective attrition we document in Table 2, our pdf for Flint show that the health distribution shifted to the left in Flint following the water change and did not shift in comparison cities.

Additionally, while the results in Tables 3-5 and 7 are not definitive, taken together, they also support our main result that fertility rates decrease because of both selective attrition and scarring from a biological effect of an increase in the lead content of water. In Table 7, we find no evidence to support a decrease in sexual relations among individuals living in Flint during this time period, while Table 3 shows an increase in fetal deaths occurring after 20 weeks. These fetal deaths occur in a hospital and are separate from abortions. Additionally, a 0.9 percentage point increase (1.8%) in female births following the water change is consistent with medical literature (Trivers and Willard 1973). Sanders and Stoecker (2015) find that an increase in particulates in the air reduces the ratio of male births. For our results to be explained by behavioral changes, we would have to postulate a theory that at the same time Flint changed its water source, parents

[29] I.e., $E\left(X \middle| X > \mu + \sigma\Phi^{-1}(p)\right) = \mu + \frac{\sigma\phi\left(\Phi^{-1}(p)\right)}{1-p}$, where μ is the mean, σ the standard deviation, Φ the standard normal CDF, φ the standard normal PDF, and p the truncation cutoff probability.

changed their preference for male children and began performing sex-selective abortions showing a preference for *female* children.[30] This result would run counter to the prevailing evidence of lower female births than expected, especially in Asian countries (see e.g. Sen 1990; Das Gupta 2005), but also in the US (Abrevaya 2009).

Finally, we stress that our measure of health may not capture the full health effects of this water change. Firstly, infants born during this time period would have been exposed to water both in utero and for a period post-birth. Hanna-Attischa et al. (2016) show that children exposed to the new water regime had higher levels of blood lead. Secondly, the Barker hypothesis posits that measured health at birth only partially describes later life health. An additional component can be denoted as latent health, which may be exhibited later as poor health in adulthood, decreased educational attainment, increased behavioral problems and criminal behavior, and worse labor market outcomes (see e.g., Almond and Currie 2011, Aizer et al. 2016, Aizer and Currie 2017, Reyes 2007, 2015, Billings and Schnepel 2017).

9. **Conclusion**

Failure to provide safe drinking water has large health implications. We provide the first estimates of the in utero effect of increased amounts of lead in drinking water in Flint. General fertility rates in Flint decreased substantially following the water change while health outcomes displayed mixed results, with suggestive evidence of an overall decrease in abnormal conditions and a decrease in birth weight and gestational age.

An overall decrease in fertility rates can have lasting effects on a community, including school funding due to a decrease in the number of students. Alternatively, if the decrease in births

[30] While male child preference is generally considered in an international setting (see e.g. Sen 1990; Das Gupta 2005), Abrevaya (2009) finds evidence of "missing girls" in the US as well.

truly decreased the number of less healthy babies, it may reduce the health expenditures of the community. However, given the research demonstrating a substantial increase in blood lead levels among children in the community, an overall decrease in health expenditures in both the short and long-term seem highly unlikely (Hanna-Attischa et al. 2016; Edwards, Triantafyllidou, and Best 2009). Furthermore, the children that were born with seemingly fewer abnormal conditions may still have worse latent health at birth, which could manifest itself later in life (Barker 1992; Barker 1995).

Additionally, Michigan State University recently received a large grant to create a voluntary registry of affected individuals. [31] It is very possible that many residents who may have had a stillborn baby or miscarried during the water switch do not realize that exposure to lead increased their risk of these outcomes. While researchers are aware of these risks, the public may not be. Therefore, this work may inform citizens that they should sign up for this registry as they were more affected by the water switch than they may have previously realized.

This study has several limitations. First, previous work has demonstrated that lead builds up in the body over time, so that focusing on neonatal outcomes may underestimate the overall effects of lead on health and human development. Other contaminants may be present in the water that also effect health making our estimates an upper bound on the effect of lead on these outcomes. Additionally, the health effects of a change in water supply are not limited to pregnant women and neonates. This is just one piece of the health effects of this switch in water supply; however, given the litany of evidence linking fetal and birth outcomes to later life health, education, and labor outcomes, this study is an important step in investigating this public health issue. Despite these

[31] https://www.washingtonpost.com/national/grant-to-create-registry-of-flint-residents-exposed-to-lead/2017/08/01/78c8fa66-7707-11e7-8c17-533c52b2f014_story.html?utm_term=.f89d3f64e273

limitations, the culling of births in Flint provides robust evidence of the effect of lead on the health of not just infants, but on the health of potential newborns in utero.

This paper presents the first study of the Flint water change on fertility and birth outcomes. This is a natural experiment from which to study the effect of high concentrations of lead in water on birth outcomes. Lead problems in many municipalities have recently been reported, making these estimates important in informing public policy (see Wines and Schwartz 2016).

This study is of great importance as the current legislative environment includes calls for a substantial decrease in funding for the EPA which is charged with ensuring localities maintain minimum water standards. Our results suggest that a more lax regulatory environment in the context of drinking water may have substantial unforeseen effects on maternal and infant health, including large reductions in the number of births.

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Appendix A. Synthetic Control Methods

The synthetic control method creates a weighted control group matched on pre-water supply trends, including the outcome of interest fertility rates and birth outcomes, such that the vector of weights (W) minimizes:

$$\|X_1 + X_0W\| = \sqrt{(X_1 + X_0W)'V(X_1 + X_0W)}$$

where X_1 is an unweighted vector of pre-intervention characteristics of the treatment counties and X_0 denotes a similar vector for control counties. The pool of control counties consists of the largest 15 cities in Michigan that did not change their water supply over this time period.[32] One strength of a synthetic control analysis is if a control county is trending differently from the treatment, it can receive zero weight. This method creates a weighted comparison group that minimizes the root mean squared error of the outcome variables in the pre-treatment period, which is the standard deviation in the difference between the actual outcome value of the treatment group and the predicted outcome value of the synthetic control group (Abadie, Diamond, and Hainmueller 2010).

The basic specification adjusts for the average pre-period general fertility rate of interest in each and the average of the following variables over the same pre-period: mother's educational attainment including less than high school, high school graduate, some college, and college graduate, race, age of mother, and gender of the child.

The main strengths of this method are it creates a matched control group that follows similar pre-trends in terms of the outcome of interest, and it allows for rigorous inference testing. Because the control areas follow similar pre-trends and are matched on level as well, they are

[32] Cities included are Dearborn, Detroit, Farmington Hills, Flint, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, and Westland.

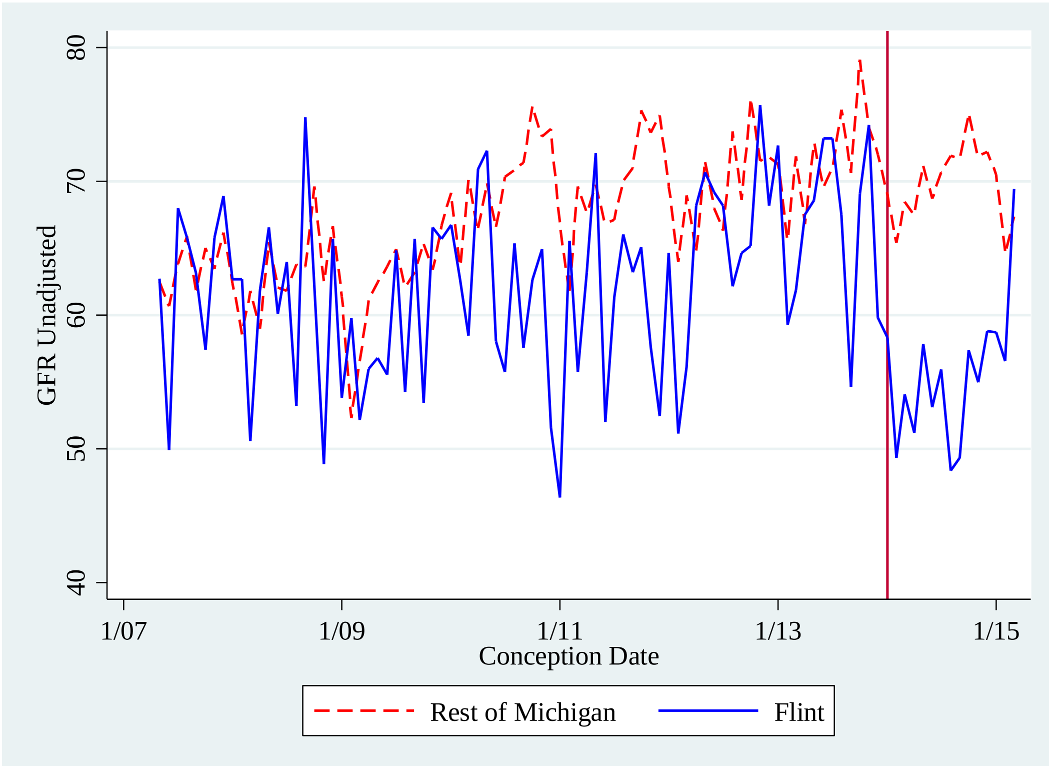
plausibly a better counterfactual representation of what one would expect to have happened to pregnancy and birth outcomes in Flint had the city never switched its water source.

Inference testing consists of systematically assigning treatment to each control zone, creating a synthetic control group using the city of Flint (the treatment zone) as a control as well as the full pool of control zones, minus the city assigned to treatment. We separately calculate the average treatment effect in the post-period of assigning treatment to each control zone. This creates a distribution of average treatment effects by which to evaluate the average treatment effect of the actual water supply change in Flint. So if there are 14 average treatment effects and the Flint effect is larger than the other 13 control area average treatment effects, the estimate is statistically significant at the 7.1 percent level.[33]

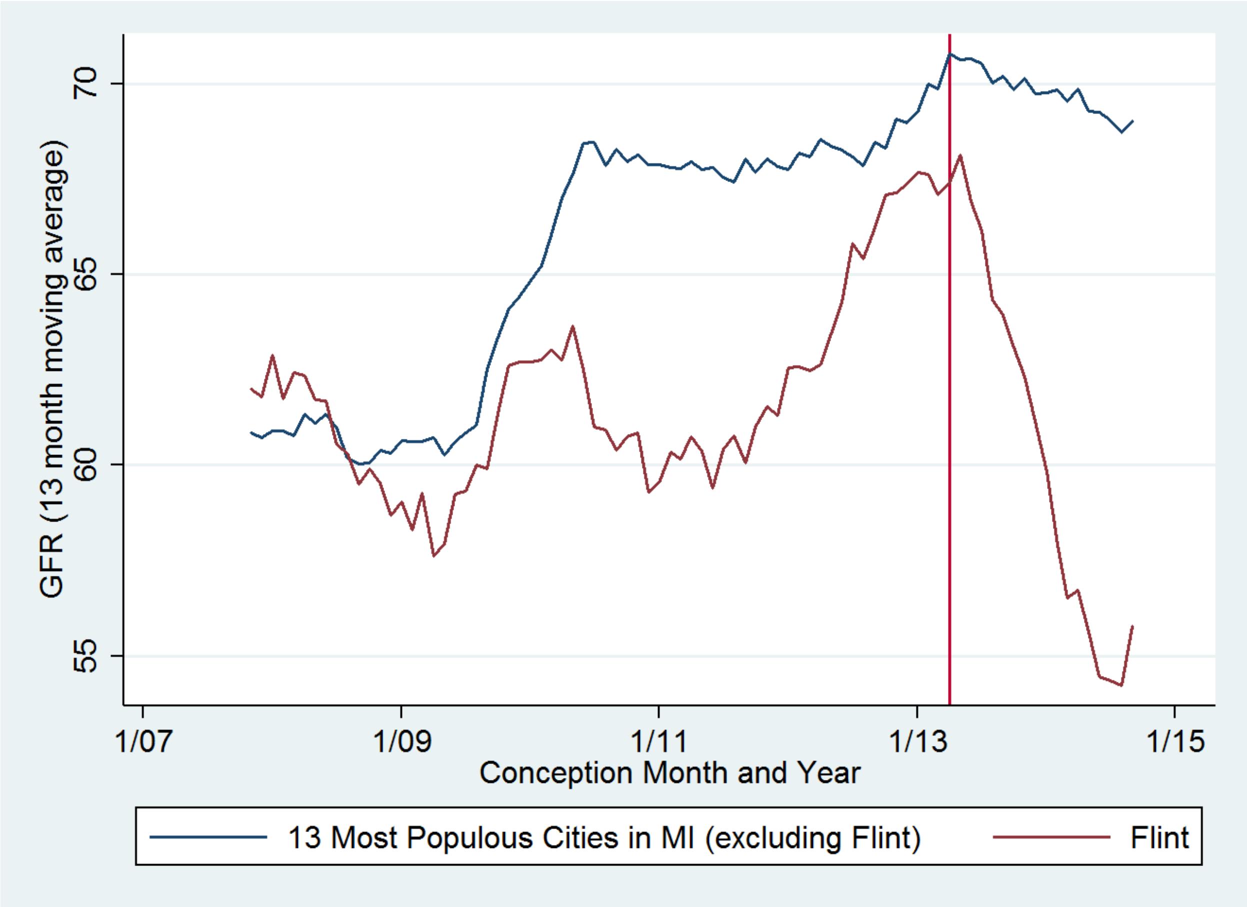
[33] 1/14=0.071

Appendix B: Additional Tables and Figures:

Appendix Figure B1. Unadjusted Monthly GFR



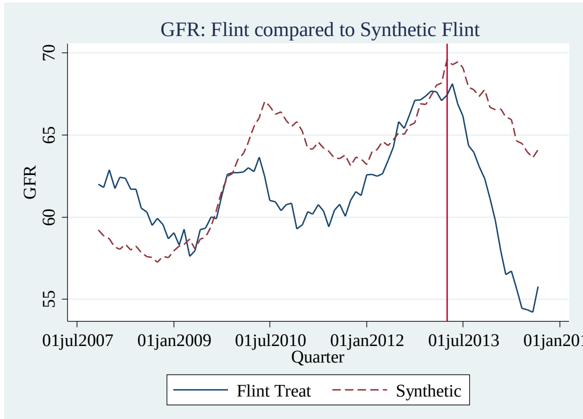
Appendix Figure B2: Moving Average Fertility Rate Over Time in Flint and Comparison Cities – Dropping Outlier Cities



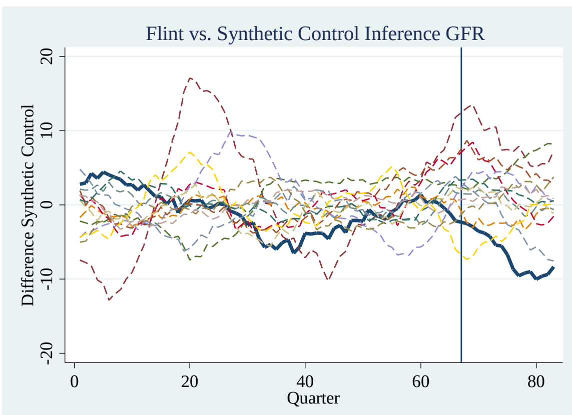
Note: The red vertical line is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average.

Appendix Figure B3. Synthetic Control Results for General Fertility Rates, Adjusting for March 2008-2013 GFR

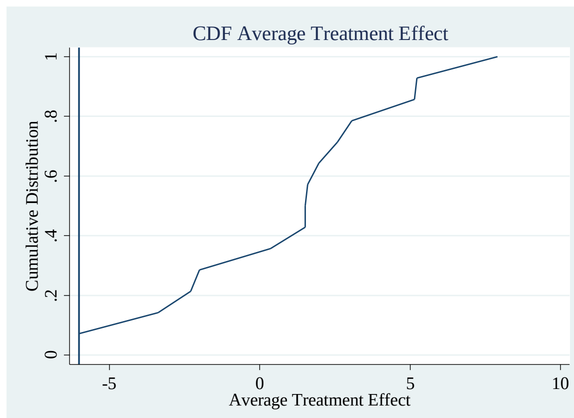
Panel A. Flint GFR compared to Synthetic Flint GFR



Panel B. Difference Between Each City and it's Synthetic Counterpart



Panel C. Inference using Average Treatment Effect



Note: We include GFR for March 2008, March 2009, March 2010, March 2011, March 2012, and March 2013 in the Synthetic Control Model to create a better pre-treatment control group for Flint. The red vertical line in Panel A is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average. The blue solid line in Panel B represents the difference between GFR in Flint and "synthetic Flint." The horizontal blue line in Panel C displays the average treatment effect. It is the largest average treatment effect compared to assigning all areas to treatment, suggesting statistical significance.

Appendix Table B1: Lead in Water on General Fertility Rate at the City Level Omitting Outlier Cities

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-8.173***	-8.173***	-8.173***	-8.933***	-8.933***	-8.931***
	(0.693)	(0.698)	(0.697)	(1.986)	(1.624)	(1.730)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,330	1,330	1,330	190	190	190
Cities	14	14	14	14	14	14
R-squared	0.003	0.043	0.285	0.206	0.513	0.556
Mean	62.28	62.28	62.28	62.28	62.28	62.28

Notes: Robust standard errors clustered at the city level in parentheses. Ann Arbor and Wyoming, the cities with the lowest and highest GFR, are omitted. *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table B2: Lead in Water on General Fertility Rate – Through September 2014

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-8.797***	-8.797***	-8.797***	-9.705***	-9.705***	-10.22***
	(0.690)	(0.695)	(0.694)	(2.454)	(1.873)	(1.949)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,424	1,424	1,424	178	178	178
Counties & Flint	16	16	16	16	16	16
R-squared	0.003	0.019	0.236	0.258	0.547	0.601
Mean	62.28	62.28	62.28	62.28	62.28	62.28

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. GFR through September 2014 removes births conceived post September 2014, when residents began to learn about potential water problems in Flint.

Appendix Table B3: Lead in Water on General Fertility Rate - ln(births) – All Cities

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.175***	-0.175***	-0.175***	-0.150***	-0.150***	-0.149***
	(0.0123)	(0.0124)	(0.0124)	(0.0275)	(0.0239)	(0.0262)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,520	1,520	1,520	190	190	190
Counties & Flint	16	16	16	16	16	16
R-squared	0.001	0.007	0.258	0.997	0.998	0.998

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Note that coefficients are in log points.

Appendix Table B4: Lead in Water on General Fertility Rate – Poisson (All Cities)

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.151***	-0.151***	-0.151***	-0.151***	-0.151***	-0.150***
	(0.0166)	(0.0166)	(0.0166)	(0.0276)	(0.0241)	(0.0251)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
City Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	1,520	1,520	1,520	190	190	190
Counties & Flint	16	16	16	16	16	16
R-squared	0.00924	0.0113	0.955	0.992	0.994	0.994

Notes: Robust standard errors clustered at the city level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Note that coefficients are in log points.

Appendix Table B5: Lead in Water on General Fertility Rate at the County Level

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-1.360***	-1.360***	-1.360***	-1.261	-1.261*	-1.004
	(0.341)	(0.342)	(0.342)	(1.086)	(0.725)	(0.673)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
Conception Month#Genesee Fixed Effects						X
Observations	2,755	2,755	2,755	190	190	190
Counties	29	29	29	29	29	29
R-squared	0.009	0.122	0.257	0.124	0.614	0.659
Mean	51.77	51.77	51.77	51.77	51.77	51.77

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. This table defines treatment as all of Genesee County and uses the 28 largest counties in Michigan as the comparison group.

Appendix Table B6. Flint Compared Only to Genesee County GFR and Sex Ratio

	(1)	(2)	(3)	(4)	(5)	(6)
	GFR	GFR	GFR	Sex Ratio	Sex Ratio	Sex Ratio
Water (β_1)	-6.568***	-6.568***	-6.568***	-0.007***	-0.007***	-0.007***
	(0.000)	(0.000)	(0.000)	(0)	(0)	(0)
Conception Month Fixed Effects		X	X		X	X
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			X
Observations	190	190	190	190	190	190
Counties & Flint	2	2	2	2	2	2
R-squared	0.604	0.695	0.285	0.015	0.123	0.114
Mean	62.28	62.28	62.28	0.510	0.510	0.510

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. This table defines treatment as Flint and uses the rest of Genesse County as the comparison group.

Appendix Table B7. Genesee County Except Flint as Treatment GFR and Sex Ratio

	(1)	(2)	(3)	(4)	(5)	(6)
	GFR	GFR	GFR	Sex Ratio	Sex Ratio	Sex Ratio
Water (β_1)	0.366	0.366	0.366	0.00476*	0.00476*	0.000387
	(0.341)	(0.342)	(0.342)	(0.00260)	(0.00261)	(0.00296)
Conception Month Fixed Effects		X	X		X	X
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			X
Observations	2,755	2,755	2,755	2,755	2,755	2,755
Counties & Flint	29	29	29	29	29	29
R-squared	0.002	0.116	0.257	0.000	0.004	0.004
Mean	48.08	48.08	48.08	0.510	0.510	0.510

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. This table defines treatment as the rest (i.e. parts that are not in Flint) of Genesee county and uses the 28 largest counties in Michigan as the comparison group.

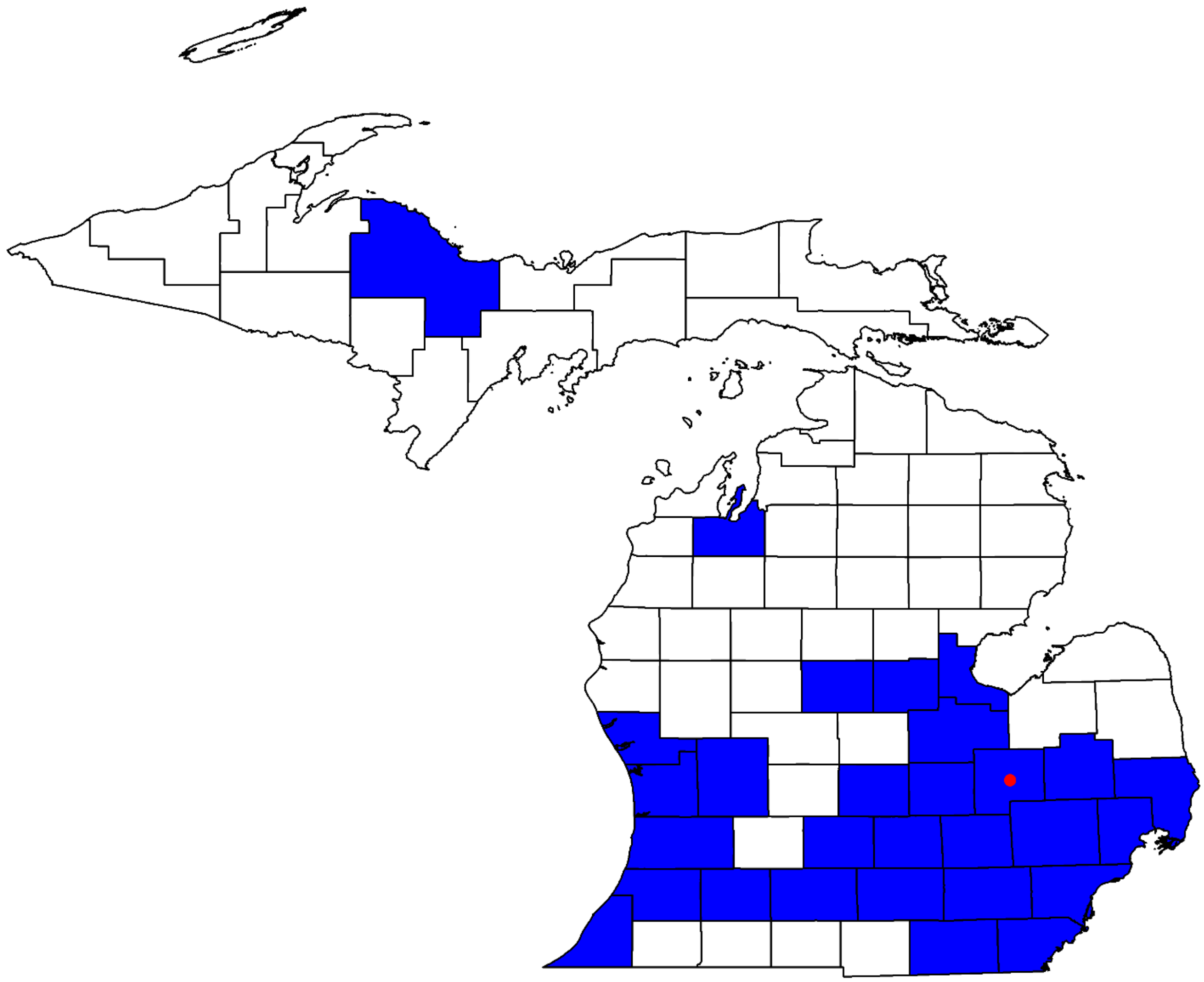
Appendix C: County Level Analysis

For the county level analysis, we consider Flint as the treatment unit, and then assign the rest of Genesee County as a rump control Genesee County with the remainder of the county's population.[34] Annual population data at the county level is only available from Census for high population counties, and so our main specification only uses those counties.[35]

34 https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_1YR_S0101&prodType=table

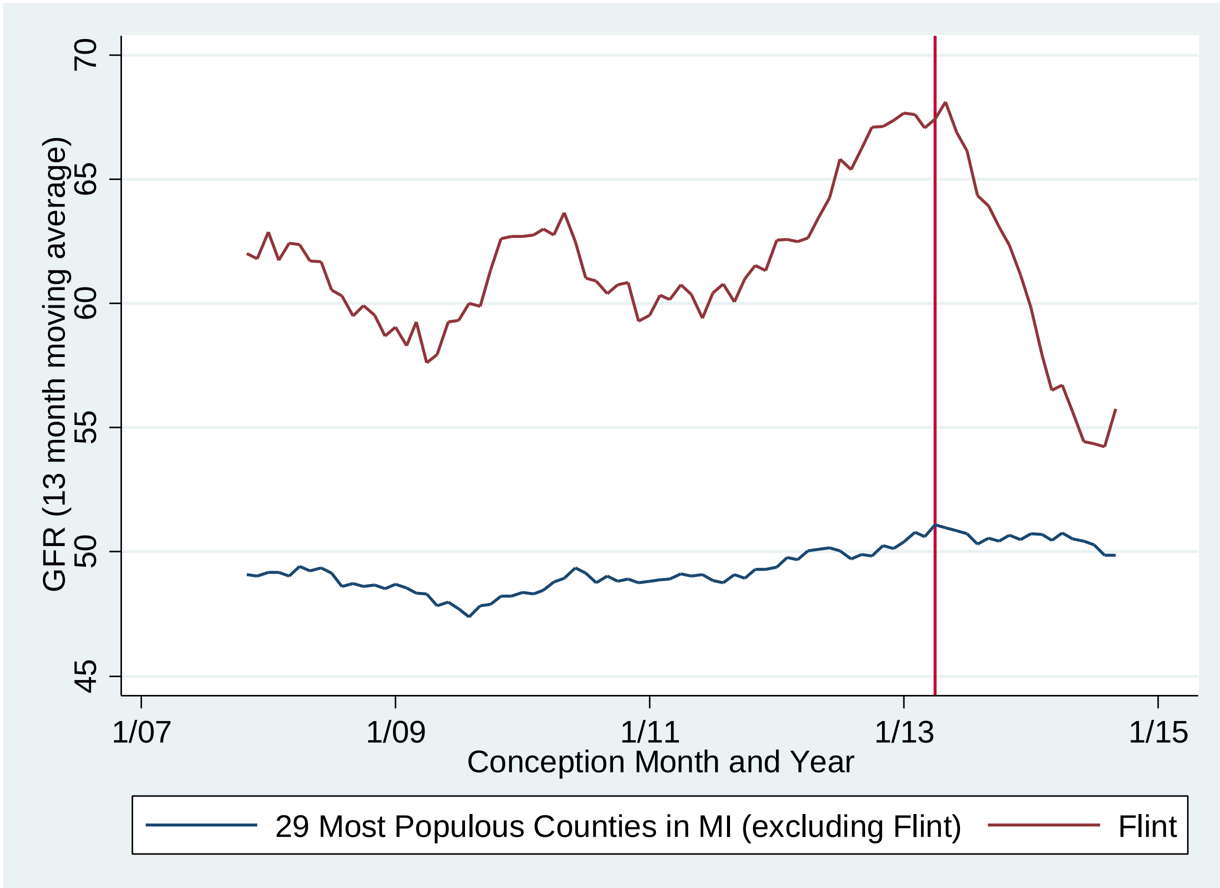
35 I.e., Allegan County, Bay County, Berrien County, Calhoun County, Clinton County, Eaton County, Genesee County, Grand Traverse County, Ingham County, Isabella County, Jackson County, Kalamazoo County, Kent County, Lapeer County, Lenawee County, Livingston County, Macomb County, Marquette County, Midland County, Monroe County, Muskegon County, Oakland County, Ottawa County, Saginaw County, St. Clair County, Shiawassee County, Van Buren County, Washtenaw County, and Wayne County.

Appendix Figure C1: Comparison Counties



Notes: Blue counties are comparison counties. Flint is shown in red.

Appendix Figure C2: Moving Average Fertility Rate Over Time in Flint and Comparison Cities



Note: The red vertical line is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average.

Appendix Table C1.

	(1)	(2)	(3)	(4)	(5)
	Non-Flint Births		Flint Births		
	Pre-Water Change (N=740,535)	Post-Water Change (N=158,288)	Pre-Water Change (N=10,623)	Post-Water Change (N=2,010)	Difference in Differences
Demographic variables:					
Mother's age (years)	27.62 (5.88)	28.15 (5.64)	24.66 (5.60)	25.17 (5.37)	-0.02
Mother no high school	0.144	0.119	0.294	0.271	0.00
Mother high school grad	0.258	0.249	0.317	0.343	0.04***
Mother some college	0.320	0.334	0.337	0.337	-0.01
Mother college grad	0.272	0.291	0.050	0.047	-0.02***
Outcome variables:					
General fertility rate	49.27 (2.64)	49.98 (2.85)	62.28 (6.81)	56.87 (6.76)	-6.12***
Male-Female Sex Ratio (percent male)	51.21 (0.50)	51.19 (0.63)	51.05 (4.59)	50.20 (3.06)	-0.82**
Abnormal Conditions	0.090	0.100	0.185	0.177	-0.02*
Birth weight (grams)	3,288 (612)	3,273 (624)	3,082 (632)	3,042 (651)	-25*
Estimated gestational age (weeks)	38.60 (2.85)	38.51 (2.39)	38.10 (3.14)	37.89 (2.69)	-0.12*
Gestational Growth (grams/week)	84.83 (14.36)	84.52 (14.22)	80.36 (14.36)	79.58 (14.48)	-0.47

Notes: For Columns (1)-(4), standard deviation for non-dummy variables in parenthesis. For Column (5), robust standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table C2: Lead in Water on General Fertility Rate at the County Level

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-6.215***	-6.215***	-6.215***	-6.121***	-6.121***	-6.085***
	(0.329)	(0.330)	(0.330)	(1.931)	(1.653)	(1.731)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	2,850	2,850	2,850	190	190	190
Counties & Flint	30	30	30	30	30	30
R-squared	0.089	0.191	0.249	0.590	0.704	0.730
Mean	62.28	62.28	62.28	62.28	62.28	62.28

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table C3: Fetal Death by County

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	0.0961***	0.0961***	0.0961***	0.143	0.143	0.164
	(0.0171)	(0.0172)	(0.0172)	(0.110)	(0.108)	(0.101)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	2,850	2,850	2,850	190	190	2,850
Counties & Flint	30	30	30	30	30	30
R-squared	0.004	0.015	0.015	0.030	0.143	0.004
Mean	0.182	0.182	0.182	0.182	0.182	0.182

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table C4: Fetal Death Added Back to Live Births by County

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-6.106***	-6.106***	-6.106***	-5.962***	-5.962***	-5.899***
	(0.331)	(0.332)	(0.332)	(1.910)	(1.630)	(1.721)
Conception Month Fixed Effects		X	X		X	
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
Conception Month#Flint Fixed Effects						X
Observations	2,850	2,850	2,850	190	190	190
Counties & Flint	30	30	30	30	30	30
R-squared	0.087	0.190	0.250	0.591	0.706	0.732
Mean	62.47	62.47	62.47	62.47	62.47	62.47

Notes: Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table C5: Lead in Water on Other Birth Outcomes by County

	(1)	(2)	(3)	(4)	(5)
Abnormal Conditions	-0.0188*	-0.0173*	-0.0175*	-0.0174*	-0.0187*
	(0.00962)	(0.00962)	(0.00958)	(0.00958)	(0.00959)
Birthweight (grams)	-24.89*	-30.89**	-29.05**	-27.88*	-19.90
	(13.37)	(14.41)	(14.26)	(14.57)	(14.48)
Gestational Age (weeks)	-0.112*	-0.132**	-0.112*	-0.112*	-0.0984*
	(0.0581)	(0.0608)	(0.0592)	(0.0590)	(0.0593)
Gestational Growth (grams/week)	-0.471	-0.601*	-0.574*	-0.542*	-0.357
	(0.301)	(0.322)	(0.320)	(0.329)	(0.328)
Census Tract Fixed Effects		X	X	X	X
Conception Month Fixed Effects			X	X	X
Conception Year Fixed Effects			X	X	X
Child Sex Control				X	X
Mom Controls					X

Notes: Robust standard errors clustered at the census tract level in parentheses. *** p<0.01, ** p<0.05, * p<0.1