The Impact of the Flint Water Crisis on Fertility

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Abstract

Flint switched its public water source in April 2014, increasing exposure to lead and other contaminants. We compare the change in the fertility rate and in health at birth in Flint before and after the water switch to the changes in other cities in Michigan. We find Flint fertility rates decreased by 12%, and overall health at birth decreased. This effect on health at birth is a function of two countervailing mechanisms: negative selection of less healthy embryos and fetuses not surviving (raising the average health of survivors) and those that survived being scarred (decreasing average health). We untangle this and find a net of selection scarring effect of 5.4% decrease in birth weight. Due to long-term effects of in utero exposure, these effects are likely lower bounds on the overall effects of this exposure.

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

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1. Introduction

Overwhelming evidence shows 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). Despite this, reports suggest that current EPA plans to test for chemical pollutants including lead are lacking (Davis 2017; Brackton 2018; Hall 2019).

Lead also may affect health through indirect channels by decreasing the latent health of those infants carried to term. Latent health is difficult to measure and may not manifest until much later in life, as demonstrated interdisciplinarily in the literatures of epidemiology (Barker 1995), biology (Schultz 2010), and economics (Almond and Currie 2011). As such, exposure to lead in utero and in infancy may represent only a lower bound on the overall effect of lead on health and human capital development.

We study the effect of the corrosive water sourced from the Flint River, which leached lead from the pipes into the water supply, on fertility and birth outcomes. It is important to note that, during the period when water was sourced from the Flint River, government officials continually reassured residents that the water was safe. Officials did not issue a lead advisory until September 2015 (Fonger 2015a). This reduced the scope of an avoidance behavioral response to the crisis (Neidell 2009).

High blood lead content is associated with cardiovascular problems, high blood pressure, and developmental impairment affecting sexual maturity and the nervous system (ATSDR 2007; Zhu et al. 2010). Maternal lead exposure is linked to fetal death, prenatal growth abnormalities, reduced gestational period and birth weight (Zhu et al. 2010; Edwards 2014; Taylor, Golding, and Emond 2014; Wang, Chen, and Li 2019), and increased infant mortality rates (Troesken

2006a; Troesken 2008; Clay, Troesken, and Haines 2014). Maternal lead crosses the placenta, poisoning the fetus (Taylor, Golding, and Emond 2014; Lin et al. 1998). Lead exposure also decreases sperm count and male fecundity (Paul 1860; Vigeh et al. 2011).

The Flint water supply also contained higher rates of trihalomethanes, which can be detrimental to pregnant women (Gallagher et al. 1998; Nieuwenheijsen et al. 2000; Cao et al. 2016), although others dispute this (e.g. Yang et al. 2007; Horton et al. 2011). The water switch likely also caused a Legionnaires' disease outbreak that killed at least 12 individuals (Rhoads et al. 2017). Unfortunately, we cannot separately identify the effects of these contaminants. However, we focus on lead for two reasons. First, because of the large literature linking lead to poor pregnancy outcomes and the specific results from Flint showing elevated lead levels (Hanna-Attisha et al. 2016). Second, early efforts to treat bacterial contaminants (with chlorine disinfectants) and trihalomethane byproducts (with ferric chloride) had the unfortunate consequence of increasing the corrosiveness of the water and the potential level of lead poisoning (Torrice 2016; Masten et al. 2016).

Only the city of Flint switched its water source at this time, while the rest of Michigan did not. These other areas in Michigan provide a natural control group for Flint as they are economically similar and otherwise followed similar trends in fertility and birth outcomes over this time period. Nevertheless, we also compare Flint to cities across the US.

Using all live births in Michigan from 2008-2015, we estimate the effect of a switch in the water supply on fertility and health. Following the switch, the general fertility rate (GFR) in Flint decreased by 7.5 live births per 1,000 women aged 15-49 (12%). Because the higher lead content of the new water supply was unknown at the time, this decrease in GFR likely reflects increased fetal death and miscarriage and not behavior changes related to conception such as contraceptive use or reduced sexual activity. Additionally, the ratio of male to female live births decreases by 0.9 percentage points in Flint compared to surrounding areas.

Because of the large decrease in fertility, selection into birth is a major concern for our birth outcome results. We therefore perform a bounding exercise which provides an upward bound on the birth weight effect caused by the water switch (Bozzoli, Deaton, and Quintana-Domeque 2009). Accounting for selection, we find a 5% decrease in birth weight.

This estimate of the selection-scarring effect of in utero exposure to a contaminated water source is a contribution to both the fetal origin literature and the health effects of lead literature. Furthermore, our paper contributes to a growing interdisciplinary literature on the consequences of the Flint water switch. Others show increased child lead levels (Hanna-Attisha et al. 2016; Zahran et al. 2017), diminished test scores (Sauve-Syed 2017), increased bottled water purchases (Christensen, Keiser, and Lade 2017), and worse health at birth (Abouk and Adams 2018; Wang, Chen, and Li 2019). Unfortunately, we know of no published studies on lead levels in adults in Flint. However, one study finds statistically significantly higher blood lead concentrations in dogs in Flint after the water switch compared to dogs elsewhere, with several dogs having levels higher than 20 parts per billion (Langlois et al. 2017).[1]

Our paper contributes to the literatures of economics, health, and epidemiology. We are the first to investigate the impact of the Flint water switch on fertility rates. We use multiple control groups, including cities across the US, other cities in Michigan, and areas directly proximate to Flint. We also use standard methods, including difference-in-differences, synthetic

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[1] There are anecdotal references in news reports suggesting adult data is largely nonexistent. For example: “We know the effects become more profound as your blood-lead concentration increases, but in Flint, relatively few adults were ever tested for exposure, says Michael Kosnett, a professor of pharmacology and toxicology at the University of Colorado School of Medicine.” (Patterson, 2016).

control, and brand new methods (imperfect synthetic control). Additionally, the amount of lead in the water from the water switch was relatively small compared to historical contexts (Clay, Haines and Troesken 2014) making our estimates particularly informative. No amount of lead in the water is considered safe (NTP 2012).

More broadly, as fresh water sources become more scarce and aquifers dry up, other local governments will be faced with the difficult decision to switch water sources. Our paper focuses on the demographic and health consequences of a water switch in the context of crumbling infrastructure and the fiscal decisions of unelected leaders. It provides important information about the potential unintended consequences of these decisions.

2. Background on Flint[2]

Flint, an old manufacturing city, is the birthplace of General Motors (GM) (Scorsone and Bateson 2011). The city has been shedding residents for many years; its contraction followed GM closing several plants in and around Flint.[3]

In 1967, Flint stopped supplying water from the Flint River because of concerns about serving a growing population (Carmody 2016). The city began to receive Lake Huron water via pipeline from the Detroit Water and Sewerage Department (DWSD).

In 2011, based on the city's precarious economic situation, the Governor of Michigan installed an Emergency Manager who would make all fiscal decisions and "rule local government" (Longley 2011). Citizens and elected officials would have little recourse to fight decisions made by the Emergency Manager. Concurrently, DWSD water rates were rising

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[2] Appendix Figure B1 provides a timeline of events around the water switch.

[3] GM employment in Flint decreased from 80,000 in 1978 to 30,000 in the 1990s to under 10,000 today (Scorsone and Bateson 2011).

(Zahran, McElmurry, and Sadler 2017). To cut costs, the Emergency Manager together with other Genesee County officials began to build a pipeline directly to Lake Huron in March 2013 (City of Flint 2015; Walsh 2014). However, the project would take more than two years to complete. In the interim, Flint decided to switch its water source from Lake Huron to the Flint River between April 2014 and the completion of the new pipeline, while Genesee County continued to receive water from DWSD (Carmody 2016).

Flint had to treat the new water source. While they used some of the same products as the DWSD, they did not use anti-corrosive inhibitors such as orthophosphate (Pieper et al. 2017; Olson et al. 2017). 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). In August 2014, 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 advisory was announced for a similar issue. In response to these issues, the city determined to increase chlorine levels in the water (Fonger 2014b). Then in October 2014, GM announced they would switch off of the Flint River as the water source for 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 continued to advise that the water was safe for human consumption. In 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).

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). Concurrently, 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, organized by Mark Edwards began independently testing Flint consumers' water. In August 2015, they reported much higher levels of lead than previously reported, noting that Flint River water was many times more corrosive than the DWSD water (Edwards, Pruden, and Falkinham 2015). Mona Hanna-Attisha, 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 forced the city to issue a lead warning and ultimately to switch back to Lake Huron water on October 16, 2015 (Emery 2015).

3. Literature Review

3.1. Background on Lead

Lead is a naturally occuring heavy metal that is associated with health problems. Human activities, including burning fossil fuels and industrial chemical reactions, cause the majority of lead emission into the environment (ATSDR 2007). The U.S. dramatically decreased the incidence of lead emissions and blood lead levels by banning lead paint in the 1970s and reducing leaded-gasoline throughout the 1980s before banning it in 1996 (CDC 2005, Zhu et al. 2010).

Previous work has investigated the effects of general exposure to lead, lead levels in the blood, lead exposure from a water source, and the mechanisms through which lead and other in utero exposure affects current and future health. Each has implications for our study of Flint.

3.2. General Exposure to Lead

Exposure to lead 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, spontaneous abortion, and reduced birth weight (Borja-Aburto et al. 1999; Hertz-Picciotto 2000; Joffe et al. 2003; Bellinger 2005; Hu et al. 2006; Cleveland et al. 2008; Vigeh et al. 2010; Zhu et al. 2010; Taylor, Golding, and Emond 2014). Clay, Portnykh, and Severnini (2018), using variation in lead exposure from the introduction of the Interstate Highway System and the Clean Air Act, find that exposure to lead in the air resulted in reductions in the birth rate and a worsening of birth outcomes. Additionally, men exposed to lead, including in industrial settings, have lower fecundity (Paul 1860; Hamilton and Hardy 1983; Assennato et al. 1987; Coste et al. 1991; Winder 1993; Alexander et al. 1996; Lin et al. 1996; Bonde and Kolstad 1997; Apostoli, Porru, and Bisanti 1999; Apostoli et al. 2000; Hernberg 2000; Sallmén, Lindbohm, and Nurimnen 2000; Sallmén 2001; Shaiau, Wang, and Chen 2004; Wirth and Mijal 2010; Vigeh et al. 2011; Wu et al. 2012; Eibensteiner 2013). Even moderate blood lead levels reduce female fertility. There is sufficient evidence ("chance, bias, and confounding could be ruled out with reasonable confidence") that blood lead levels <5 μg/dL reduces fetal growth and limited evidence that blood lead levels <10 μg/dL increased spontaneous abortion and preterm birth (NTP 2012).

3.3. Lead Exposure from a Water Source

High lead content in water results in increases in lead content in the blood (Troesken and Beeson 2003; Edwards, Triantafyllidou, and Best 2009; Hanna-Attisha et al. 2016), in turn increasing the risk of the negative health outcomes detailed above. Clay, Troesken, and Haines (2014) find historical evidence of higher rates of fetal deaths in cities with more lead service pipes and more acidic water. Areas with higher water lead levels have higher rates of preeclampsia (Troesken 2006b). Fetal death rates increased and birth rates decreased following the increase of lead in the water in Washington, DC from 2000 to 2003 (Edwards 2014). While our paper is similar to Edwards (2014), we use a substantially larger group of comparison cities. That study compares only Washington, DC to overall U.S. and Baltimore, MD. This makes proper inference difficult due to small clusters in both treatment and control cities (see e.g. Cameron, Gelbach, and Miller 2008).

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. Thus, they cannot rule out that these worse birth outcomes are actually associated with an omitted variable.

Lead increased in the Flint water supply because of improper water treatment. Officials did not treat the Flint River water using corrosion inhibitors. Furthermore, they used 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 amount of lead leached from the pipes (Pieper, Tang, and Edwards 2017; Olson et al. 2017). Lead, galvanized, and unknown service line connections all potential leach lead into the water source and each accounted for approximately 7%, 21% and 27% of all connections in Flint (UM-Flint GIS Center 2017; Clark et al. 2015).

3.4. Other Outcomes from Lead Exposure

Previous studies have found that increases in lead levels have an adverse effect on later life cognitive function (Hernberg 2000; Ferrie, Rolf, and Troesken 2012; Reuben et al. 2017), mental health and criminality (Reyes 2007; 2015), educational outcomes (Aizer et al. 2018), and school suspensions (Aizer and Currie 2018; Billings and Schnepel 2018). However, Billings and Schnepel (2018) and Gazze (2016) find that lead remediation can moderate the negative effects of those exposed to lead and reduce blood lead levels. This finding underscores the importance of lead testing and access to information and healthcare.

3.5. Mechanisms Through Which Lead Affects Health

This study contributes to the large literature on fetal origins hypothesis, where in utero shocks may affect health. The sign of the effect of these shocks is ambiguous due to two countervailing mechanisms (Almond 2006).

First, fetal insults may lead to "selective attrition," or the culling of weaker fetuses through miscarriage or fetal death (Edwards 2014; Clay, Troesken, and Haines 2014; Almond 2006). Thus, the less healthy fetuses would not be born, leaving only the healthier fetuses; this has a potentially positive effect on population health. Additionally, higher rates of lead may shift the overall health distribution of infants affected in utero towards being more unhealthy, leading to worse health outcomes. The two effects (selection and scarring) could even approximately cancel each other out for surivors (Bozzoli, Deaton, and Quintana-Domeque 2009).[4] Behavioral selection into pregnancy may occur if women decide not to get pregnant because of concerns about their future children's health. Dehejia and Lleras-Muney (2004) document non-random selection into pregnancy in response to changing labor market conditions. Clay, Portnykh, and Severnini (2018) 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

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[4] In the Great Chinese Famine, taller children were more likely to survive but were stunted, resulting in minimal height change but taller, unscarred grandchildren (Gørgens, Meng, and Vaithianathan 2012).

following the switch, they did not know about the lead content in the water until nearly the end of the Flint River water regime.[5]

4. Data

We use vital statistics data for the state of Michigan from 2008-2015. These data contain detailed information on every birth in the state. This includes health at birth and background information on the mother and father such as race, ethnicity, education, marital status, as well as prenatal care during pregnancy. We calculate the date of conception for a woman from the clinical gestational estimate and exact date of birth. We define Flint per the census tract-level (UM-Flint GIS Center 2017) data on lead pipes, and then use HUD census tract to ZIP code matching[6] and SAS ZIP code to city matching[7] for the 15 largest non-Flint cities (Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming). As a robustness check, we also use National Vital Statistics data from 2008-2015 with a marker for the city of residence. These data provide 220 additional comparison cities.

Using population data from the American Community Survey[8], we calculate general fertility rate (GFR) as:

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

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[5] See Appendix Figure B2.

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

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

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

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.[9] We multiply by 12 to make this an annual measure. We also estimate our models by conception quarter in Appendix Tables B8 and B11.

5. Methods

To assess the relationship between water source and fertility outcomes, we use a difference-in-differences model, comparing areas that received the new source to areas that did not switch their water source but were trending similarly in the pre-period:

$$Outcome_{ct} = a + \beta_1 Water_{ct} + \alpha_c + \delta_t + \varepsilon_{ct} \tag{2}$$

c indexes the city, and t the month and year. We chose the 15 most populous cities in Michigan (excluding Flint) as comparison cities, as shown in the map in Figure 1. *Outcome* includes measures of *GFR* and male to female sex ratio (sex ratio). *Water* is a binary variable indicating whether the date of conception of the child occurred after the water supply switched and whether the mother lived in Flint. We define being in utero during the new water regime as a birth conceived November 2013 or later, which would mean at least one trimester was affected by the water switch.[10] 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. We also investigate models using subsets of the data based on race and age of mothers.

For birth outcomes, we estimate the following model:

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

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[9] Our sample covers 95 conception months: May 2007-March 2015, corresponding to January 2008-December 2015 birth data.

[10] Our results are robust to varying the treatment date (see Appendix Figure B3).

where i indexes the individual, c the city, and t the month. *Birthoutcome* includes a continuous variable for birth weight, a binary variable for low birth weight, estimated time of gestation in weeks, or fetal growth rate, defined as the birth weight divided by weeks in gestation. *Water* is defined as above. X_{ict} is a vector of variables capturing individual level socioeconomic characteristics of the mother and child including child gender and maternal ethnicity, marital status, and educational attainment. We include census tract fixed effects, γ_{cen}, to control for time-invariant characteristics of the 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.

A strength of our study is that it exploits a natural experiment in the exposure of women to contaminants, including lead, caused by an exogenous switch in the water supply. Because policy shifts may occur in response to local conditions that were already changing, or other additional factors unobservable to the econometrician, there is a risk of policy endogeneity. However, an EPA memo citing lead concerns was leaked to the public only in July 2015, and not confirmed by other researchers until September 2015 (Robbins 2016).

6. Results

Table 1 presents summary statistics. Columns (1) and (2) present means of births to individuals who did not reside in Flint before and after the water switch, respectively. Descriptive statistics for mothers who lived in Flint at the time of birth before the water switch are presented in Column (3) while results for Flint mothers who gave birth after the water switch are presented in Column (4).

Mothers who gave birth outside of Flint were older 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. 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 switch. In addition, 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 GFR in Flint was lower by 8.5 births per 1000 women aged 15-49 in Flint following the water switch compared to control areas. The sex ratio of babies born in Flint skewed more female following the water switch, a decrease in males of 0.74 percentage points. Babies born in Flint were nearly 150 grams lighter than in other areas, were born one-half of a week earlier and gained 5 grams per week of gestation less than babies in other areas in the pre-period. The unadjusted difference-in-differences for these variables was a decrease of 15 grams at birth, 0.12 weeks of gestational age and 0.27 grams per gestational week in growth rate.

6.1.Fertility Results

In Figure 2 we present trends in GFR for Flint and the rest of Michigan separately. We present unadjusted fertility rates.[11] While births in Flint are 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 November 2013, and the decrease persisting through the beginning of 2015. Flint switched its water source in April 2014, so these births would have been exposed to this new water for at least one trimester in utero. Other cities in Michigan had similarly seasonally volatile GFR trends, but did not display large decreases in GFR following the Flint water switch.

Table 2 presents regression results for GFR by city. The main coefficient of interest is

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[11] We calculated a 13 month moving average (+/- 6 months) to remove seasonality and idiosyncratic noise (see Appendix Figure B4).

β_1, the parameter of $Water_{ct}$ calculated using equation (2). The unit of observation is city-month. We estimate that women living in Flint following the water switch gave birth to 7.5 fewer infants per 1,000 women aged 15-49 compared to control cities. These results are statistically significant at the 0.001 (0.1%) level. On a base of 62 births per 1000 women aged 15-49 this signifies a 12.0% decrease. In Column 2 we include a more flexible measure of fixed effects by interacting month into year. Estimates are nearly identical. We adjust our standard errors using the wild bootstrap method (Cameron, Gelbach, and Miller 2008) because we only have one treated cluster and find consistent inference results. We include city-specific linear time trends in Column 3, and the results are statistically significant, but we do not consider them our main results because of concerns about potentially-biased treatment group-specific time trends (Wolfers 2006, Lindo and Packham 2017).[12,13]

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[12] We tested for statistically significant differences in pre-trends by dropping the treated months for Flint and then regressing GFR on a linear time trend interacted with the Flint dummy, as well as city and month-year fixed effects. We find a monthly pre-trend difference of -0.0385 (0.0180)**.

However, we are not concerned with this difference for three reasons. First, the magnitude is small. Suppose that this pre-trend continued after the water switch and was driving our results. With 95 months of data (78 pre and 17 post), at the end of the pre-period the Flint GFR would be 78*-0.0385 =-3.00 lower than the cities', and so the average pre-period difference would be -1.50. At the end of the post-period, Flint would have grown to -3.66 (95 *-0.0385), resulting in a post-period difference in averages of -3.33. A difference in difference analysis would therefore give a result of -1.83. But this would only explain 24.5% of our main result (-7.451). So nonparallel trends explain less than a quarter of our variation. Furthermore, removing this -1.83 from our estimate in Column (2) gives -5.62, which is almost exactly the result in Column (3) that controls for city-specific linear time trends.

Second, this pre-trend difference has a p-value of 0.49, whereas our main result has a t-stat of -9.19. So our main results are much more precisely estimated.

Finally, below we find consistent results when applying both the synthetic control method and the imperfect synthetic control method, both of which by design better match pre-trends between the treatment and control cities.

We also 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). 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) find that birth ratios skew more male following the implementation of the Clean Air 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. In light of the concerns of biased treatment group-specific time trends (Wolfers 2006, Lindo and Packham 2017), we are not concerned by the results in Column 6 being smaller in magnitude.

In Table 3, we limit our sample to demographic subgroups. We use demographic characteristics of mothers because this is more accurately measured and available for nearly all births. These results are from Poisson regressions because we do not have good measures of population by subgroup. For the full sample, we find a decrease in births of 0.15, which can be interpreted as similar to a 15% decrease in births in Flint. This decrease drops to 5% including city-specific linear time trends. Results by age show a similar pattern for all age groups, although these results differ when including a city-specific linear time trend, especially for older mothers. Decreases in births are also apparent for both white and black mothers. We find our results are driven by decreases in sex ratio among mothers aged 25-49 and white mothers. Results for black mothers show an oppositely signed, statistically significant estimate.

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[13] We sought administrative records on fetal deaths from the state of Michigan. Unfortunately, the state sent us two different data files which show different results, and so we are unable to report whether the fetal death rate increased or decreased. However, using the data set that gives the largest increase in the fetal death rate only explains 2% of the decrease in the fertility rate.

6.2. Birth Outcomes

Next, we turn our focus to birth outcomes. If increased lead in the water supply has only 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 switch in water supply caused a change in birth weight in Table 4.[14] We cluster standard errors in these regressions at the census tract level. We find negative results for birth weight; however, they are imprecisely measured. Adding census tract, month and year of conception fixed effects and additional covariates in Columns 2-5 does not substantially change the coefficient.

Results for low birth weight, gestational age and gestational growth rate all indicate worse health, but no finding was statistically significant. The magnitudes on the coefficients are all small, with the exception of low birth weight, suggesting non-economically meaningful effect sizes.[15]

6.3. Behavioral Changes

Behavioral changes, rather than the physiological impacts of lead, could be driving our results. Following Barreca, Deschenes, and Guldi (2018), in Table 5 we use the American Time Use Survey to investigate time spent engaged in sexual relations, proxied by any time spent in

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[14] We also estimate models using abnormal conditions as the dependent variable, but this variable is often missing data. We estimate models only for 2010 onwards and find no evidence of changes in abnormal conditions.

[15] Clustering at the city level, rather than the census tract level, provides mostly statistically significant estimates. Still, scarring and selection may be negating each other, and so the disentangling below applies.

"personal or private activities."[16] 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 one-quarter of the population of Genesee County. 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.[17] While only suggestive, this evidence supports our conclusion that reduced conception rate is not driven by reduced sexual activity.[18]

6.4. Synthetic Control Methods

We perform an analysis of fertility rates using a synthetic control method (Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010).[19] This method creates a weighted control group that more closely resembles the characteristics of Flint in the period before the water switch 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 3, Panel A displays GFR trends in Flint and its synthetic control group before and after the water switch. 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

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

[17] This is analogous to Barreca, Deschenes, and Guldi (2018) which also finds a statistically significant *increase* in time in the probability that individuals spend time on sex during environmental conditions that reduce fertility.

[18] The ATUS only has county/CBSA identifiers. In Appendix Table B1, we repeat our results are the county level and show that while considering the rest of Genesee County (where Flint is) as treated reduces the magnitude of our results, they are still directionally consistent and statistically significant in some specifications.

[19] We describe this method in Appendix A.

is a decrease of 11.6 births, presented in Panel C by the vertical black bar, a slightly larger effect size than we found in Table 2. The average treatment effect in Flint is substantially larger than the average treatment effect for all other cities.[20]

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 switch (2008-2013). The strength of this analysis is thatit creates a better pre-trend match on GFR, but it may over-fit on GFR and ignore other covariates (see Kaul et al. 2018).[21]

Finally, we use an *imperfect* synthetic control method (Powell 2017). This method solves two issues in Abadie et al. (2010). First, it improves inconsistent pre-period match due to transitory shocks by using pre-period outcomes predicted from city-specific flexible time trends, instead of the actual per-period outcomes. Second, this approach allows the treated group to be an outlier, and therefore not a convex combination of the control groups (i.e., with nonnegative weights). Using the *imperfect* synthetic control method, a convex combination of the treated group and the rest of the control group can match the outcome of a control group that has been assigned a falsification treatment. If the treated group has a positive weight in this situation, that weight can be inverted to describe the mapping from the control group to the treated group.

Figure 4, Panel A shows that the *imperfect* synthetic control group is a better match for Flint in the pre-period. Panel B demonstrates that the decrease in GFR in Flint is larger than in any other area following the water switch which provides additional evidence of the statistical

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[20] We find similar effect sizes dropping outlier cities (Appendix Figure B5 and dropping Flint from the inference analysis so that when we assign treatment to each control group, Flint cannot be part of a synthetic control.

[21] Our estimates are robust to this alternative specification (see Appendix Figure B6). We also find similar results matching on the 4th quarter GFR for each year before the water switch (2007, 2008, 2009, 2010, 2011, 2012) and using a 13 month moving average for GFR.

significance of our estimates.

7. Robustness Checks

We perform several robustness checks. First, we perform a randomization inference permutation test (Fischer 1935; Cunningham and Shah 2018). This testsystematically assigns treatment status to each control area and compares the size of thetreatment effect for each control area to that of the actual treated area. As shown in Appendix Figure B7, we find our effect size in Flint is larger than all control area "treatment effects" providing additional support for our main analyses.

Second, we compare county-level GFR rates in Appendix Table B1. The treatment in this table includes all of Genesee County, of which Flint comprises approximately one-quarter of the population. Our estimates are just 17% as large as in Table 2, 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 switch.[22]

Appendix Table B2 presents robust results to limiting our sample to GFRs of births conceived before September 2014 and dropping the cities with the highest and lowest GFRs. We investigate births conceived before September 2014 because of potential avoidance following boil advisories due to fecal coliform in the Flint water source reported around this time. The decrease in fertility rates was larger in this early period than in our main results which use the full post period. One potential explanation for this change is that avoidance behaviors caused Flint residents to begin buying bottled water at higher rates after September 2014 (Christensen,

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[22] With the exception of the county-specific linear time trend, which biases the results for the reasons described above.

Keiser, and Lade 2017).[23]

In Appendix Table B3 we estimate the effect of the water switch on log births. We find a 15%-18% decrease in Flint following the water switch, which is comparable to our 12%-14% result in Table 2. In Appendix Table B4 we estimate a Poisson model and find a decrease in births of 0.15 (i.e., a 15% decrease in births in Flint). These results assume a constant population in Flint over the study period. Estimates of population in Flint decrease over the study period which may partially explain the larger magnitude of the effect in these models. In Appendix Table B5, we estimate a 90% confidence interval using Conley-Taber standard errors and find that our fertility results are still statistically significant (Conley and Taber 2011).

We find consistent results comparing only Flint and the rest of Genesee County (Appendix Table B6). As a falsification 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.

Appendix Table B8 shows that when we aggregate our analysis to the quarterly level we find nearly identical results. In Appendix Table B9 we limit our analysis period to births conceived in 2011 to 2015. This analysis contains a length of time similar to that of the lookback and follow-up periods. We find similarly-sized, statistically significant estimates of GFR and non-statistically significant estimates for sex ratio.

To determine whether Michigan cities are a good comparison group for Flint, we use data for all U.S. cities of 100,000 population or larger from NCHS for the same 2008-2015 period. In these analyses, our Flint sample remains the same as in the analyses above. Our estimates using

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[23] Our final time period, March 2015, shows an increase in GFR for Flint, from which we are unable to determine if that month GFR is an outlier or a general trend towards higher GFRs.

these data, presented in Appendix Table B10 are slightly smaller, but still statistically significant. Our results are substantially larger when including city-specific linear time trends, which may be more justified because these cities are distributed across many states and thus may trend differently. In addition, we focus on cities with a larger black population, like Flint, and consistently find effects for GFR that are more negative and more in line with our main results from Table 2.[24]

We perform several robustness checks on our SCM analyses in Appendix Table B11. First, we include our main results by month as in Figure 3 and Appendix Figure B6 as a reference. We also perform these analyses collapsing the data to the quarterly level in Columns (3) and (4) and find very similar results. In Panel B, we increase our donor pool to include all cities in the NCHS data. We estimate all four specifications on this sample and again find qualitatively and quantitatively similar 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.

8. Discussion

Our results for the decrease in the fertility rate are plausible given the broader scientific literature on this topic. 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 similar 12% decrease in the fertility rate.

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

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[24] Limiting the comparisons to cities with similar population density to Flint (approximately 3,000 individuals per square mile) also provides comparable results.

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 switched its water source.[25] We consider this strong empirical support for the existence of a culling effect caused by increased lead in the water. Our results on sex ratios suggest that among the live births that occurred in Flint following the switch in water supply, an additional 18 female infants were born than expected.[26]

We now turn to a discussion of our non-finding for the effects of the Flint water switch on birth outcomes. In isolation, one could infer from these results that there was no biological effect of lead on birth outcomes at the population level. However, this inference would be naïve given our finding of a statistically significant decrease in fertility rates and the likely nonrandom selection mechanism behind it, which could have balanced out a negative scarring effect.

We therefore perform an analysis in the spirit of Bozzoli, Deaton, and Quintana-Domeque (2009) to disentangle scarring and selection effects. We assume that the pre-water switch birth weight distribution in Flint is normally distributed (see Figure 5) with mean (3082 g) and standard deviation (632 g) as in Column 3 of Table 1. We assume that the 12% reduction in the live birth rate all came from the left tail of the birth weight distribution, as birth weight is often thought of as a proxy for infant health. Or, put differently: there is some minimal birth weight cutoff for live birth, and the selection shock of adding lead to the water shifted the entire distribution left such that the bottom 12% of birth weight did not survive.

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[25] Change in GFR in Flint (62-57) * population aged 15-49 in Flint (26,000) * the number of years affected (17/12) = 198; Difference-in-differences estimate (7.5) * 26,000 * 17/12 = 276.

[26] Change in sex ratio (0.009) * the number of post water switch births (2,010) = 18.

Using the formula for the mean of a truncated normal[27] we calculate that mean birth weight of the surviving newborns, without any scarring, would have been 3242 g. The observed Flint mean birth weight in the post period is 3042 g, a decrease of 200 g from 3242 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 3217 g) leaving a scarring effect of 175 g; a 5.4% decrease compared to 3217 g. 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 4. We consider this a bounding exercise for the full effect of scarring if no selective attrition had occurred. As Figure 5 makes clear, despite the large amount of selective attrition we document in Table 2, our probability density function for Flint show that the health distribution shifted to the left in Flint following the water switch and did not shift in comparison cities.

Additionally, while our sex ratio results are not definitive, they support our main result that fertility rates decrease because of both selective attrition and scarring from a biological effect of an increase in contaminants including lead in the water. The 0.9 percentage point increase (1.8%) in female births following the water switch is consistent with worse health at birth (Trivers and Willard 1973; Sanders and Stoecker 2015). Moreover, as in Table 5, we find no evidence to support a decrease in sexual relations among individuals living in Flint during this time period. For our results to be explained by behavioral changes, we would have to hypothesize that at the same time Flint switched its water source, parents changed their preference for male children and began performing sex-selective abortions showing a preference

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

for *female* children. This result would run counter to the prevailing evidence of lower female births than expected, especially in Asian countries (e.g. Sen 1990; Das Gupta 2005), but also in the U.S. (Abrevaya 2009).

9. Conclusion

We provide the first estimates of the in utero effect of increased amounts of lead and other contaminants in drinking water in Flint. General fertility rates in Flint decreased substantially following the water switch while health outcomes displayed mixed results, with suggestive evidence of an overall decrease in birth weight and an increase in rates of low birth weight. Our careful empirical approach sufficiently eliminated potential biases in the comparison groups and our use of several comparison groups provides credence to our results.

An overall decrease in fertility rates can have lasting effects on a community, including by decreasing school funding due to a decrease in the number of students. If the decrease in births reflected only a culling effect, that effect could reduce the health expenditures of the community. Given the research demonstrating a substantial increase in blood lead levels among children exposed to lead, an overall decrease in health expenditures in both the short- and long-term is highly unlikely (Edwards, Triantafyllidou, and Best 2009; Hanna-Attisha et al. 2016). Furthermore, children who seemed to be healthy at birth may still have worse latent health at birth, which could manifest later in their lives (Barker 1992; Barker 1995). While local programs work to counteract the water crisis (e.g. Hanna-Attisha 2017), these latent health effects remain a concern.

This study has several limitations. First, other contaminants may be present in the water that also affect health, so our results estimate the *overall* effect of the water switch on these outcomes. Additionally, we are not able to follow women long-term to determine whether these fertility rate decreases persist after Flint switched back to the less corrosive water source. Future research should investigate the long-term effects on fecundity of both men and women and associated pathways following an increased exposure to lead. In addition, the health effects of a switch in water supply are not limited to pregnant women and neonates. This is just one consequence of this water supply switch. With the litany of evidence linking fetal and birth outcomes to health, education, and labor outcomes later in life, 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.

This paper represents the first study of the Flint water switch 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 less restrictive regulatory environment in the context of drinking water may have substantial unforeseen consequences on maternal and infant health, including large reductions in the number of births.

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Table 1: Summary Statistics

	(1)	(2)	(3)	(4)	(5)
	Non-Flint Births		Flint Births		
	Pre-Water Switch (N=238,733)	Post-Water Switch (N=52,311)	Pre-Water Switch (N=10,620)	Post-Water Switch (N=2,010)	Difference in Differences
Demographic variables:					
Mother's age (years)	27.49 (6.07)	28.10 (5.78)	24.66 (5.59)	25.17 (5.37)	-0.105
Mother no high school	0.190	0.155	0.294	0.271	0.011
Mother high school grad	0.268	0.266	0.317	0.343	0.028*
Mother some college	0.275	0.292	0.337	0.337	-0.0168
Mother college grad	0.258	0.276	0.050	0.047	-0.021**
Outcome variables:					
General fertility rate	67.14 (33.38)	69.18 (31.83)	62.28 (6.81)	56.87 (6.76)	-7.45**
Male-Female Sex Ratio (percent male)	51.11 (4.44)	51.20 (4.95)	51.05 (4.59)	50.20 (3.06)	-0.92
Birth weight (grams)	3,225 (631)	3,200 (645)	3,082 (632)	3,042 (651)	-15
Low Birth Weight	0.097 (0.30)	0.108 (0.31)	0.135 (0.34)	0.158 (0.37)	
Estimated gestational age (weeks)	38.50 (2.99)	38.38 (2.58)	38.08 (2.97)	37.89 (2.69)	-0.078
Gestational Growth (grams/week)	83.32 (14.63)	82.79 (14.61)	80.38 (14.33)	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 ‹ .10; *p ‹ .05; **p ‹ .01; ***p ‹ .001

Table 2: Lead in Water on General Fertility Rate and Sex Ratios

	General Fertility Rates			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.451*** (0.791) [0.004]	-7.451*** (0.811) [0.004]	-5.682*** (0.603) [0.004]	-0.0092*** (0.00262) [0.004]	-0.0092*** (0.00268) [0.004]	-0.00121 (0.00411) [0.778]
Conception Month Fixed Effects (FE)	X	X	X	X	X	X
Conception Year FE	X	X	X	X	X	X
City FE	X	X	X	X	X	X
Conception Month into Year FE		X	X		X	X
City Linear Time Trends			X			X
Observations	1,520	1,520	1,520	1,520	1,520	1,520
Cities	16	16	16	16	16	16
R-squared	0.235	0.269	0.303	0.235	0.269	0.303
Mean	62.28	62.28	62.28	0.510	0.510	0.510

Notes: Robust standard errors clustered at the city level in parentheses. Brackets contain wild bootstrapped p-values for the most saturated models. †p ‹ .10; *p ‹ .05; **p ‹ .01; ***p ‹ .001

Table 3: Lead in Water on General Fertility Rate and Sex Ratio, Subsample Analyses

	Births			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
All	-0.151***	-0.151***	-0.051***	-0.0092***	-0.0092***	-0.00121
	(0.0166)	(0.0166)	(0.0010)	(0.00262)	(0.00268)	(0.00411)
Age 15-24	-0.0688***	-0.0688***	-0.0629***	0.0111	0.0112	-0.00214
	(0.00717)	(0.00717)	(0.0119)	(0.00770)	(0.00784)	(0.0157)
Age 25-34	-0.148***	-0.148***	0.0244	-0.0238***	-0.0238***	-0.000642
	(0.00806)	(0.00806)	(0.0244)	(0.00449)	(0.00457)	(0.00531)
Age 35-49	-0.101***	-0.101***	0.0669***	-0.0344***	-0.0344***	-0.0374***
	(0.0212)	(0.0212)	(0.0188)	(0.00464)	(0.00473)	(0.00957)
White	-0.140***	-0.140***	-0.0804***	-0.0111***	-0.0111***	-0.00657
	(0.0172)	(0.0172)	(0.0262)	(0.00348)	(0.00357)	(0.00661)
Black	-0.125***	-0.125***	-0.0180	0.0182*	0.0181*	0.0249
	(0.0164)	(0.0164)	(0.0177)	(0.00943)	(0.00978)	(0.0169)
Conception Month Fixed Effects (FE)	X	X	X	X	X	X
Conception Year FE	X	X	X	X	X	X
City FE	X	X	X	X	X	X
Conception Month into Year FE		X	X		X	X
City Linear Time Trends			X			X
Observations	1,520	1,520	1,520	1,520	1,520	1,520
Cities	16	16	16	16	16	16

Notes: Results for births use Poisson regressions while sex ratio results use OLS. All contain conception month into year fixed effects and city fixed effects. Robust standard errors clustered at the city level in parentheses. †p ‹ .10; *p ‹ .05; **p ‹ .01; ***p ‹ .001 .

Table 4: Lead in Water on Other Birth Outcomes

	(1)	(2)	(3)	(4)	(5)
Birth Weight (grams)	-14.69	-20.82	-19.47	-18.42	-10.78
	(13.65)	(14.65)	(14.48)	(14.77)	(14.64)
Low Birth Weight	0.0124	0.0142	0.0136	0.0135	0.0114
	(0.00873)	(0.00884)	(0.00880)	(0.00887)	(0.00900)
Gestational Age (weeks)	-0.0668	-0.0878	-0.0830	-0.0835	-0.0701
	(0.0586)	(0.0612)	(0.0603)	(0.0602)	(0.0603)
Gestational Growth (grams/week)	-0.265	-0.392	-0.364	-0.336	-0.159
	(0.307)	(0.328)	(0.325)	(0.334)	(0.332)
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
N	303,674	303,674	303,674	303,674	303,674

Notes: Robust standard errors clustered at the census tract level in parentheses. †p ‹ .10; *p ‹ .05; **p ‹ .01; ***p ‹ .001

Table 5: Time Use Data on Sex

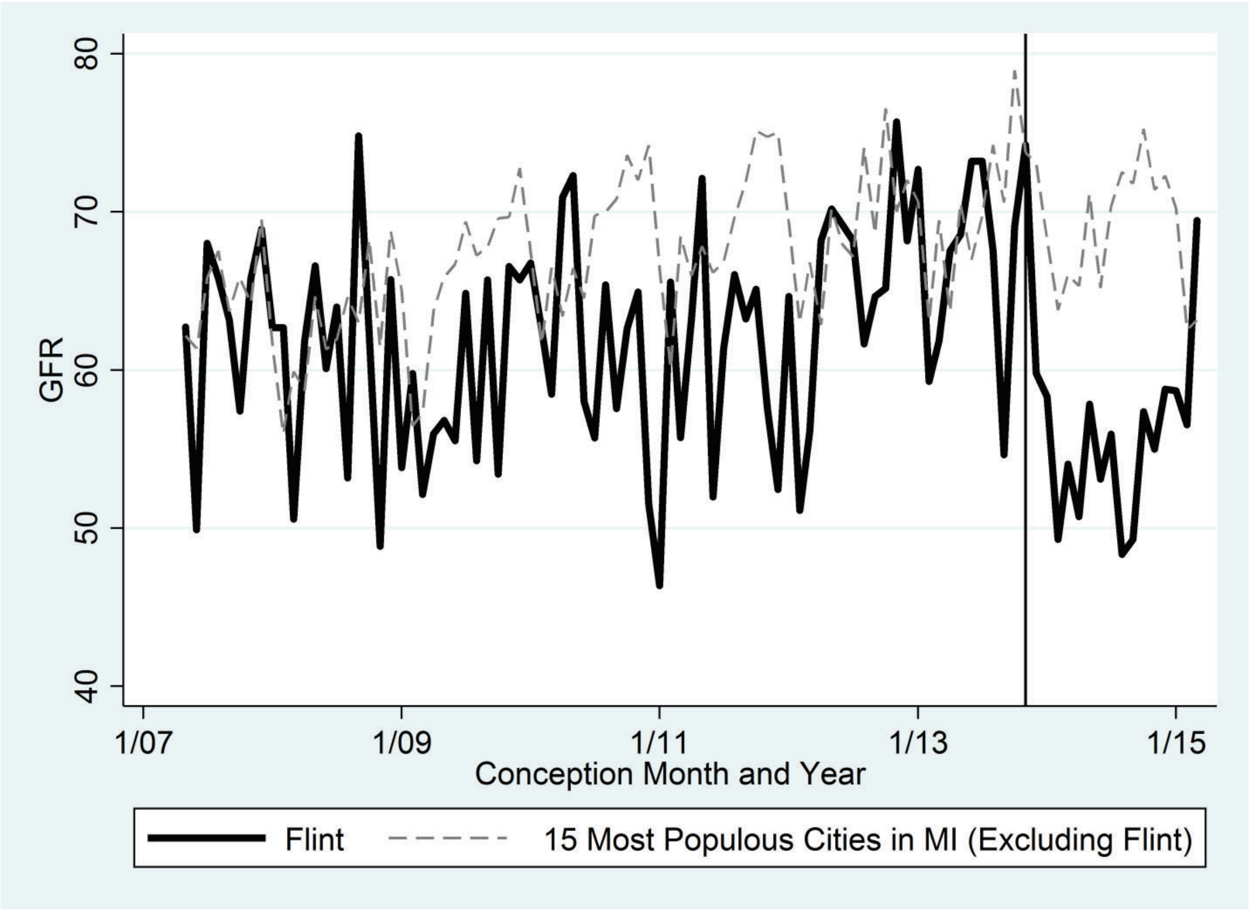
	(1)	(2)	(3)	(4)	(5)	(6)
	County-level			CBSA-level		
Water (β_1)	0.0148*** (0.00203)	0.0158*** (0.00133)	0.0157*** (0.00131)	0.0186*** (0.00229)	0.0206*** (0.00319)	0.0205*** (0.00310)
Interview Month Fixed Effects		X	X		X	
Interview Year Fixed Effects		X	X		X	X
County Fixed Effects			X			
CBSA Fixed 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. Time fixed effects are for interview month and year, not conception month and year as this portion of the analysis uses contemporaneous survey data instead of administrative birth data. †p ‹ .10; *p ‹ .05; **p ‹ .01; ***p ‹ .001

Figure 1: Comparison Cities

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

Figure 2: Unadjusted Monthly GFR[28]



Note: The vertical black line is at November 2013, the first month in which all conceived births would have been affected by the water supply for at least one trimester.

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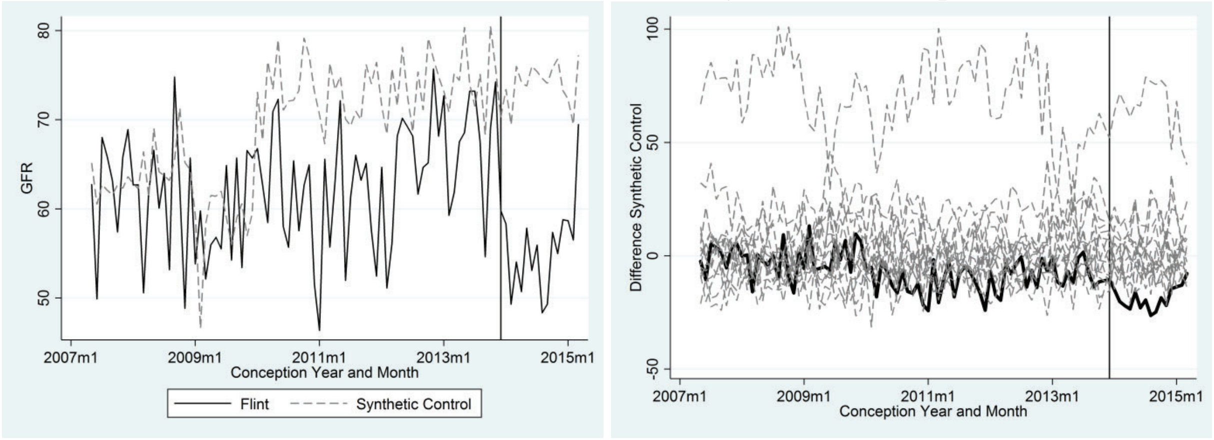
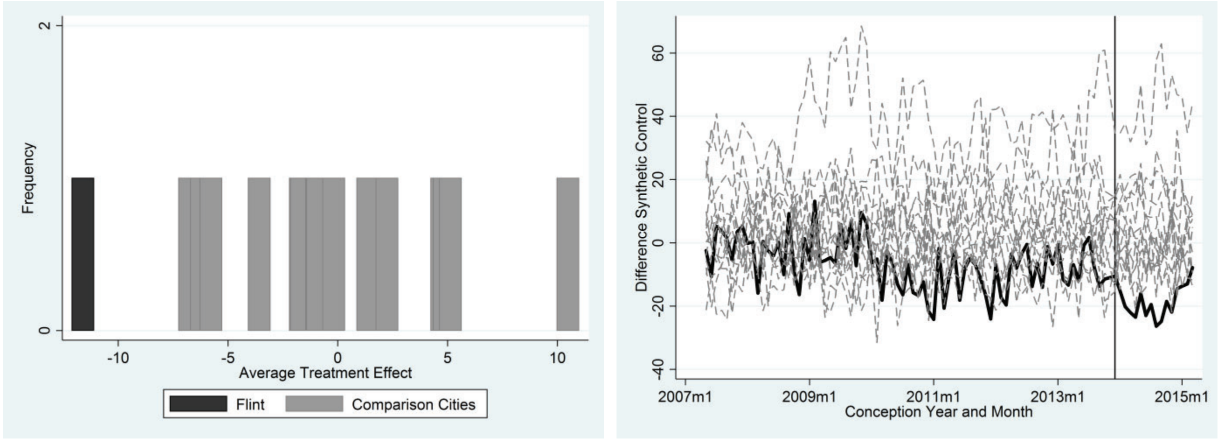
[28] This figure does appear to show city-specific seasonality. Given the differences in the demographic composition of Flint and some other cities and the correlation between socioeconomic status and birth seasonality (Trivers and Willard 1973) we run a specification using city specific month fixed effects and find virtually identical results.

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 its Synthetic Counterpart

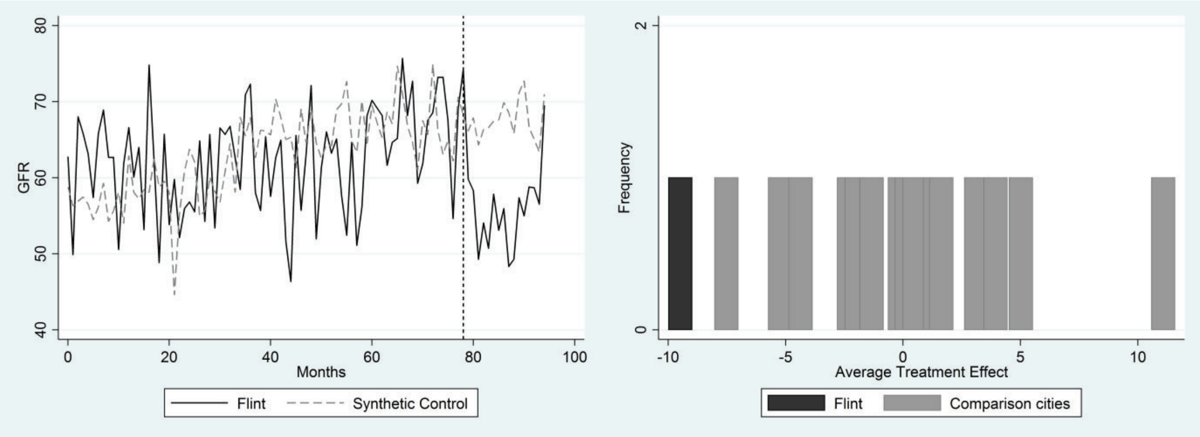


Panel C. Inference Using Average Treatment Effect

Panel D. Dropping outlier (same as panel b above without Wyoming, Michigan)

Note: The black vertical line in Panel A is at November 2013, which is the last conception date for which women would have been exposed for at least one trimester to the new water supply. The black solid line in Panel B represents the difference between GFR in Flint and "synthetic Flint." The black bar in Panel C displays the average treatment effect (ATE) for Flint, while gray bars show comparison city ATEs. It is the most negative ATE compared to assigning all areas to treatment, suggesting statistical significance.

Figure 4: Imperfect Synthetic Controls



Panel A. Flint GFR compared to Imperfect Synthetic Flint GFR

Panel B. Inference Using Average Treatment Effect

Note: The black vertical line in Panel A is at November 2013, which is the last conception date for which women would have been exposed for at least one trimester to the new water supply. The black bar in Panel B displays the average treatment effect (ATE) for Flint, while gray bars show comparison city ATEs. It is the most negative ATE compared to assigning all areas to treatment, suggesting statistical significance.

Figure 5: Probability Density Function of Birth Weight Before and After the Water Switch.