

The Impact of the Flint Water Crisis on Fertility: Online Appendix

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 switch their water supply over this time period.²⁹ 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 and Gardeazabal 2003; 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.

²⁹ Cities included are Ann Arbor, Dearborn, Detroit, Farmington Hills, Flint, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming.

The main strengths of this method are it creates a matched control group that follows similar pre-trends in terms of the outcome of interest, and it allows for rigorous inference testing. Because the control areas follow similar pre-trends and are matched on level as well, they are plausibly a better counterfactual representation of what one would expect to have happened to pregnancy and birth outcomes in Flint had the city never switched its water source.

Inference testing consists of systematically assigning treatment to each control zone, creating a synthetic control group using the city of Flint (the treatment zone) as a control as well as the full pool of control zones, minus the city assigned to treatment. We separately calculate the average treatment effect in the post-period of assigning treatment to each control zone. This creates a distribution of average treatment effects by which to evaluate the average treatment effect of the actual water supply switch in Flint. So if there are 16 average treatment effects and the Flint effect is larger than the other 15 control area average treatment effects, the estimate is statistically significant at the 6.25 percent level.³⁰

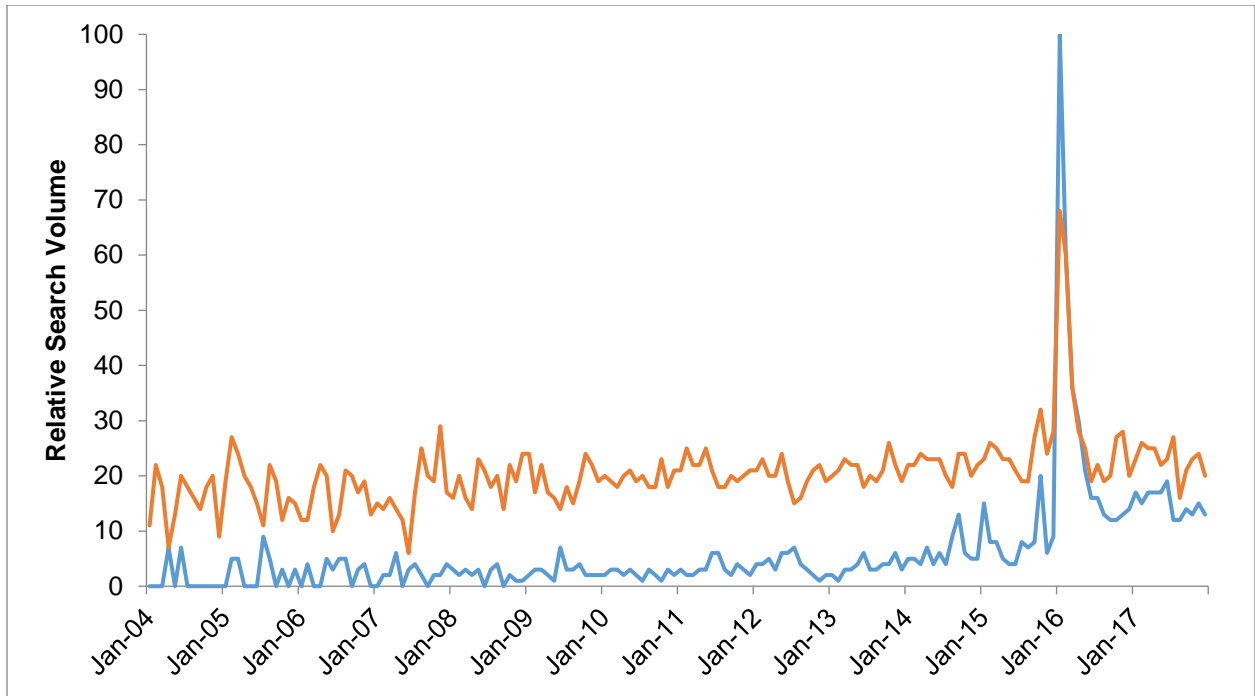
³⁰ $1/16=0.06$

Appendix B: Additional Tables and Figures:

Appendix Figure B1: Timeline of Important Events in Flint

1897: Flint passes ordinance that all connections with any water main be made with lead pipes (Masten et al. 2016)	1967-2014: Flint receives water from Detroit Water and Sewerage Department (DWSD)	2011: Governor appoints Emergency Manager	2009-2013: Water rates (prices) consistently increase	March 2014: Flint and Genesee County plan own pipeline to Lake Huron	April 2014: Flint changes water source to Flint River, Genesee County stays with DWSD	Aug – Sept 2014: Positive test for fecal coliform, first boil advisory
Oct 2014: Flint GM plant switches off Flint water supply because of engine corrosion.	Dec 2014: EPA violation for too much trihalomethane concentration in the Flint water.	Jan – Mar 2015: Emergency manager stresses water is safe, refuses to return to DWSD	Jun – Jul 2015: Dr. Edwards independently tests Flint water lead levels, 19 times more corrosive than DWSD.	Sept 2015: Dr. Hanna-Attisha holds press conference announcing increased rates of child blood lead levels.	Oct 2015: Flint stops receiving water from Flint River and switches back to DWSD.	

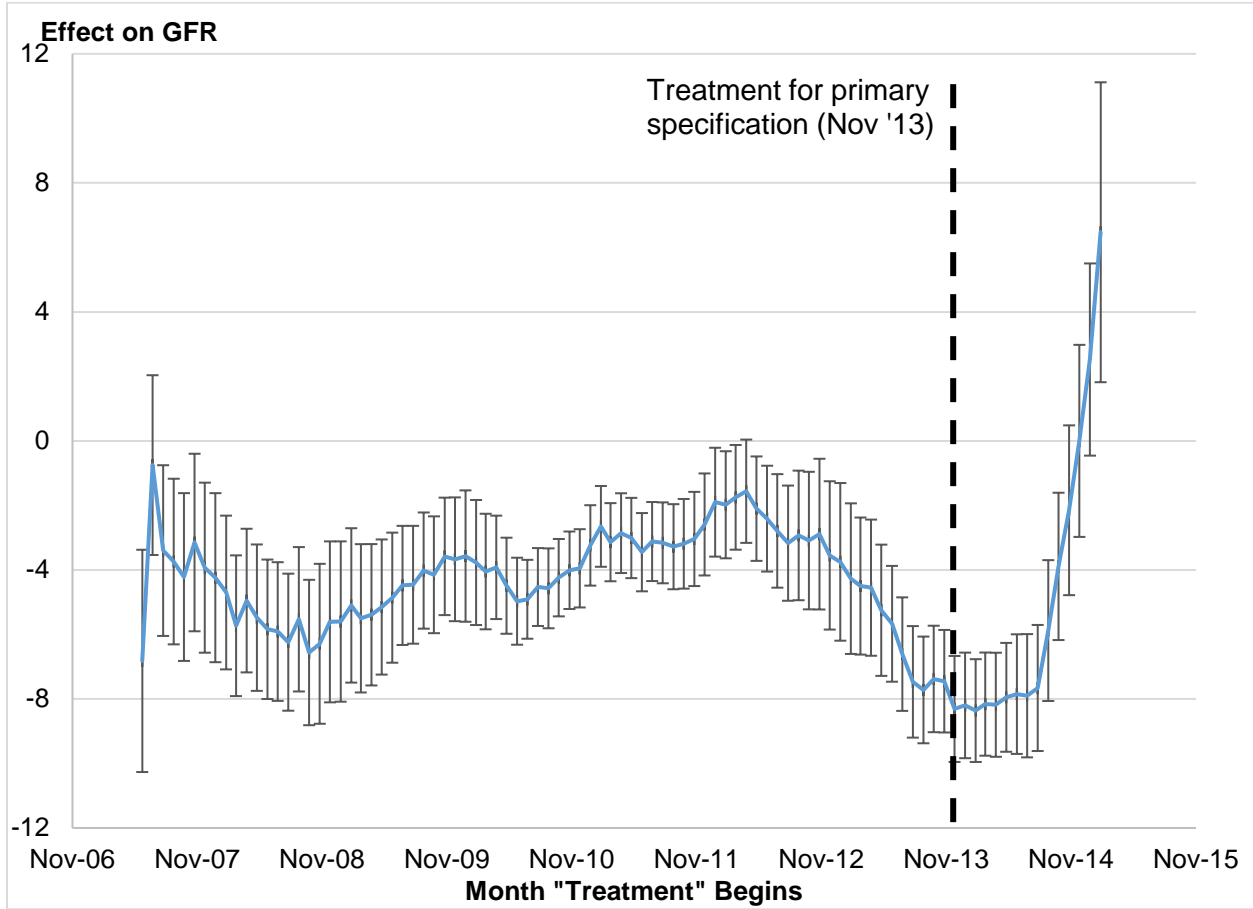
Appendix Figure B2: Google Trend Data on Searches for Water and Lead in Flint



Source: Google Trends

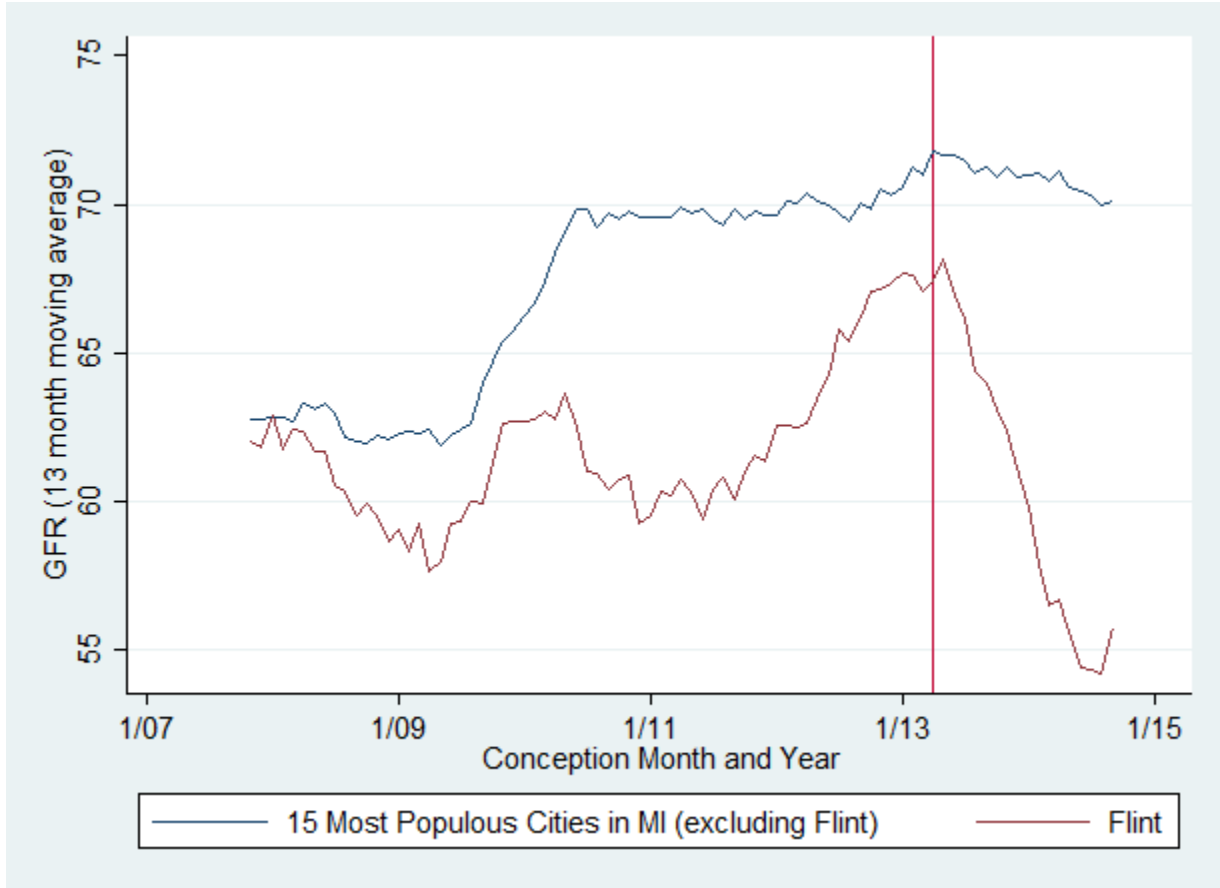
Notes: Searches for “flint water” in blue and “lead” in orange.

Appendix Figure B3: Results from Regressions with Alternate Treatment Dates



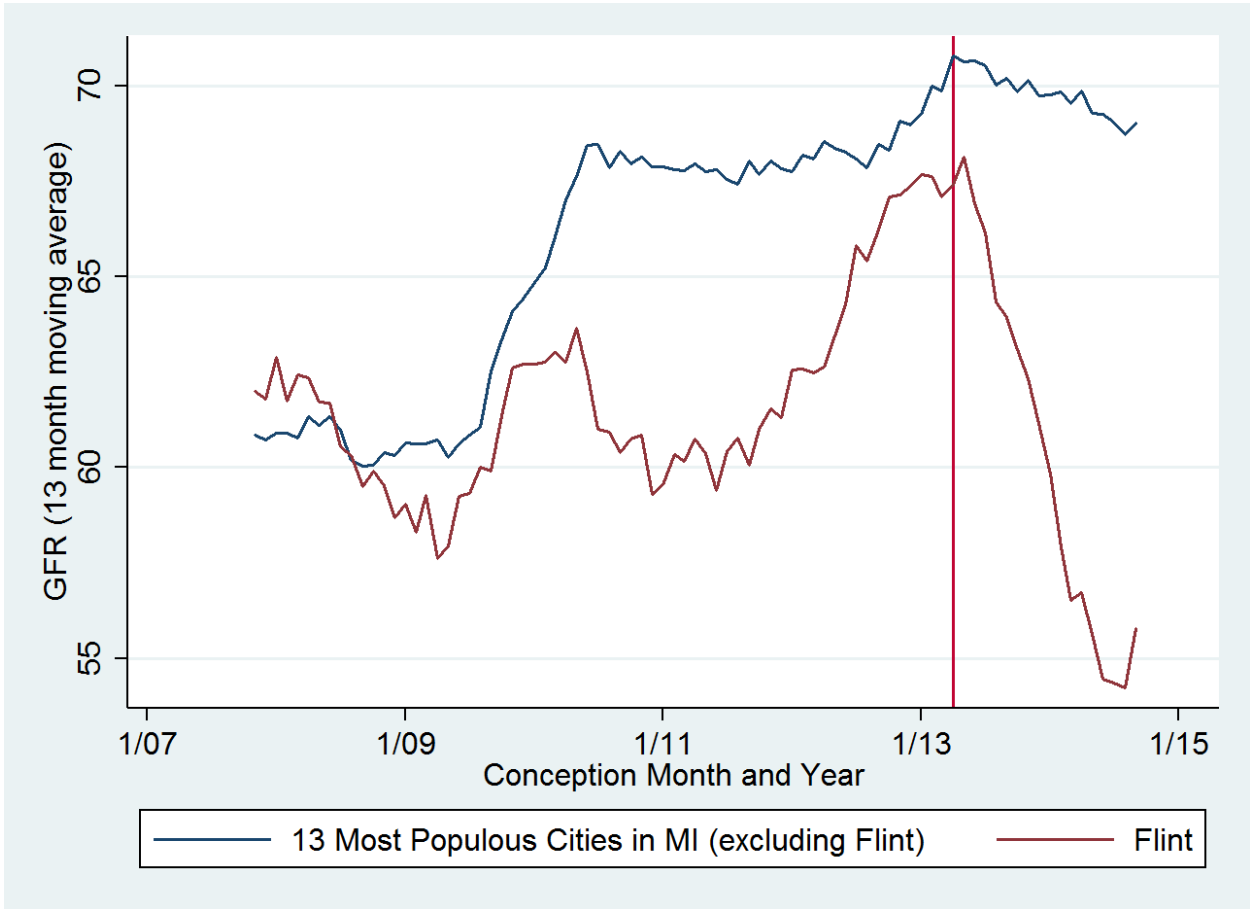
Note: Each point is the coefficient from a different regression. 95% confidence interval around each regression coefficient. All regressions include city and conception month into year fixed effects.

Appendix Figure B4: Moving Average Fertility Rate 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.

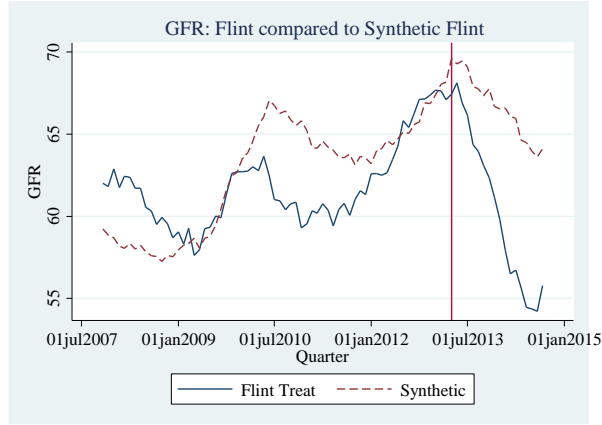
Appendix Figure B5: Moving Average Fertility Rate Over Time in Flint and Comparison Cities – Dropping Outlier Cities



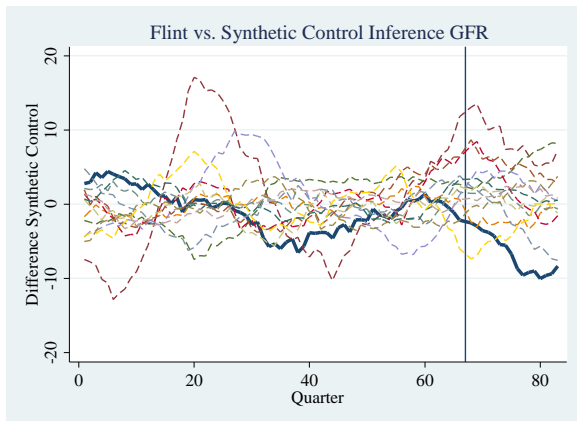
Note: The red vertical line is at April 2013, which is the last conception date for which no affected birth rates are included in the moving average.

Appendix Figure B6: Synthetic Control Results for General Fertility Rates, Adjusting for March 2008-2013 GFR

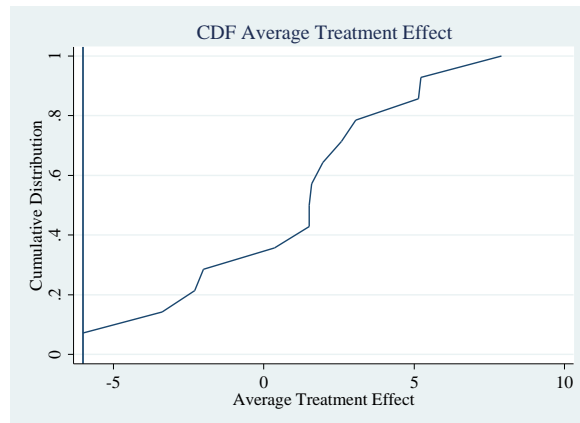
Panel A. Flint GFR Compared to Synthetic Flint GFR



Panel B. Difference Between Each City and its Synthetic Counterpart

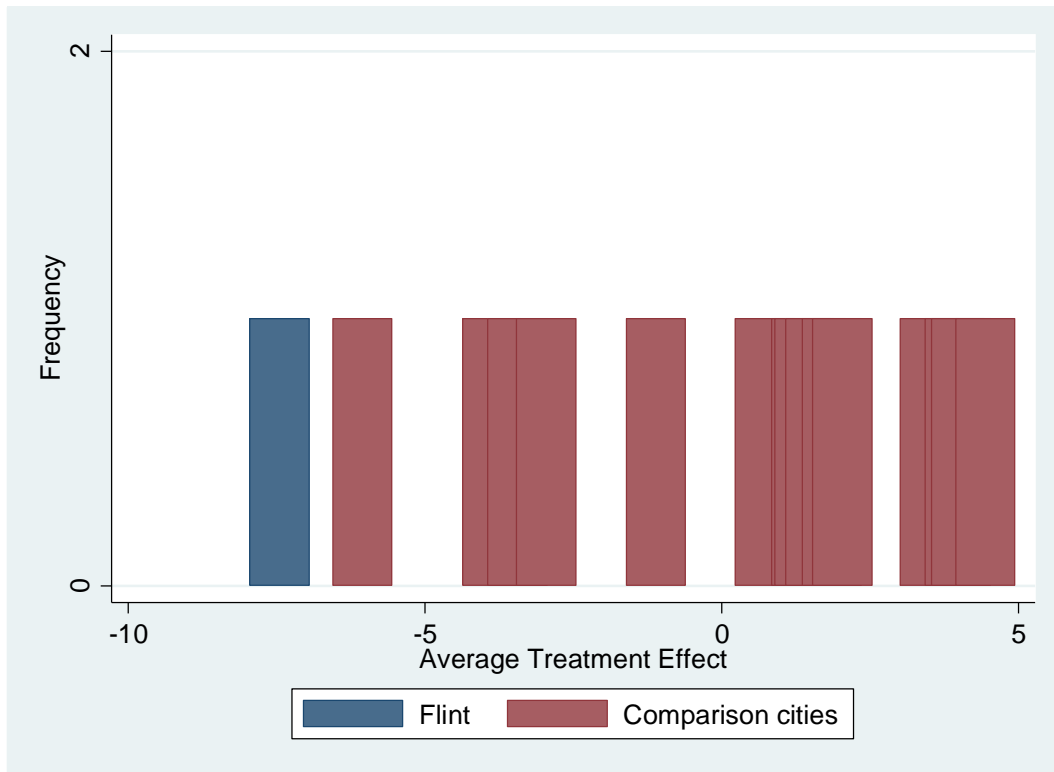


Panel C. Inference Using Average Treatment Effect



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

Appendix Figure B7: Randomization Inference Permutation Test



Appendix Table B1: Lead in Water on General Fertility Rate at the County Level

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-1.360*** (0.341)	-1.360*** (0.342)	-1.360*** (0.342)	-1.360*** (0.347)	-0.382 (0.366)
Conception Month Fixed Effects		X	X	X	X
Conception Year Fixed Effects		X	X	X	X
City Fixed Effects			X	X	X
Conception Month into Year Fixed Effects				X	X
County Linear Time Trends					X
Observations	2,755	2,755	2,755	2,755	2,755
Counties	29	29	29	29	29
R-squared	0.009	0.122	0.257	0.296	0.315
Mean	51.77	51.77	51.77	51.77	51.77

Notes: Robust standard errors clustered at the county level in parentheses. †p < .10; *p < .05; **p < .01; ***p < .001 . This table defines treatment as all of Genesee County and uses the 28 largest counties in Michigan as the comparison group.

Appendix Table B2: Lead in Water on General Fertility Rate and Sex Ratios, Sample Changes

	General Fertility Rates			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
Main Results (N=1520)	-7.451*** (0.791)	-7.451*** (0.811)	-5.682*** (0.603)	-0.0092*** (0.00262)	-0.0092*** (0.00268)	-0.00121 (0.00411)
Before 9/2014 (N=1424)	-8.797*** (0.694)	-8.797*** (0.712)	-6.900*** (0.585)	-0.00231 (0.00292)	-0.00231 (0.00300)	0.00447 (0.00445)
Drop Outlier Cities (cities=14, N=1330)	-8.173*** (0.697)	-8.173*** (0.718)	-5.549*** (0.678)	-0.0090** (0.00301)	-0.0090** (0.00310)	-0.00352 (0.00409)
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

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

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

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-0.175*** (0.0123)	-0.175*** (0.0124)	-0.175*** (0.0124)	-0.175*** (0.0128)	-0.042*** (0.0096)
Conception Month Fixed Effects		X	X	X	X
Conception Year Fixed Effects		X	X	X	X
City Fixed Effects			X	X	X
Conception Month into Year Fixed Effects				X	X
City Linear Time Trends					X
Observations	1,520	1,520	1,520	1,520	1,520
Counties & Flint	16	16	16	16	16
R-squared	0.001	0.007	0.980	0.981	0.981

Notes: Robust standard errors clustered at the city level in parentheses. †p < .10; *p < .05; **p < .01; ***p < .001 . Note that coefficients are in log points.

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

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-0.151*** (0.0166)	-0.151*** (0.0166)	-0.151*** (0.0166)	-0.151*** (0.0166)	-0.051*** (0.0010)
Conception Month Fixed Effects		X	X	X	X
Conception Year Fixed Effects		X	X	X	X
City Fixed Effects			X	X	X
Conception Month into Year Fixed Effects				X	X
City Linear Time Trends					X
Observations	1,520	1,520	1,520	1,520	1,520
Counties & Flint	16	16	16	16	16
Pseudo R-squared	0.0092	0.0113	0.9553	0.9558	0.9558

Notes: Robust standard errors clustered at the city level in parentheses. †p < .10; *p < .05; **p < .01; ***p < .001 . Note that coefficients are in log points.

Appendix Table B5: Lead in Water on General Fertility Rate and Sex Ratios Using Conley-Table Standard Errors

	General Fertility Rates			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.451*	-7.451*	-5.682*	-0.0092	-0.0092	-0.00121
	(0.791)	(0.811)	(0.603)	(0.00262)	(0.00268)	(0.00411)
Confidence Interval Using Conley Taber SE	[-11.620, -1.776]	[-11.620, -1.776]	[-8.260, -3.453]	[-0.033, 0.0005]	[-0.033, 0.0005]	[-0.019, 0.015]
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. Conley-Taber 90% Confidence Intervals in brackets. *p < .10.

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

	(1)	(2)	(3)	(4)	(5)	(6)
	GFR	GFR	GFR	Sex Ratio	Sex Ratio	Sex Ratio
Water (β_1)	-6.568** (2.071)	-6.568*** (1.918)	-6.568*** (1.918)	-0.00711 (0.0137)	-0.00711 (0.0136)	-0.00711 (0.0136)
Conception Month Fixed Effects		X	X		X	X
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			X
Observations	190	190	190	190	190	190
Counties & Flint	2	2	2	2	2	2
R-squared	0.604	0.695	0.285	0.015	0.123	0.114
Mean	62.28	62.28	62.28	0.510	0.510	0.510

Notes: †p < .10; *p < .05; **p < .01; ***p < .001. This table defines treatment as Flint and uses the rest of Genesee County as the comparison group.

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

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

Notes: Robust standard errors clustered at the county level in parentheses. †p < .10; *p < .05; **p < .01; ***p < .001 . This table defines treatment as the rest (i.e. parts that are not in Flint) of Genesee county and uses the 28 largest counties in Michigan as the comparison group.

**Appendix Table B8: Lead in Water on General Fertility Rate and Sex Ratios Using
Aggregating to Quarter of Birth**

	General Fertility Rates			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
Water (β_1)	-7.398*** (0.814)	-7.398*** (0.829)	-5.699*** (0.689)	-0.0100*** (0.00275)	-0.0100*** (0.00281)	0.00208 (0.00455)
Conception Quarter 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 Quarter 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. †p < .10; *p < .05; **p < .01; ***p < .001

Appendix Table B9: Lead in Water on General Fertility Rate and Sex Ratios, Limiting Sample Period to 2011 to 2015

	(1)	(2)	(3)	(4)	(5)	(6)
	GFR	GFR	GFR	Sex Ratio	Sex Ratio	Sex Ratio
Water (β_1)	-6.920*** (0.770)	-6.920*** (0.787)	-11.254*** (1.912)	-0.00185 (0.00292)	-0.00185 (0.00311)	-0.00185 (0.00311)
Conception Month Fixed Effects		X	X		X	X
Conception Year Fixed Effects		X	X		X	X
County Fixed Effects			X			X
Observations	816	816	816	816	816	816
Counties & Flint	29	29	29	29	29	29
R-squared	0.218	0.948	0.949	0.019	0.047	0.080
Mean	63.86	63.86	63.86	0.504	0.504	0.504

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

Appendix Table B10: Lead in Water on General Fertility Rate and Sex Ratios Using Expanded Comparison Sample from Outside Michigan, 2008-2015

	GFR			Sex Ratios		
	(1)	(2)	(3)	(4)	(5)	(6)
220 Comparison Cities	-3.641*** (0.359)	-3.641*** (0.360)	-12.06*** (0.309)	-0.0086*** (0.00060)	-0.0086*** (0.00060)	-0.00091 (0.00078)
68 Comparison Cities (≥25% black)	-5.228*** (0.877)	-5.228*** (0.882)	-12.41*** (0.772)	-0.0057*** (0.00098)	-0.0057*** (0.00099)	0.00079 (0.0012)
24 Comparison Cities (≥45% black)	-7.186*** (1.640)	-7.186*** (1.668)	-12.82*** (1.600)	-0.0061*** (0.00215)	-0.0061*** (0.0021)	0.0047** (0.0020)
156 Comparison Cities (1000-5000 Pop Den)	-4.208*** (0.442)	-4.208*** (0.443)	-11.99*** (0.386)	-0.0083*** (0.00071)	-0.0083*** (0.00071)	8.90e-05 (0.00092)
98 Comparison Cities (2000-4000 Pop Den)	-4.393*** (0.611)	-4.393*** (0.613)	-12.12*** (0.541)	-0.0079*** (0.00090)	-0.0079*** (0.00091)	0.00031 (0.0011)
45 Comparison Cities (2500-3500 Pop Den)	-5.467*** (0.953)	-5.467*** (0.961)	-12.65*** (0.801)	-0.0090*** (0.00152)	-0.0090*** (0.00154)	-0.00056 (0.0020)
City Fixed Effects (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: % black refers to the percent of city residents who are black. Pop Den refers to population density of the comparison cities. The population of Flint is approximately 57%. It has a population density of approximately 3,000 individuals per square mile. All regressions include conception month and conception year fixed effects. †p < .10; *p < .05; **p < .01; ***p < .001

Appendix Table B11: Lead in Water on General Fertility Rate Using Synthetic Control Methods

	Monthly		Quarterly	
	Main Analysis	Matching GFR Annually	Main Analysis	Matching GFR Annually
Panel A.	(1)	(2)	(3)	(4)
Main Michigan Analysis Sample	-11.606† [0.0625]	-11.566† [0.062]	-12.182† [0.0625]	-12.082† [0.0625]
Panel B.				
Full U.S. Cities Analysis Sample	-6.965† [0.0682]	-15.015** [0.0045]	-6.771† [0.0682]	-6.453** [0.0045]

Notes: P-values in brackets come from comparing Flint’s average treated effect to the distribution of average treatment effects from each city systematically assigned to treatment and the synthetic version of the city. †p < .10; *p < .05; **p < .01; ***p < .001

Appendix C: County Level Analysis

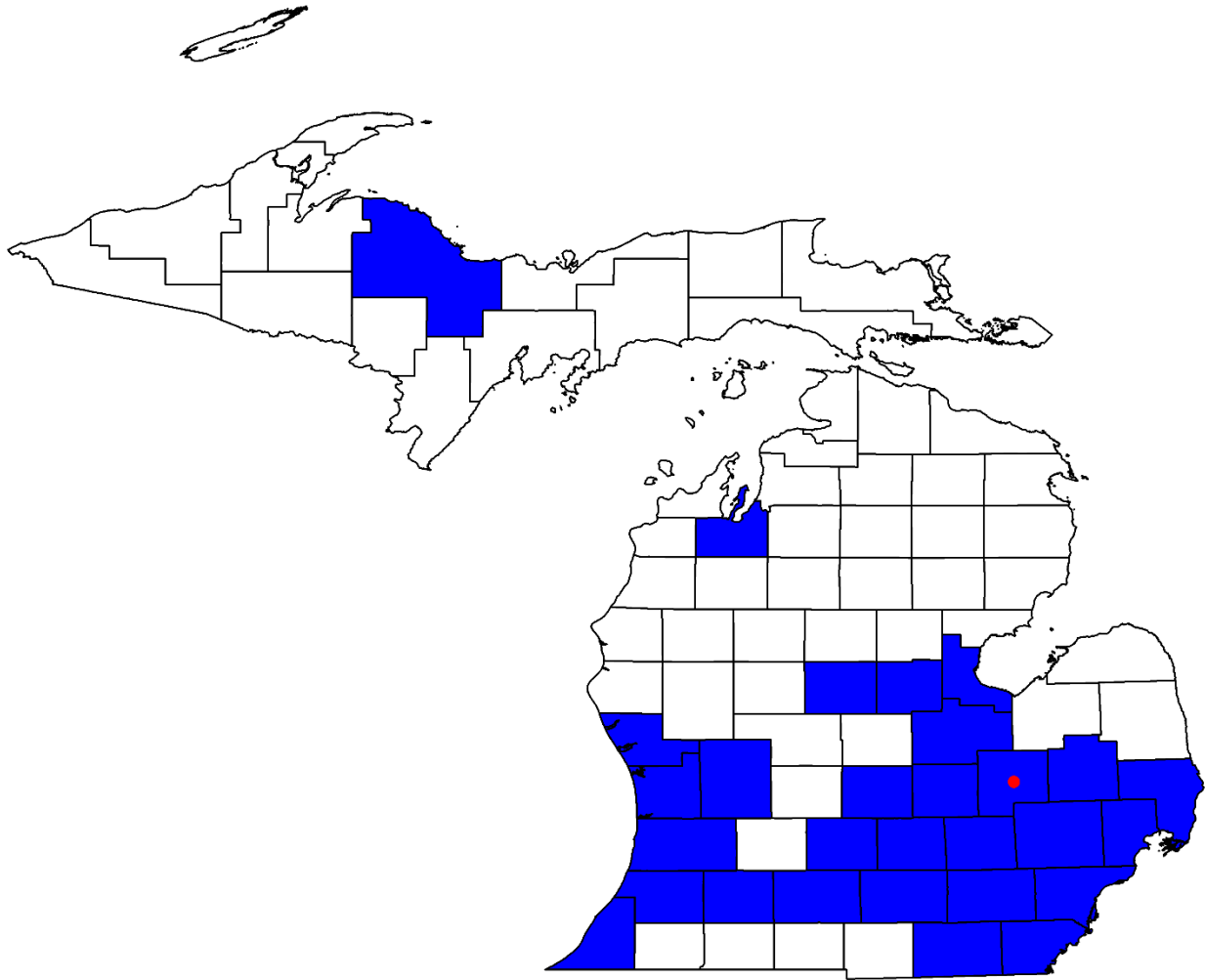
For the county level analysis, we consider Flint as the treatment unit, and then assign the rest of Genesee County as a rump control Genesee County with the remainder of the county's population.³¹ Annual population data at the county level is only available from Census for high population counties, and so our main specification only uses those counties.³²

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

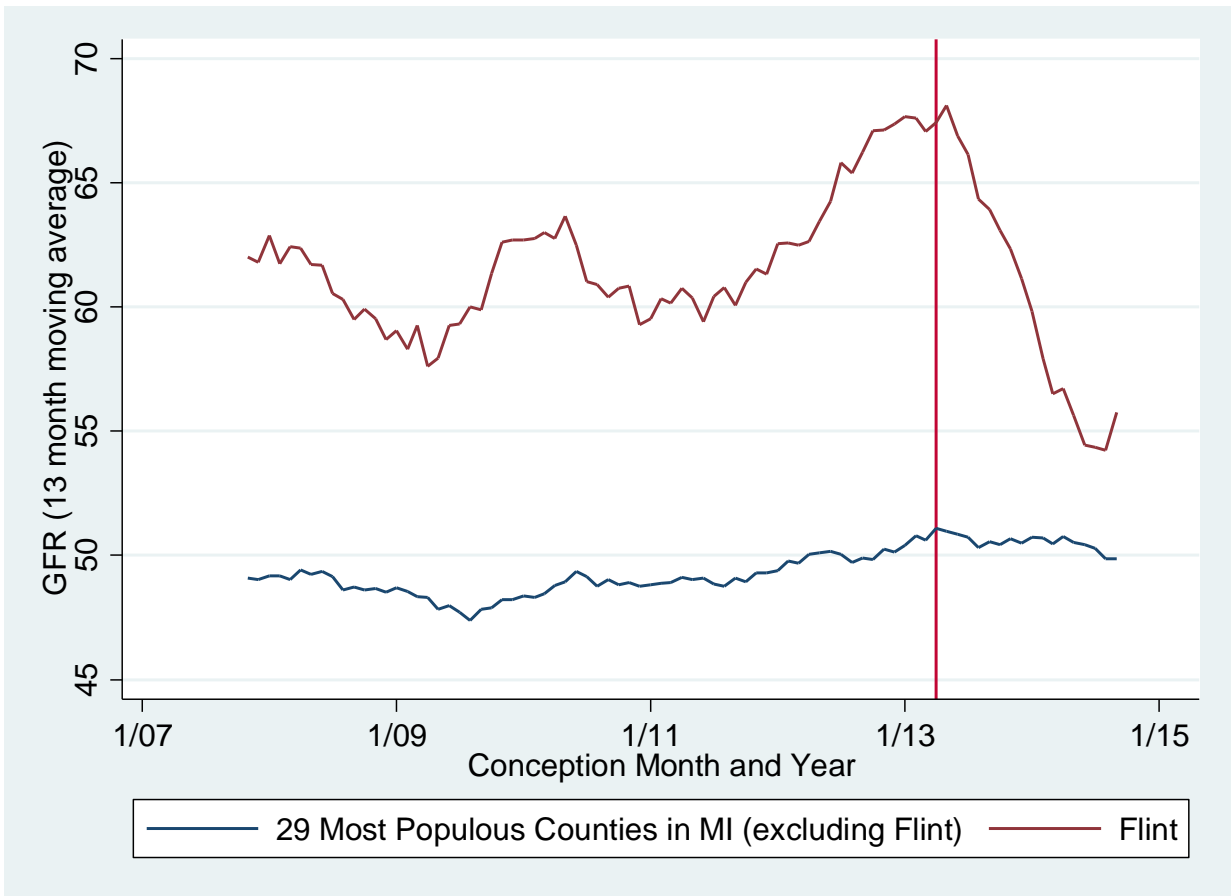
³² I.e., Allegan County, Bay County, Berrien County, Calhoun County, Clinton County, Eaton County, Genesee County, Grand Traverse County, Ingham County, Isabella County, Jackson County, Kalamazoo County, Kent County, Lapeer County, Lenawee County, Livingston County, Macomb County, Marquette County, Midland County, Monroe County, Muskegon County, Oakland County, Ottawa County, Saginaw County, St. Clair County, Shiawassee County, Van Buren County, Washtenaw County, and Wayne County.

Appendix Figure C1: Comparison Counties



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

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



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

Appendix Table C1: Summary Statistics

	(1)	(2)	(3)	(4)	(5)
	Non-Flint Births		Flint Births		
	Pre-Water Switch (N=643,955)	Post-Water Switch (N=137,808)	Pre-Water Switch (N=10,620)	Post-Water Switch (N=2,010)	Difference in Differences
Demographic variables:					
Mother's age (years)	27.78 (5.90)	28.32 (5.63)	24.66 (5.60)	25.17 (5.37)	-0.024
Mother no high school	0.141	0.115	0.294	0.271	0.003
Mother high school grad	0.249	0.240	0.317	0.343	0.035**
Mother some college	0.315	0.329	0.337	0.337	-0.014
Mother college grad	0.289	0.308	0.050	0.047	-0.023***
Outcome variables:					
General fertility rate	47.59 (7.96)	48.39 (8.27)	62.28 (6.81)	56.87 (6.76)	-6.22**
Male-Female Sex Ratio (percent male)	51.21 (0.50)	51.19 (0.63)	51.05 (4.59)	50.20 (3.06)	-0.82
Birth Weight (grams)	3,279 (616)	3,262 (627)	3,082 (632)	3,042 (651)	-23.7
Low Birth Weight	0.085 (0.28)	0.092 (0.29)	0.135 (0.34)	0.158 (0.37)	0.017†
Estimated gestational age (weeks)	38.56 (2.77)	38.48 (2.41)	38.08 (2.97)	37.89 (2.69)	-0.108
Gestational Growth (grams/week)	84.65 (14.44)	84.29 (14.27)	80.38 (14.33)	79.58 (14.48)	-0.437

Notes: For Columns (1)-(4), standard deviation for non-dummy variables in parenthesis. For Column (5), we present robust standard errors. †p < .10; *p < .05; **p < .01; ***p < .001

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

	(1)	(2)	(3)	(4)	(5)
Water (β_1)	-6.215*** (0.329)	-6.215*** (0.330)	-6.215*** (0.330)	-6.215*** (0.335)	-8.711*** (0.363)
Conception Month Fixed Effects		X	X	X	X
Conception Year Fixed Effects		X	X	X	X
City Fixed Effects			X	X	X
Conception Month into Year Fixed Effects				X	X
County Linear Time Trends					X

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

Appendix Table C3: Lead in Water on Other Birth Outcomes by County

	(1)	(2)	(3)	(4)	(5)
Birth weight (grams)	-23.72† (13.38)	-29.70* (14.41)	-27.95† (14.26)	-26.74† (14.57)	-18.77 (14.47)
Low Birth Weight	0.017† (0.009)	0.019* (0.009)	0.018* (0.009)	0.018* (0.009)	0.016† (0.009)
Gestational Age (weeks)	-0.108† (0.0574)	-0.126* (0.0601)	-0.119* (0.0593)	-0.119* (0.0591)	-0.104† (0.0594)
Gestational Growth (grams/week)	-0.437 (0.301)	-0.567† (0.322)	-0.532† (0.320)	-0.499 (0.329)	-0.316 (0.328)
Census Tract Fixed Effects		X	X	X	X
Conception Month Fixed Effects			X	X	X
Conception Year Fixed Effects			X	X	X
Child Sex Control				X	X
Mom Controls					X

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