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

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Abstract

Flint, Michigan changed the source of its publicly provided water in April 2014, causing an increase in the levels of lead in water delivered to its citizens. The effect of high levels of lead in water on fertility and birth outcomes is not well established. Exploiting variation in the timing of births, we find overall general fertility rates decrease by 10% in Flint following the water change. We also find a decrease in health among births. These results suggest both a culling of the least healthy fetuses and a shift in the health distribution in Flint due to scarring.

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 budge plan calls for extensive cuts to the EPA workforce and budget, including "compliance monitoring" which consists of testing for pollutants like lead in water (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. 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.

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, local and state officials continually reassured residents that the water was safe, reducing the scope of behavioral response in the form of avoidance behaviors to the water crisis (see e.g. Neidell 2009).[2]

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

[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.

maturity and the nervous system (Agency for Toxic Substances and Disease Registry; Zhu et al. 2010). Recent studies have linked maternal exposure to lead to prenatal growth abnormalities, reduced gestational period, and reduced birth weight (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 2008). 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, and not otherwise similar areas switched their water source at this time. Other municipalities in the county and in surrounding areas continued to receive water from Lake Huron. 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 6 live births per 1,000 women aged 15-49 lower than control women, or a 10 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 not a behavior change in conception or contraception. Additionally, the ratio of male to female live births decreases by 1 percentage point 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 10% in Flint following the water switch compared to controls.

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 health. Alternatively, although not mutually exclusively, the increased lead may lead to a shift in 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 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 present a literature review of health conditions associated with lead. Section 3 describes our data. We present our empirical methods in section 4 and our results in section 5. Section 6 concludes.

2. 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).

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 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).

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. However, women would need to be aware of the water crisis in advance for this explanation to affect our analysis.

Additionally, lead may effect health through indirect channels including by decreasing latent health of those infants carried to term. This latent health measure 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). 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.

3. 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, and then assign the rest of Genesee County as a rump control Genesee County with the remainder of the county's population.[3]

Using population data from the ACS[4], we calculate general fertility rate (GFR) as:

[3] Our results are robust to a city-level definition, using HUD census tract to ZIP code matching (from https://www.huduser.gov/portal/datasets/usps_crosswalk.html#data) and SAS ZIP code to city matching (from https://support.sas.com/downloads/download.htm?did=104285#) 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). See Appendix Tables A1 and A2 and Appendix Figures A1, A2, and A3.

[4] https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_1YR_S0101&prodType=table. Annual population at the county level is only available from Census for high population counties, and so our main specification only uses those counties.

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

where c indexes either the city or county, and t the month and year.[5] 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. We multiply by 12 to make this an annual measure.

4. 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:

$$Outcome_{ct} = a + \beta_1 Water_{ct} + \alpha_c + \delta_t + \varepsilon_{ct}$$

Where c indexes the city/county, and t the month and year.[6] *Outcome* includes measures of *GFR* and male to female sex ratio (sex ratio).[7] *GFR* is a measure of the number of births in a month given the total population of the high population city or county,[8] as defined above, and as shown below in Figure 1.

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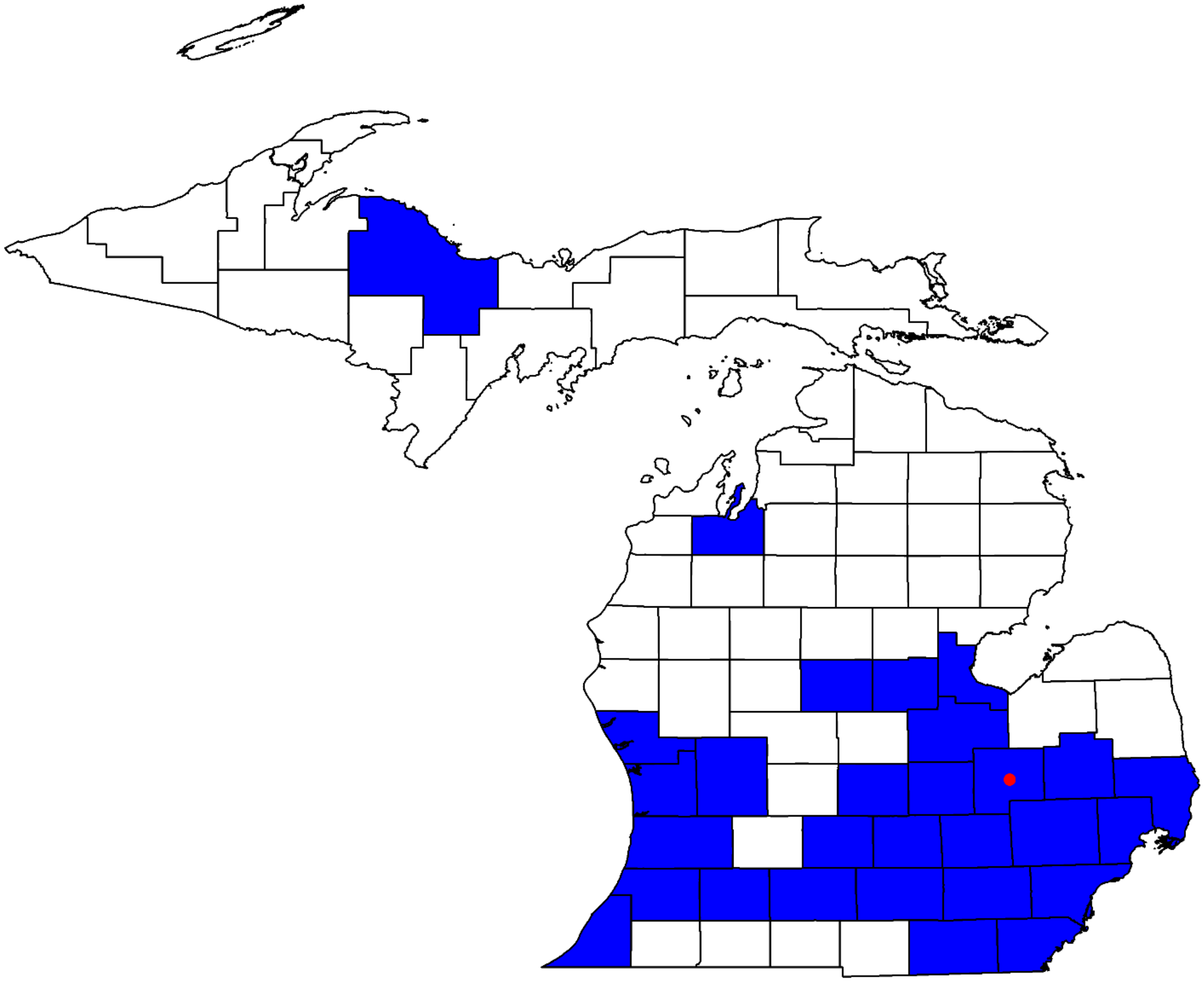
[5] Flint comprises approximately ¼ of the population of Genesee County. For Flint, we calculate the population at the city level, while for other areas we rely on county level population data.

[6] For the remainder of the manuscript we will refer to city/county as "county." With the exception of Flint and the remaining Genesee County excluding Flint, all areas are classified by county.

[7] Our results are robust to using alternative specifications, including the natural log of the count of births and a nonlinear Poisson specification of the county of births. See Appendix Tables A3 and A4, and note that the coefficients are in log points, which for this range are approximately numerically the same as percentage points.

[8] 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. Our analysis is robust though to include all counties and annual population estimates from SEER (see Appendix Table A5). See Appendix Tables A6 and A7, which are parallel in using every county-conception month-conception year

Figure 1: Comparison Counties



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

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 include county fixed effects, α_c, to control for time-invariant characteristics of the county. δ_t is a vector of month and year fixed effects. County and time fixed effects subsume the main effects of living in Flint and

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that has a live birth (as we cannot take the log of zero). We also repeat the Poisson specification including county-month-years with zero births (see Appendix Table A8) and the results are consistent.

being in utero during the new water regime, respectively. ε is an idiosyncratic error term, clustered at the county level to allow for serial correlation.[9]

For birth outcomes, we estimate the following model:

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

where i indexes the individual, c the county, 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 county 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

[9] We calculate standard errors using a wild bootstrap method (Cameron, Gelbach, and Miller 2008) and find similar inference results.

for a municipality that was decided by an unelected official, the Emergency Manager, appointed by the state Governor.[10] 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 county 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.

5. 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 October 2013 or later.[11]

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

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[10] 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 2014).

[11] 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.

degree and less likely to have obtained a college degree. While the proportion of mothers who did not receive a high school degree 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 degree and non-Flint mothers were more likely to complete some college or a college degree.

The general fertility rate in Flint was nearly 13 births per 1000 women aged 15-49 higher than in other areas. However, in an unadjusted depiction of our main results, GFR decreased by 5.5 births per 1000 among Flint mothers and remained largely unchanged in other areas of Michigan. Babies born in Flint were nearly 200 grams lighter than in other areas, were born ½ a week earlier and gained 4 grams per week less than babies in other areas. The unadjusted difference-in-differences for these variables was a decrease of 25 grams, 0.12 weeks of gestational age and 0.47 grams per week in growth rate.

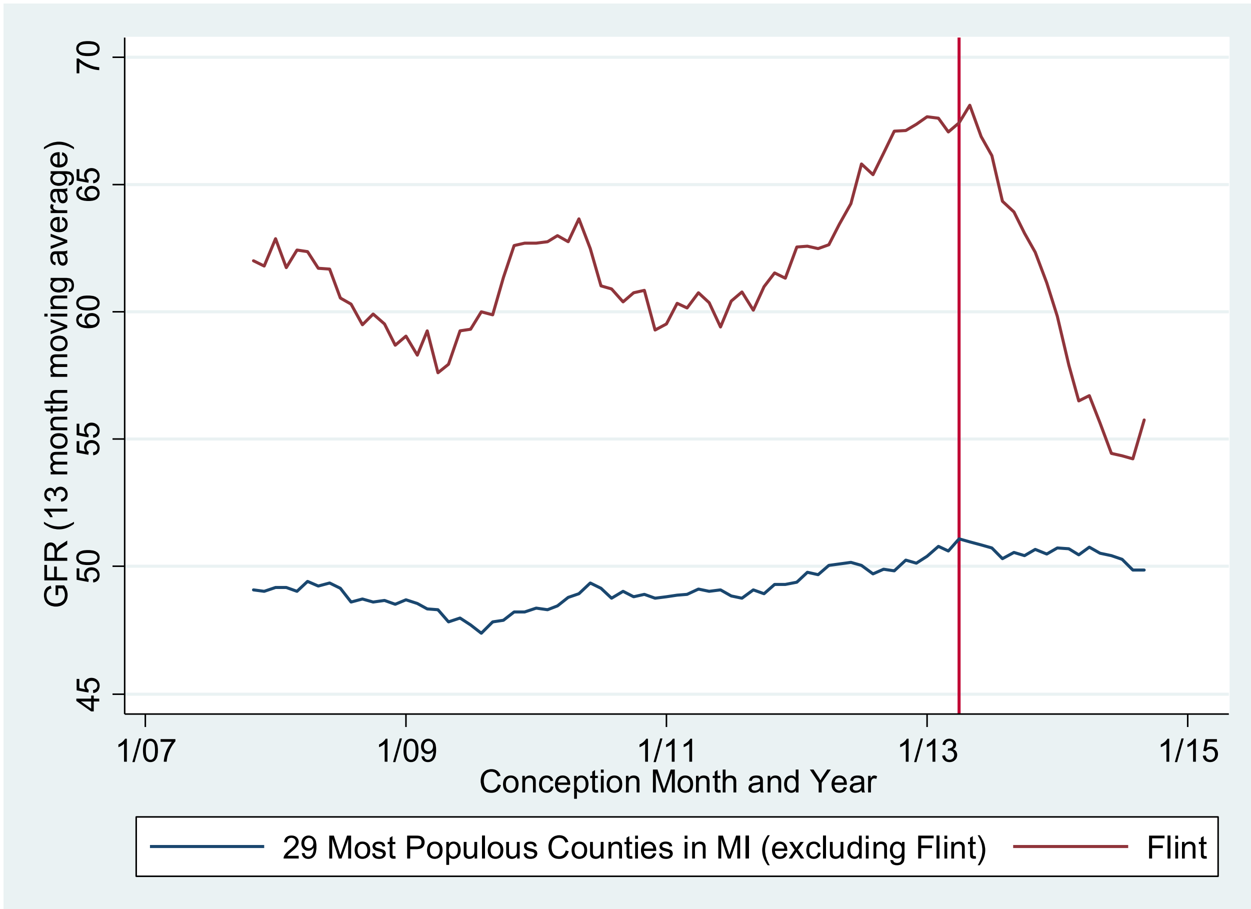
Table 1: Summary Statistics

	(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
Male	0.488	0.488	0.488	0.499	0.01
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***
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
Male-Female Sex Ratio (% male)	51.21 (0.50)	51.19 (0.63)	51.05 (4.59)	50.20 (3.06)	0.82**

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

5.2. Fertility Results

Figure 2: Moving Average Fertility Rate Over Time in Flint and Comparison Counties



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 2 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. 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 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)	-6.215*** (0.329)	-6.215*** (0.330)	-6.215*** (0.330)	-6.121*** (1.931)	-6.121*** (1.653)	-6.085*** (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. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2 presents regression results for GFR by county.[12] The main coefficient of interest is β_1, the parameter of $Water_{ct}$ calculated using equation 1 above. The unit of observation is county-month. Column 1 does not include any covariates. We estimate that women living in Flint following the water change gave birth to 6 fewer infants per 1000 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 10 percent decrease in births in Flint. In Column 2 we include conception month fixed effects and conception year fixed effects and in

[12] GFR for Flint is calculated separately and Genesee County results do not include Flint.

Column 3 we additionally include county 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.

We present results from a placebo test in Table 3 (following Slusky 2015). First, in column (1) we shorten our study period to include only 2 years before and after the water change. This is so that we can run placebo tests earlier in time using the same number of years. Results from this specification are actually even stronger than those using the full study period as GFR decreased by nearly 8 births per 1000 in Flint compared to the rest of Michigan following the water change. Column 2 limits the sample to years 2010-2012 as the pre period and 2012-2014 as the post period. This specification includes a "treated" sample composed of births partially captured under the new water regime and our results thus show a much weaker effect. Columns 3-5 include only pre-treatment years and each demonstrate no effect of the placebo treatment. These results provide additional support that the decrease in GFR in Flint can be attributed to change in water supply.

Table 3: Placebo Results for General Fertility Rate

	(1)	(2)	(3)	(4)	(5)
Control Years	2011-2013	2010-2012	2009-2011	2008-2010	2007-2009
Treated Years	2013-2015	2012-2014	2011-2013	2010-2012	2009-2011
Water (β_1)	-7.859***	3.706*	1.772	-1.456	1.586
	(1.891)	(2.001)	(1.999)	(2.097)	(2.177)
Observations	94	94	94	94	94
R-squared	0.807	0.836	0.790	0.729	0.766

Notes: All regressions using conception year and conception month#Flint. Robust standard errors clustered at the county level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5.3. 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 the 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 4.[13] Abnormal conditions decrease by 1.9 percentage points (10 percent) in Flint compared to the rest of Michigan after the switch to Flint River water. This result is statistically significant at the 10 percent level. 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.

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

Table 4: Lead in Water on Abnormal Conditions

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-0.0188* (0.00962)	-0.0173* (0.00962)	-0.0175* (0.00958)	-0.0174* (0.00958)	-0.0187* (0.00959)
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
Observations	900,999	900,999	900,999	900,999	900,999
Number of Census Tracts	3,279	3,279	3,279	3,279	3,279
R-squared	0.001	0.000	0.001	0.001	0.002
Mean	0.185	0.185	0.185	0.185	0.185

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

In Table 5, we estimate the effect of the water change on birth weight, measured in grams. Being exposed to Flint River water leads to a 25 gram decrease in birth weight. The effect size fluctuates between 20 and 30 grams when we add fixed effects and additional covariates. However, in our most satiated model, the estimate is not statistically significant at conventional levels.

Table 5: **Lead in Water on Birthweight (grams)**

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-24.89*	-30.89**	-29.05**	-27.88*	-19.90
	(13.37)	(14.41)	(14.26)	(14.57)	(14.48)
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
Observations	911,456	911,456	911,456	911,456	911,456
Number of Census Tracts	3,280	3,280	3,280	3,280	3,280
R-squared	0.002	0.000	0.001	0.010	0.026
Mean (grams)	3082	3082	3082	3082	3082

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

We provide estimates of the effect of the water change on estimated weeks of gestation in Table 6. These estimates 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 result is statistically significant and robust across specifications; however, whether it is economically significant is questionable. This amounts to a reduction of less than 1 day in utero.

Table 6: Lead in Water on Estimated Gestational Age (weeks)

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-0.112*	-0.132**	-0.112*	-0.112*	-0.0984*
	(0.0581)	(0.0608)	(0.0592)	(0.0590)	(0.0593)
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
Observations	911,456	911,456	911,456	911,456	911,456
Number of Census Tracts	3,280	3,280	3,280	3,280	3,280
R-squared	0.001	0.000	0.051	0.052	0.056
Mean (weeks)	38.58	38.58	38.58	38.58	38.58

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

In Table 7, we compare growth rate in utero for Flint and the rest of Michigan. 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 0.5 grams per week less. This result is not particularly robust to our additional specifications.

Table 7: Lead in Water on Gestational Growth (grams/week)

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-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
Observations	911,456	911,456	911,456	911,456	911,456
Number of Census Tracts	3,280	3,280	3,280	3,280	3,280
R-squared	0.001	0.000	0.002	0.015	0.032
Mean (grams/week)	84.71	84.71	84.71	84.71	84.71

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

In Table 8, we use fetal death data, and repeat our analysis for the fetal death rate. Fetal deaths are reported by hospitals and are comprised of pregnancies lasting more than 20 weeks that do not result in a live birth.[14] Deaths are calculated analogously to the fertility rate, i.e., divided by the number of women 15-49 in the associated geography area. They are assigned to a conception month using the available information on gestational age.

[14] 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 8: Fetal Death

	(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

The results show that fetal death did increase in Flint after the water source was switched, as compared to the rest of Michigan. Fetal death rates increased by 0.1 per 1000 women aged 15-49 in Flint in Column 3. This is a more than 50% 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. Still, the point estimates are all positive and of a comparable, though slightly larger, magnitude.

Table 9: Fatal Death Added Back to Live Births

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-6.106*** (0.331)	-6.106*** (0.332)	-6.106*** (0.332)	-5.962*** (1.910)	-5.962*** (1.630)	-5.899*** (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

Adding fetal deaths to our live birth numerator, we calculate live births and fetal deaths per 1000 women aged 15 to 49 in Table 9. Our results are comparable to those of Table 2 (only live births) but the effect is about 3% smaller,[15] 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 driving the decrease in the birth rate.

One possible concern with lower conception rates having a role is that they are result in behavioral changes (i.e., less sex) and not the physiological impacts of lead. Following Barreca, Deschenes, and Guldi (2015) 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".[16] Table

[15] 1-(-5.899/-6.085) = 3%.

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

10 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 population of Genesee County. Appendix Table 2 provides our main results treating all of Genesee County as treated.

Table 10: Time Use Data on Sex

	(1)	(2)	(3)	(4)	(5)	(6)
	County-level			CBSA-level		
Water (β_1)	0.0148***	0.0158***	0.0157***	0.0186***	0.0206***	0.0205***
	(0.00203)	(0.00133)	(0.00131)	(0.00229)	(0.00319)	(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 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. So from this we are not concerned that a reduction in the conception rate is driven by a reduction in sexual activity.[17]

Finally, in Table 11, we examine how the sex ratio of live births changed in Flint, given

[17] As an extension of the CPS, the ATUS lacks city identifiers and only has county or CBSA ones. In Appendix Table A9, we repeat our results are the county level and show that while the inclusion of the rest of Genesee County (where Flint is) as treated reduces the magnitude of our results, they are still directional consistent and statistically significant in some specifications.

the medical literature that male fetuses are more susceptible to fetal insults (Trivers and Willard 1973, Sanders and Stoecker (2015).

Table 11: Sex Ratios

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.0067** (0.00285)	-0.0067** (0.00286)	-0.0067** (0.00286)	-0.0083 (0.00910)	-0.0083 (0.00898)	-0.0119 (0.00965)
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	0.001	0.005	0.005	0.008	0.096	0.156
Mean	0.510	0.510	0.510	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

We find that sex ratios decrease by 0.7 percentage points, which is about a 1.3% decrease.

5.4. 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 A1 and Appendix Figure A1 we compare GFR in Flint to the 15 largest other cities in Michigan. We find slightly larger decreases in fertility rates of between 7 and 8 births per thousand women 15-49 in Flint compared to these other cities. Appendix Table A2 omits the cities with the highest and lowest GFR in the sample and compares 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 Tables A3 we estimate the effect of the water change on log births. We find a 12 percent decrease in Flint following the water change, which is comparable to our 10 percent result in Table 2. In Appendix Table A4 we estimate a poisson model and find a decrease in births of 0.13, which can be interpreted as similar to a 13 percent decrease in births in Flint.

In Appendix Table A5 we compare GFR in Flint to all counties in Michigan. Our results are robust to the inclusion of more counties and are even a little larger. Appendix Tables A6 and A7 estimate similar models to Appendix Tables A3 and A4 but include all counties. The results are quite robust to the inclusion of these additional, smaller counties. In Appendix Table A8, we estimate a Poisson model including any county-months with zero births and find nearly identical effects.[18]

We compare county level GFR rates in Appendix Table A9. 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 A10, 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. Again, our results are robust to this specification and the magnitudes slightly larger.

Lastly, we perform an analysis of fertility rates using a synthetic control methods approach (Abadie, Diamond, and Hainmueller 2010).[19] This method creates a weighted matched control

[18] N=37 for county-months with zero births.
[19] We describe this method in detail in Appendix A.

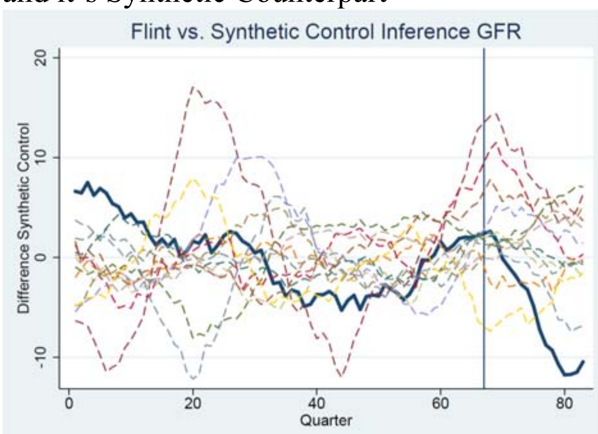
group that more closely resembles the characteristics of Flint in the period before the water change on both level and trend of fertility rates. It also controls for demographic characteristics of mothers in the preperiod. Figure 2 presents the results of this method. Panel A displays GFR trends in Flint 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 affected birth rates are included in the moving average. [20] Panel B shows the difference between city systematically assigned to treatment and the synthetic version of the city for each month. 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.

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

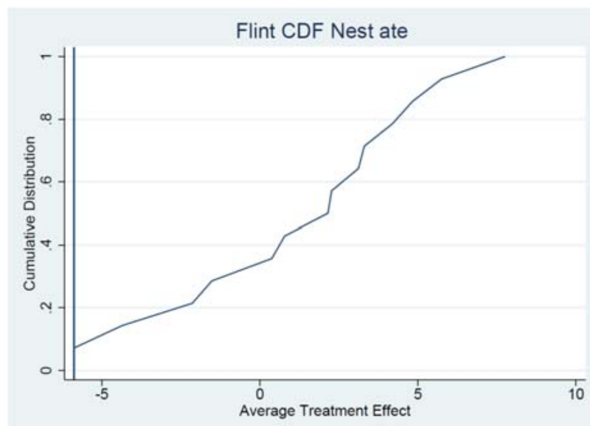
Figure 3. Synthetic Control Results for General Fertility Rates

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

5.5.Discussion

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 approximately 140 more children would have been born had Flint not enacted the switch in water. We consider this strong empirical support for the existence of a culling effect of increased lead in the water.[21] Our results on sex ratios suggest

[21] Using log births instead of GFR provides consistent results, as shown in Appendix Table A3.

that among the live births that occurred in Flint following the change in water supply, an additional 14 female infants were born than expected. 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.

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 and has the mean (3082 g) and standard deviation (632 g) as in column 3 of Table 1. Using the 10% 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 10% of birth weight did not survive.

Using the standard formula for the mean of a trucated normal[22] we calculate that mean birthweight of the surviving newborns, without any scarring, would have been 3205 g. From here to the observed Flint mean birthweight in the post period (3042 g) is a decrease of 163 g. Removing the pre-post difference in the rest of Michigan (from Columns 1 and 2 of Table 1)

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[22] 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.

reduces this by 15 g to a scarring effect of 148 g, which is a 4.6% 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 5. We consider this a bounding exercise for the full effect of scarring had no selective attrition occurred.

Additionally, while the results in Tables 8-11 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. We find no evidence to support a decrease in sexual relations among individuals living in Flint during this time period and an increase in fetal deaths occurring after 20 weeks. These fetal deaths occur in a hospital and are separate from abortions. Additionally, a 0.7 percentage point increase (1.3%) 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 changed their preference for male children and began performing sex-selective abortions showing a preference for *female* children.[23] 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

[23] 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.

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).

6. **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. 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 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 and experienced substantial fetal stress, which could manifest itself later in life (Barker 1992; Barker 1995).

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. 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 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.

To our knowledge this paper presents the first natural experiment from which to study the effect of high concentrations of lead in water on birth outcomes. This is an increasingly non-rare outcome in that many municipalities have reported lead issues in their water over the past several years (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.[24] 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, they are plausibly a better counterfactual

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

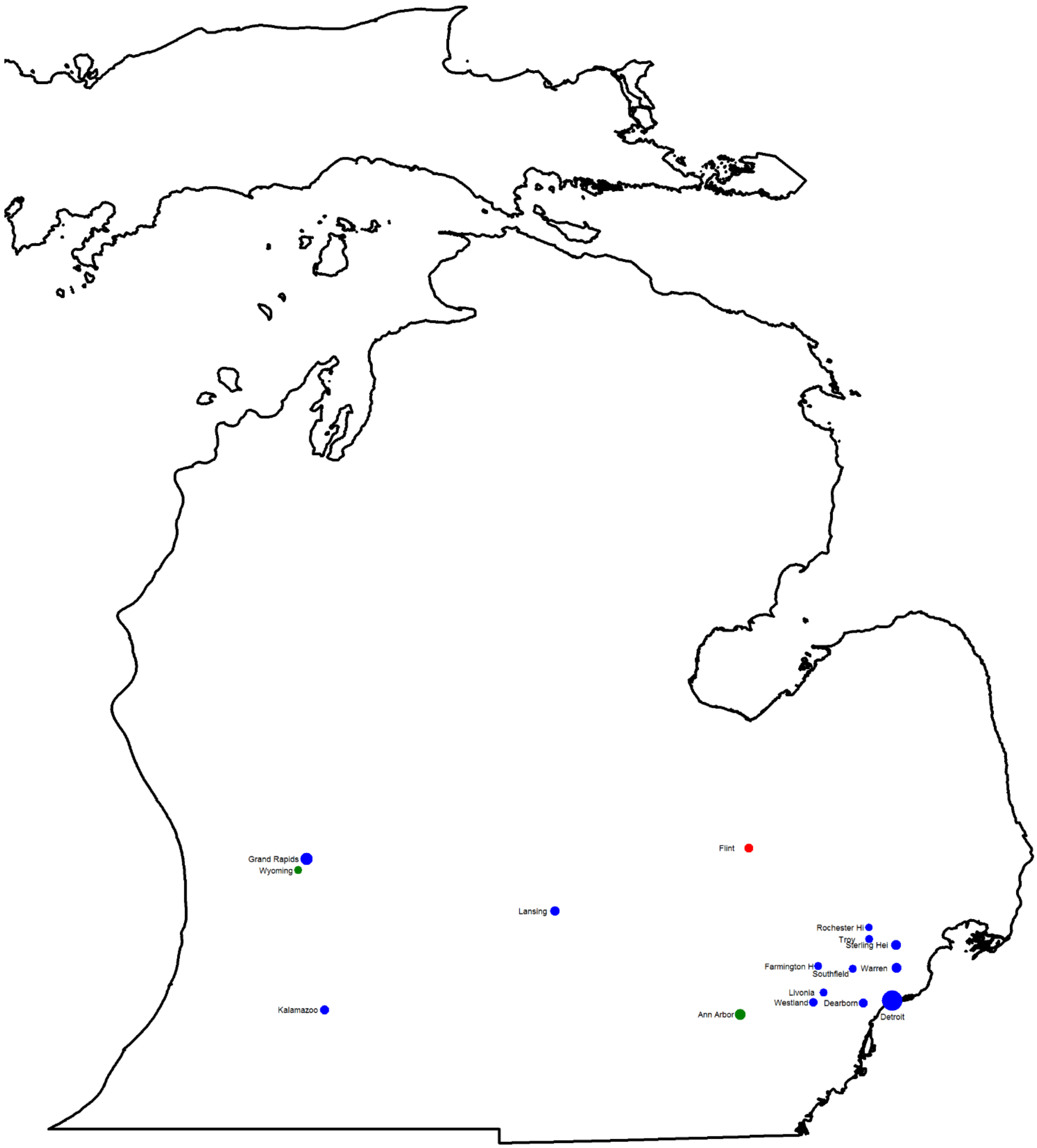
representation of what one would expect to have happened to pregnancy and birth outcomes in Flint had the city never switched its water source.

The 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 are as well as the full pool of control zones, minus the city assigned to treatment. We separately calculate the average treatment effect and the root mean squared prediction error 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% level.[25]

[25] 1/14=0.071

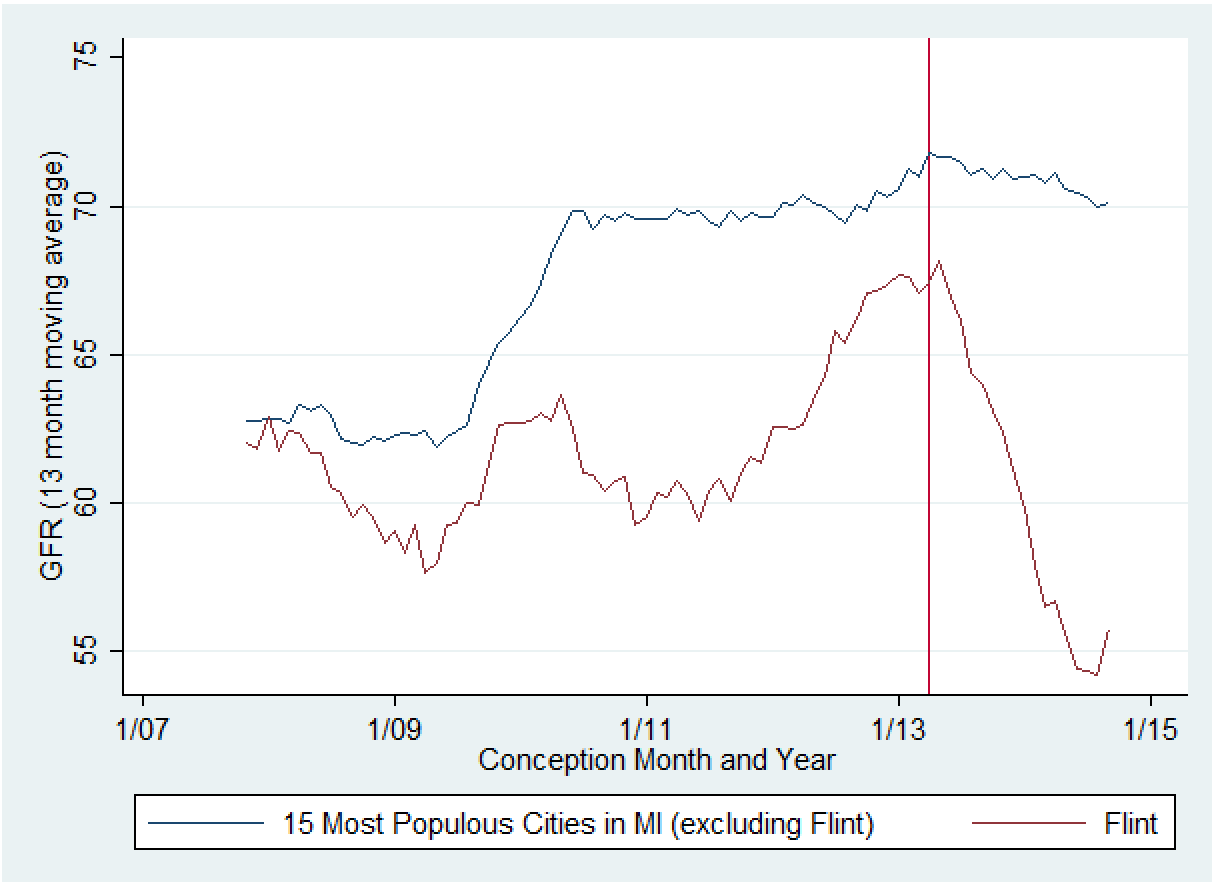
Appendix B: Additional Tables and Figures:

Appendix Figure A1: Comparison Cities



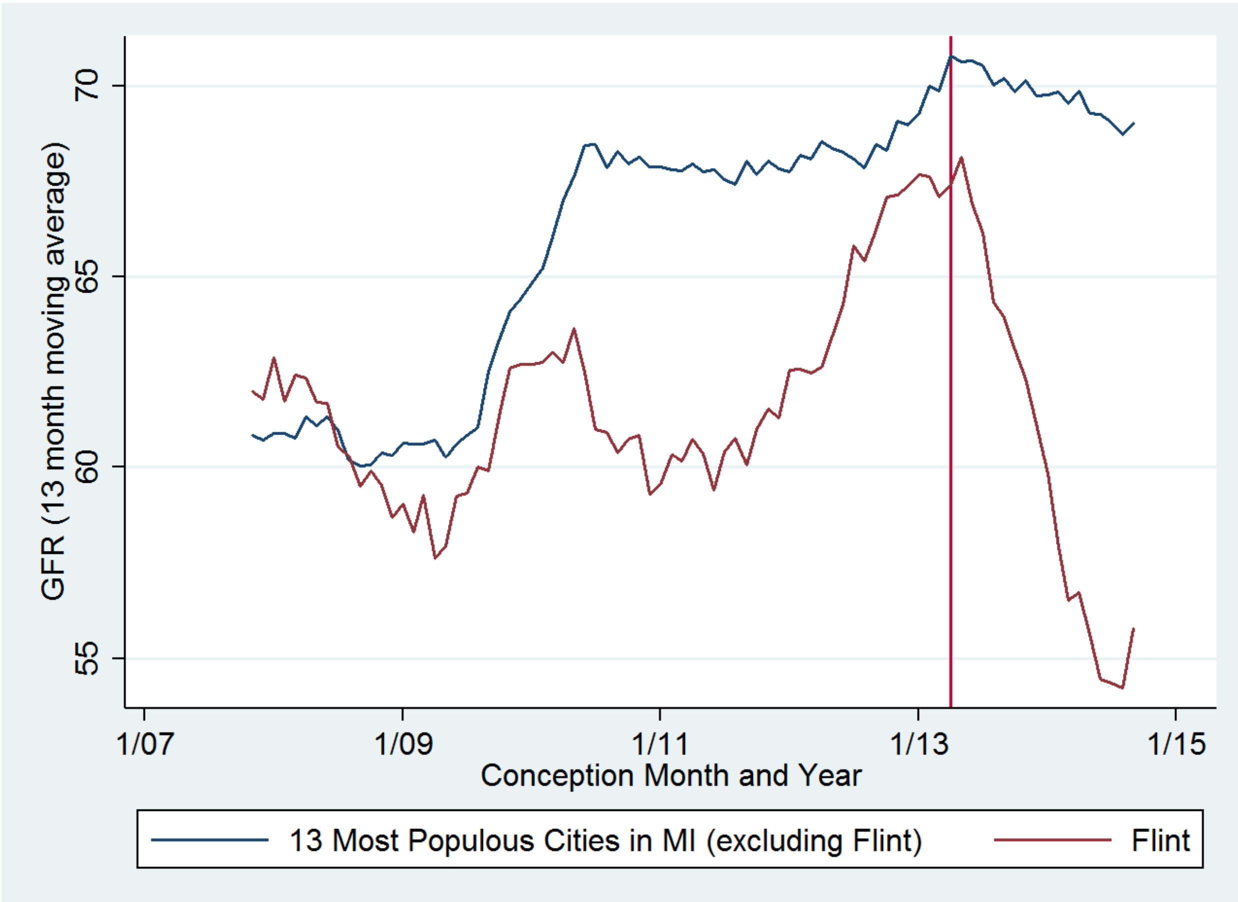
Note: Comparison cities are in blue, Flint in red, and cities with outlier GRF in green. Point size is proportional to the population of women age 15-49 in that city in 2014.

Appendix Figure A2: 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 Figure A3: 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 Table A1: Lead in Water on General Fertility Rate at the City Level

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.451***	-7.451***	-7.451***	-8.450***	-8.450***	-8.467***
	(0.786)	(0.791)	(0.791)	(1.993)	(1.640)	(1.746)
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	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.

Appendix Table A2: 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
County 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 A3: Lead in Water on General Fertility Rate - ln(births)

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.122***	-0.122***	-0.122***	-0.127***	-0.127***	-0.126***
	(0.00705)	(0.00707)	(0.00707)	(0.0295)	(0.0242)	(0.0258)
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	0.002	0.007	0.288	0.998	0.999	0.999

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

Appendix Table A4: Lead in Water on General Fertility Rate - Poisson

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.129***	-0.129***	-0.129***	-0.129***	-0.129***	-0.128***
	(0.00631)	(0.00631)	(0.00631)	(0.0295)	(0.0242)	(0.0246)
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	0.00938	0.0117	0.976	0.995	0.998	0.998

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

Appendix Table A5: Lead in Water on General Fertility Rate – All Counties

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.097***	-7.093***	-7.070***	-6.043***	-6.043***	-6.018***
	(0.385)	(0.389)	(0.394)	(1.935)	(1.801)	(1.732)
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	7,943	7,943	7,943	190	190	190
Counties & Flint	84	84	84	84	84	84
R-squared	0.013	0.069	0.079	0.580	0.822	0.722
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. Annual population for all counties for the denominator of GFR is from SEER.

Appendix Table A6: Lead in Water on General Fertility Rate - ln(births) – All Counties

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.121***	-0.121***	-0.122***	-0.127***	-0.127***	-0.126***
	(0.00881)	(0.00885)	(0.00800)	(0.0297)	(0.0243)	(0.0258)
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	7,943	7,943	7,943	190	190	190
Counties & Flint	84	84	84	84	84	84
R-squared	0.009	0.012	0.060	0.998	0.999	0.999

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

Appendix Table A7: Lead in Water on General Fertility Rate – Poisson (All Counties)

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.129***	-0.129***	-0.129***	-0.129***	-0.129***	-0.128***
	(0.00566)	(0.00567)	(0.00550)	(0.0296)	(0.0243)	(0.0246)
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	7,943	7,943	7,943	190	190	190
Counties & Flint	84	84	84	84	84	84
R-squared	0.000173	0.00150	0.975	0.996	0.998	0.998

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

Appendix Table A8: Lead in Water on General Fertility Rate – Poisson (All Counties, Years, and Months)

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-0.129***	-0.129***	-0.129***	-0.129***	-0.129***	-0.128***
	(0.00550)	(0.00550)	(0.00550)	(0.0296)	(0.0243)	(0.0246)
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	7,980	7,980	7,980	190	190	190
Counties & Flint	84	84	84	84	84	84
R-squared	0.000181	0.00151	0.975	0.996	0.998	0.998

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

Appendix Table A9: Lead in Water on General Fertility Rate at the County Level

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-1.360*** (0.341)	-1.360*** (0.342)	-1.360*** (0.342)	-1.261 (1.086)	-1.261* (0.725)	-1.004 (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

Appendix Table A10: Lead in Water on General Fertility Rate – Through September 2014

	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.781***	-7.781***	-7.781***	-7.467***	-7.467***	-7.833***
	(0.360)	(0.366)	(0.366)	(2.387)	(1.944)	(1.903)
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	2,670	2,670	2,670	178	178	178
Counties & Flint	30	30	30	30	30	30
R-squared	0.092	0.201	0.270	0.596	0.836	0.745
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. GFR through September 2014 removes births conceived post September 2014, when residents began to learn about potential water problems in Flint.