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Something in the water: contaminated drinking water and infant health

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Abstract

This paper provides estimates of the effects of in utero exposure to contaminated drinking water on fetal health. To do this, we examine the universe of birth records and drinking water testing results for the state of New Jersey from 1997 to 2007. Our data enable us to compare outcomes across siblings who were potentially exposed to differing levels of harmful contaminants from drinking water while in utero. We find small effects of drinking water contamination on all children, but large and statistically significant effects on birth weight and gestation of infants born to less educated mothers. We also show that those mothers who were most affected by contamination were the least likely to move between births in response to contamination.

1. Introduction

Health at birth is predictive of important child outcomes, including educational attainment and adult earnings. Hence, economists are increasingly concerned with understanding the impacts of conditions during pregnancy on birth outcomes (Almond and Currie 2010, 2011; Black, Devereux, and Salvanes 2007; Case and Paxson 2008; Currie 2011). Exposure to environmental pollution during pregnancy is a common source of potential fetal health shocks. Recent research shows that, even at levels below current air quality standards, air pollution can harm fetal health as measured by the incidence of low birth weight and prematurity (Currie and Neidell 2005; Currie, Neidell, and Schmeider 2009). Drinking water contamination is another, potentially important, source of in utero exposure to pollution. A series of articles in the New York Times (cf. Duhigg 2009) have highlighted lapses in drinking water quality throughout the U.S., suggesting that contamination of drinking water may be relatively common.

This paper provides estimates of the effects of in utero exposure to contaminated drinking water on fetal health. To do this, we examine the universe of birth records and drinking water testing results for the state of New Jersey from 1997 to 2007. Our data enable us to compare outcomes across siblings who were potentially exposed to differing levels of harmful contaminants from drinking water while in utero. We find small effects of drinking water contamination on all children, but large and statistically significant effects on birth weight and gestation of infants born to less educated mothers. We also show that those mothers who were most affected by contamination were the least likely to move between births in response to contamination.

Our paper highlights several methodological issues relevant to the study of a broad range of fetal and infant health effects. First, women who are exposed to pollutants differ in observable ways from those who are not, and they may also differ in unobservable ways. These differences must be accounted for, or they will bias the estimated effects of potential exposure. Second, mothers can take action to protect themselves and their children from harmful exposures, such as moving away from pollution sources. Our results are consistent with previous literature that suggests that the more educated are more likely to take these protective actions (Graff Zivin, Neidell, and Schlenker 2011; Currie 2011). Third, babies with longer gestation have a longer window in which they could have been exposed to a harmful contaminant. Since, other things being equal, babies with longer gestations have better outcomes, estimation methods that do not take account of the longer exposure window are biased against finding an effect. Since we follow mothers over time, we explicitly examine moving and use mother fixed effects in order to deal with omitted variables bias[1] and use an instrumental variable constructed assuming gestation of nine months to deal with the mechanical correlation between gestation length and exposures.

The paper proceeds as follows. The next section provides a review of related literature; section 3 discusses the data; section 4 discusses the empirical framework; section 5 presents the results; and section 6 concludes.

2. Background literature

2.1. The impact of air pollution on infant health

Much of the growing literature about pollution and health has focused on the impact of air pollution on fetal health. The reason for examining fetal health is that, unlike adults, fetuses have a relatively short window in which they could be exposed to pollutants, so one can more confidently draw a connection between a contemporaneous pollution source and an adverse health outcome. In contrast, adults have been exposed to many pollutants over the course of a lifetime, and it may be difficult to connect current health problems with recent exposures. The reason for focusing on air pollution is that most developed countries have established systems of air quality monitoring stations, so that pollution data are readily available.

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[1]Note that this strategy does not account for changes in water consumption patterns in response to water quality violations (Graff Zivin, Neidell, and Schlenker 2011). This does not introduce a bias per se but changes the interpretation of estimates, so that our estimates reflect the effect of contamination net of avoidance behaviour. See Graff Zivin and Neidell (2013) for more details.

Cross-sectional differences in ambient air pollution have been shown to be correlated with other determinants of fetal health. In particular, fetuses exposed to higher levels of air pollution are more likely to be African-American or Hispanic and tend to have less educated mothers (Currie 2011). Failing to account for these relationships leads to upwardly biased estimates of the effects of pollution. Epidemiological studies typically have few (if any) controls for these potential confounders.[2]

Chay and Greenstone (2003a, b) address the problem of omitted variables by focusing on 'natural experiments' provided by the implementation of the Clean Air Act of 1970 and the recession of the early 1980s. Both the Clean Air Act and the recession induced sharper reductions in airborne particulates in some counties than in others, and they use this exogenous variation in levels of air pollution at the county-year level to identify its effects. They estimate that a one-unit decline in particulates caused by the implementation of the Clean Air Act (or recession) led to between five and eight (four and seven) fewer infant deaths per 100,000 live births. They also find some evidence that the decline in Total Suspended Particles (TSPs) led to reductions in the incidence of low birth weight. However, only TSPs were measured at that time, so that they could not study the effects of other pollutants. And the levels of particulates studied by Chay and Greenstone (2003a, b) are much higher than those prevalent today; for example, PM10 (particulate matter of 10 microns or less) levels have fallen by nearly 50% from 1980 to 2000.

Several recent studies consider natural experiments at more recently encountered pollution levels. For example, Currie, Neidell, and Schmeider (2009) focus on a sample of mothers who lived near pollution monitors, and they showed that babies exposed to higher levels of carbon monoxide (CO) in utero (which comes largely from vehicle exhaust) suffered reduced birth weight and gestation length relative to siblings, even though ambient CO levels were generally much lower than current Environmental Protection Agency (EPA) standards.[3] The estimates suggest that moving from an area with high levels of CO to one with low levels of CO would have an effect larger than getting a woman who was smoking ten cigarettes a day during pregnancy to quit.[4] Moreover, CO exposure increases the risk of death among newborns by 2.5%. The negative effects of CO exposure are five times greater for smokers than for non-smokers, and there is some evidence of negative effects of exposure to ozone and particulates among infants of smokers. Coneus and Spiess (2012) adopt similar methods using German data and also find large effects of CO on infant health.

Currie and Walker (2011) exploit the introduction of electronic toll collection devices (E-ZPass) in New Jersey and Pennsylvania. Since much of the pollution produced by automobiles occurs during idling or accelerating back to highway speed, electronic toll collection greatly reduces auto emissions in the vicinity of a toll plaza. They compare mothers near toll plazas with those who live near busy roadways but further from toll plazas

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[2]There are some important exceptions. For example, Parker, Mendola, and Woodruff (2008) study a natural experiment caused by the closure and reopening of a steel mill in a valley in Utah, and find that the closure reduced preterm birth.
[3]This study builds on an earlier paper by Currie and Neidell (2005), which imputed pollution levels at the zip code level.
[4]The standard for eight-hour CO concentrations is nine parts per million (ppm). The mean in our sample is 1.6ppm, but some areas had levels of around four. Moving from an area with 4ppm to one with 1ppm in the third trimester would reduce low birth weight by 2.5 percentage points, while going from ten to zero cigarettes per day would reduce the incidence of low birth weight by 1.8 percentage points.

and find that E-ZPass increases birth weight and gestation. They obtain similar estimates when they follow mothers over time and compare siblings born before and after adoption of E-ZPass. E-ZPass reduced CO by about 40% in the vicinity of toll plazas and also reduced concentrations of many other pollutants found in vehicle exhaust. These reductions reduce the incidence of low birth weight by about 1 percentage point in the two kilometres surrounding the toll plaza and by as much as 2.25 percentage points in areas immediately adjacent to the toll plaza.[5]

2.2. Evidence regarding the impact of water pollution

Congress passed the Safe Drinking Water Act (SDWA) in 1974 to safeguard public health by enabling the federal regulation of the national drinking water supply. This Act requires that the Environmental Protection Agency set health-based standards for common contaminants and oversee the enforcement of these standards. Amended in 1986 and 1996 to strengthen and extend the original rules, SDWA remains the major federal law concerning the nation's drinking water.

The SDWA applies to all of the more than 160,000 public water systems in the United States. These systems provide water to almost all Americans at some time in their lives.[6] Water for public water systems is drawn from underground wells or surface water sources, including rivers and lakes, and passes through treatment facilities before reaching distribution systems.

Under the guidelines set forth by the SDWA, testing for contamination is performed by a third party. Maximum Contaminant Limits (MCL) are set as the stricter of state and federal requirements and concentrations over these limits incur violations. Testing guidelines, including frequency, location, and follow-up actions, are determined by contaminant type, the size of the population served, and other parameters.[7]

Compared with air pollution, there has been relatively little investigation of the health effects of water pollution in rich countries such as the United States. Unlike air pollution, data on water pollution are more difficult to obtain and less conducive to estimating health effects. For example, although water quality is continuously monitored at all public water systems, data are reported only when violations occur, and they are accessible on a large-scale basis only by filing a Freedom of Information Act request.

There are a number of threats to drinking water in the U.S., including improper disposal of chemicals, animal and human wastes, pesticides, and naturally occurring substances such as radon and arsenic that make understanding the impacts of water quality important for policy. While these substances are indeed routinely monitored, it appears that there are many violations of Safe Drinking Water Act standards. According to Duhigg (2009), 20% of U.S.

[5] In contrast to the results reported below, they did not find any impact of E-ZPass adoption on the demographic composition of births in the immediate vicinity of the toll plazas in the three years before and after adoption. It is possible that mothers did not realize the health benefits associated with adoption.

[6] These regulations do not apply to private wells or bottled water. For more information, see http://water.epa.gov/lawsregs/guidance/sdwa/basicinformation.cfm.

[7] An explanation of the complex testing rules by contaminant type is beyond the scope of this article. For more information, see www.nj.gov/dep/watersupply/dws_monitor.html.

water treatment systems had violated provisions of the act over the past five years. While many of these violations involved failure to report test water or to report test results accurately, there are also many water systems with illegal concentrations of chemicals such as arsenic and radioactive elements.

Other papers have shown a correlation between contaminated drinking water and infant health (Bove et al. 1995; Bove, Shim, and Zeitz 2002; Fagliano et al. 2003; and Kotz and Pyrch 1999). This paper provides the first quasi-experimental examination of the effects of water pollution on infant health.

2.3. The importance of avoidance behaviour

Another issue that affects the measurement of the effects of pollution is avoidance behaviour. People take actions ranging from changes in daily activities to moving house in order to reduce exposures to harmful pollutants. If people act to minimize their exposure, then the potentially harmful effects of pollution may be understated by estimation procedures that do not take these actions into account. A growing body of evidence suggests changes in daily actions effectively reduce exposure to pollution, whether from poor levels of air quality (Neidell 2009) or mercury levels in fish (Shimshack, Ward, and Beatty 2007).

Most relevant to this study, Graff Zivin, Neidell, and Schlenker (2011) find, using purchase data from a national grocery chain, that drinking water violations increase the consumption of bottled water. They find that violations increase consumption by 17–22%, depending on the contaminant responsible for the violation. They also find that wealthier households are more likely to respond to chemical violations. While we are unable to control for this and other contemporaneous avoidance behaviours, we will exploit this heterogeneity to investigate whether the effects of contamination are higher in children from lower SES families.

With respect to mobility, Banzhaf and Walsh (2008), using California data from the decennial Census, find that high-income families tend to move away from highly polluted areas. Currie (2011) and Currie and Walker (2011) use continuous Vital Statistics Natality data to look specifically at the responses of pregnant women to either changes in local pollution levels, or to changes in information about pollution levels. For example, Currie (2011) shows that following the announcement that a Superfund site has been cleaned up, the share of white, college-educated mothers living in the area immediately surrounding the site increases, while the share of African-American, high school dropout mothers declines. Conversely, when new information is released about hazardous emissions of heavy metals at an industrial plant, the area immediately surrounding the plant becomes less 'white' and less college educated. These analyses suggest that pregnant mothers can respond relatively rapidly to perceived changes in environmental threats, but that it is primarily white college-educated women who do so. Since we follow mothers over time, we can explore whether water quality affects their decision to move.

3. Data and summary statistics

Our analysis relies on four sources of data: New Jersey vital statistics natality records (birth certificates) for the years 1997 to 2007, records of drinking water violations for New Jersey from 1997 to 2007, temperature and precipitation statistics, and a map of drinking water service areas in New Jersey. As described in the next section, precise information on the mother's location of residence from the birth certificates enables us to match these data sets together.

Our first data source is birth certificate data obtained from the Vital Statistics Division of the New Jersey Department of Health and Human Services. These data include a record for every birth and each record has information about the infant's health at birth, including birth weight and gestational age as well as maternal characteristics such as race, education, and marital status. We were able to obtain a confidential version of the data, which included the longitude and latitude of the mother's residence. Siblings were also matched with each other in the birth sample using mother's full maiden name, race, and birth date; father's information; and social security numbers where available.[8]

The second source contains data on testing requirements, reporting requirements, and water quality from the New Jersey Department of Environmental Protection (NJ DEP), which collects records of violations of maximum contaminant limits for drinking water. In this study, we use data on violations of MCLs only. There are many other violations that have to do with reporting requirements. The violations data include the start and end date of the testing period during which the violation was recorded, the contaminant name, testing site, name of the water system, and characteristics of the water system, including the size of the population served.[9] We omit these data, since it is unclear whether these violations pose a health threat.

We divided contaminants that posed a potential threat to human health into two categories. The first category, which we label 'any chemical contaminant,' includes 1,2-dichloroethane; antimony; arsenic; barium; benzene; beryllium; cadmium; carbon tetrachloride; dichloromethane; gross alpha, including radon and uranium; gross alpha, excluding radon and uranium; haloacetic acids (haa5); iron; lead and copper rule violations; manganese; mercury; nitrate; selenium; styrene; TTHM; tetrachloroethylene; thallium; trichloroethylene; combined radium (−226 & −228); and combined uranium. The second category, which we label 'any contaminant,' is broader and includes bacterial contaminants due to coliform from fecal matter and other sources in addition to all contamination in our first 'any chemical contaminant' category.

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[8]This matching was done on site in Trenton, and then all identifiers were stripped from the data. Given that we have a fixed time window, there are siblings we cannot find because the sibling was born either before the start of our window or after the end of our window. One way to assess the accuracy of our matching algorithm is to look for second and higher birth-order children where the 'date of last live birth' is in our time window, and see if we can find these births. We would not expect to find all of them, since some women will have moved from other states between births. For this group of children we are able to find 79% of previous births, giving us some confidence in our matching algorithm.

[9]We also focus our sample on community water systems. Community water systems pipe water for human consumption to at least 15 service connections used year-round, or one that regularly serves at least 25 year-round residents. Other types of water systems include transient non-community and non-transient, non-community. These other types of water systems supply water to people for short periods of time and include gas station, campgrounds, schools, office buildings, and hospitals.

The third data source is a digitized map of the community water service areas from the New Jersey Department of Environmental Protection (DEP) (Carter et al. 2004).[10] This map was originally created to enable long-term water supply planning, and to aid in emergency management during drought. The map, reproduced as figure 1, contains the coordinates of the boundaries of all community service areas, which change little over time.

Our subsample of all community water districts for 1997–2007 that have non-missing geographic information includes 488 systems. The smallest serves 22 people (Triple Brook Mobile Home Park), while the largest serves 773,163 (Hackensack Water Company, which serves several towns in northeastern NJ). The mean number of people served per water district is 19,011, while the median is 4,012.

Of this sample, 135 water districts have MCL violations during our time period. The smallest district with a violation serves 40 people, while the largest serves 314,900. The mean number served in the subsample with violations is 30,062.

The final source of data is daily temperature statistics for each 2.5 by 2.5 mile square in the state of New Jersey. Construction of these data follows Schlenker and Roberts (2006). Using these data, we construct, for each square, the average and absolute maximum and minimum daily temperature; the percentage of days with temperature below 0°C and above 29.4°C; and the percentage of days with precipitation and average daily precipitation. These data will help us control for fluctuations in weather that might affect exposure as well as infant health; for example, when it is hotter, people may drink more tap water, but heat is also related to birth weight (Deschenes, Greenstone, and Guryan 2009).

As discussed above, the birth data include the longitude and latitude of the mother's residence. Combining these data with the NJ DEP drinking water map using ArcGIS software,[11] we are able to match births to the water systems that serve their residences. Births that do not match to our map are dropped from our sample, as these residences utilize private wells and we have no information about their water quality.

We then merge the violation history of each water system into our matched data. We create two types of indicators. The first pair measures whether there were chemical or any violations that occurred during the child's actual gestation period, and the second measures whether there were chemical or any violations during the 39 weeks following each infant's conception. Constructed exposure variables based on a fixed gestation length of 39 weeks will be used as instrumental variables for the actual exposure measures in order to correct for the mechanical correlation between gestation length and the probability of exposure described above.

We match the weather data to each birth by the location of the mother's residence. To do this, we calculate the centroid of each 2.5 by 2.5 mile square and assign each mother to her

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[10]This map was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state authorized.
[11]ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

closest centroid. Then, we calculate averages of the daily weather statistics in the given centroid over each mother's gestational period.

Of the original sample of 1,283,598, 1,044,355 could be matched to a water district. Those outside water districts rely on wells, which are not systematically tested. Deleting 'one child' families resulted in 529,565 observations. Finally, we deleted observations with missing data on birth weight and gestation, as well as their siblings, which left 521,978 observations.

Table 1 provides summary statistics for the control variables used in our analysis. The first row with numbers of observations shows that 8% of infants were potentially exposed to drinking water contamination, owing to violations of MCLs when they were in utero (42,256/521,987). Of these, 84% were exposed to chemical violations. The most common chemical violations are from combined radium, TTHM, and gross alpha, each of which make up roughly 20% of the chemical violations. The most common sources of chemical exposure during the in-utero period are TTHM, haloacetic acids, and coliform, affecting 2.95%, 1.46%, and 1.43% of births, respectively.

Table 1 is arranged as follows. The first column shows means for the entire sample of children with a sibling in the data set. Columns (2) and (3) show means for the subset of infants who were potentially exposed to any violation or to chemical violations, respectively. Columns (4) and (5) show means for the subsample of siblings who identify the effects of pollution in our models, that is, cases where one sibling was exposed and the other was not. Hence, for example, the 80,507 infants in column (4) include both the 42,256 infants in column (2) and their siblings.

Table 1 suggests that infants exposed to any contamination are more likely to be low birth weight (birth weight less than 2,500 grams) and/or preterm (gestation less than 37 weeks) than the average infant, and that infants exposed to chemical contamination of drinking water in utero are particularly likely to have one of these negative outcomes. However, the rest of the table suggests that these relationships may not be causal: infants exposed to contamination in utero tend to have mothers who are younger, less educated, and less likely to be married than other mothers. They are also much more likely to be African-American or Hispanic than the average mother in New Jersey. All of these factors except Hispanic ethnicity are independently associated with poorer birth outcomes. It will be important to control for these and other potential differences in our estimation. Moreover, a comparison of column (2) and column (4), for example, suggests that the within-family differences in outcomes between exposed and unexposed siblings are not large. On the other hand, the sample of 'switchers' does not appear to be very different from the full sample of siblings.

4. Methods

Table 1 shows that there are observable differences between pregnant women who live in water districts with violations and those who do not. We will estimate models with mother fixed effects in order to control for all factors, observed and unobserved, that are constant between mothers. These models take the form

$$\text{Outcome}_{\text{iwmt}} = \beta_0 + \beta_1{}^*\text{CNTM}_{\text{iwmt}} + \theta^1 X_{\text{iwmt}} + \eta^1 \text{TEMP}_{\text{iwmt}} + \alpha_m + \gamma_t + \varepsilon_{\text{iwmt}} \quad (1)$$

for each infant i, born in year-month t, in water system w, to mother m. The outcomes we consider include low birth weight and prematurity. We estimate linear probability models. While this can be problematic in the case of very rare outcomes, neither low birth weight nor prematurity is particularly rare in our sample, affecting 5.2% and 7.8% of births, respectively. We use the linear probability models for ease of implementation of the fixed effects, instrumental variables specification described below.

CNTM$_{iwmt}$ is an indicator of contamination – either 'any chemical contamination' or 'any contamination.' X_{iwmt} is the following vector of indicators: mother's age: 19–24, 25–34, 35+, missing; mother's race: non-Hispanic white, non-Hispanic black, Hispanic, missing race; mother's education: less than high school, some college, college or more, education missing; risk factors for the pregnancy; maternal smoking; parity indicators; mother is married, marital information is missing; child is male, sex of child is missing. TEMP$_{iwmt}$ is a vector of weather controls including: maximum daily temp; minimum daily temp; percentage of days in which the daily maximum is above 29.4°C; percentage of days in which daily minimum is below 0°C; average daily precipitation; percentage of days in which precipitation is over 0. The α_m are a vector of mother fixed effects, while the γ_t are a vector of year*month of birth effects. The key coefficient is β_1, which measures the effects of exposure to drinking water contamination on the outcome of interest.

While mother fixed effects control for all fixed characteristics of mothers, location is not necessarily a constant, because women may move in response to contamination in their water districts. If contaminants exceed maximum contaminant level (MCL) standards, the purveyor of the local drinking water system must notify the NJ DEP of the violation and notify customers within 24 hours if the contaminant poses an immediate health threat (which primarily involves microorganisms and nitrates) and within 30 days for other health threats.

If a mother moves because of contamination, revealed preference arguments suggest that she preferred her first location to the available options in the absence of contamination. Suppose a mother experiences drinking water contamination in pregnancy 1, and moves to a new location where she does not experience contamination. In this situation, the estimated effect of experiencing contamination during pregnancy 1 will be biased towards zero, because the outcome of pregnancy 1 will be compared with the outcome of pregnancy 2, in which the woman did not experience a contamination but was residing in a suboptimal location.

However, before estimating these models, and in order to gauge the extent to which our estimates may be biased by endogenous maternal mobility, we estimate a series of models of the probability that a woman who was exposed to contamination during one pregnancy has moved by the time she has a subsequent pregnancy.[12] These models take the following form:

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[12]Note that the first birth observed in the data may not be the mother's firstborn child. This is why it is still necessary to control for parity.

$$\text{Moved}_{2wmt} = \beta_0 + \beta_1 {}^*\text{CNTM}_{1wmt} + \beta_2 {}^*\text{CNTM}_{1wmt} {}^*\text{CHAR}_{1wmt} + \theta^1 X_{1wmt} + \eta^1 \text{TEMP}_{1wmt} + \gamma_t + \varepsilon_{iwmt}, \quad (2)$$

where *Moved* refers to whether the mother had moved to a different water system by the time of the second birth. The other variables are defined in the same way as above, but are measured as of the time of the first birth. Given prior literature suggesting differential responses by mothers with different characteristics, the interaction term β_2 measures the differential impact of exposure on women with different personal characteristics. We estimate these models with different characteristics one at a time, including including education, race, ethnicity, age, and whether there are risk factors for the pregnancy.

Finally, to account for the potential endogeneity of gestation, we estimate models instrumenting CNTM using a 'full term gestation' instrument that measures whether the fetus would have been exposed to contamination had the pregnancy lasted the full term. This variable is easily constructed by asking whether each mother would have been exposed had the pregnancy lasted exactly 39 weeks. Since most pregnancies do last approximately 39 weeks, this variable is very highly correlated with actual exposure. Using it eliminates the mechanical correlation between actual gestation and exposure that occurs because a longer gestation creates a larger window in which someone can be exposed.

There is a great deal of interest in the question of whether exposure during particular trimesters is especially deleterious. However, our data are not well suited to answering this question. The problem is that the data on violations are not precise in terms of the timing. Generally, the length of the reporting period depends on the contaminant, and if there was a violation during the reporting period, then the water district is reported to have been in violation over the whole period. Hence, it is easier for us to tell whether there was a violation at some point during the pregnancy than to tell exactly when it occurred or how long it actually lasted.

5. Results

Table 2 shows estimates of our models of maternal mobility. As table 1 indicates, 37% of mothers were observed to move at least once between births. Panel A shows estimates using the 'any chemical' measure, while the second panel shows estimates using the 'any contaminants' measure. The first column suggests that there is only weak evidence overall that mothers who are exposed to contaminated drinking water during the first pregnancy are likely to have moved by the time of the next birth. The coefficient on 'any chemicals' is not statistically significant, while the coefficient on 'any contaminant' is significant at the 90% level of confidence. Note that we do not have enough statistical power to enter multiple measures of contamination in the same regression.

The remaining columns of table 2 suggest that the overall results may mask heterogeneity in the responses across mothers. When we allow the response to vary with maternal characteristics, the results suggest that mothers who are less educated are less likely than other mothers to move in response to contamination, while older mothers are more likely to move. There is also suggestive evidence that black and Hispanic mothers are less likely to move, though these interactions are not statistically significant. These estimates suggest that

we should expect to see larger estimated health effects for minority and less educated women because these women are less likely to take measures to avoid pollution, including moving.

Table 3 shows our main results for the estimated effects of exposure to contaminated drinking water on low birth weight and prematurity. The table is arranged to show the effects of changes in specification on our estimates. Column (1) shows that in an Ordinary Least Squares regression without mother fixed effects and without any correction for the mechanical correlation between gestation length and exposure, exposure to contaminated drinking water appears to have little effect on birth outcomes.

Column (2) shows, however, that when we instrument actual contamination using an indicator for whether contamination would have been experienced had gestation lasted exactly 39 weeks, the estimated effect rises by an order of magnitude, though it is still imprecisely estimated. Similarly, the point estimates in column (3) show that when we include mother fixed effects to control for unobserved characteristics of the mother that might be correlated with exposure, the point estimates rise.

Our preferred specification is shown in column (4) of table 3. This specification uses both maternal fixed effects and instrumental variables and clusters the standard errors at the level of the mother in order to allow correlation for correlations between the siblings. The estimates suggest that exposure to chemicals in the drinking water during pregnancy raises the probability of low birth weight by 6.5%, while any water violation (including chemical contamination) increases the probability of low birth weight by 6.1%.

It may be argued that the appropriate level for clustering is at the level of the water district and year, which allows all of the errors within a given water district to be correlated. A specification with this change is shown in column (5). The estimates are very similar to those in column (4), although they are slightly larger.

The same exercises are repeated for preterm birth in columns (6) to (10) of table 3. The point estimates in columns (9) and (10) imply increases in prematurity; they are not statistically significant. Only the estimate in the basic OLS model in column (6) is significant, but it is wrong-signed.

The first-stage regressions corresponding to table 3 are shown in appendix table A1. Appendix table A1 shows that whether or not contamination would have been experienced if the pregnancy had lasted 39 weeks in every case is strongly predictive of actual exposure. This is not surprising, since most pregnancies last about 39 weeks. Column (3) demonstrates that controlling for omitted characteristics of the mother by including mother fixed effects increases the size of the estimated effect.

As discussed above, it is likely that we will find larger effects in subsets of the population who are less likely to take measures to avoid contaminated drinking water. This hypothesis is tested in table 4, which shows interactions of the contamination variable with the same maternal characteristics explored in table 2, using the IV-FE model.[13] Again, we show results clustering two different ways, on the mother (in Panel A) and on the water district

and year (Panel B). The main effect of contamination is generally positive, suggesting that contaminated drinking water increases low birth weight, as in table 3. The interaction terms are statistically significant only for mothers with high school or less in Panel A, indicating that it is the less educated who are most likely to suffer negative health effects. The point estimate of 0.0098 on any chemical contamination represents a large percentage increase over the baseline incidence of low birth weight in the less educated mothers in our sample: 14.55% on a baseline of 0.0673. This point estimate is slightly greater than that on 'any contamination,' suggesting that chemicals in the water have more harmful effects than exposure to fecal coliform. When we cluster on the water district and year, the interactions on 'black' also become statistically significant, suggesting that African-American mothers may be more highly impacted by contaminated water.

Table 5 shows the same models for prematurity. The main effects do not suggest any overall effect. The interactions again indicate strong negative effects on less educated mothers and on black mothers in both Panel A and Panel B.

6. Conclusions

Mounting evidence links harms suffered in utero to outcomes later in life. Economists have begun to see the fetal period as one that shapes the trajectory of one's schooling, earnings, and health. Special attention should therefore be paid to harmful substances to which pregnant women might be exposed. While a good deal of recent research focuses on the effects of air pollution on fetal health, there has been little attention paid to the potential harm caused by contaminated drinking water.

This paper provides a first investigation of the effects of contaminated drinking water on fetal health and highlights several methodological issues that bedevil the measurement of these effects. First, we show that the women who live in areas with contaminated water supplies differ from other women in ways that one would expect to be correlated with worse fetal health. It is therefore important to control for these differences. Second, women may respond to contaminated water by moving elsewhere. We show that more educated women are more likely to vote with their feet. Third, there is a mechanical positive correlation between length of gestation and the probability of being exposed to most fetal health insults. We show that correcting for this bias can have an important impact on the estimated magnitude of the effect. Fourth, there is good reason to expect effects to differ by socioeconomic status. Just as they are more likely to move, more educated women are more likely to take measures to protect themselves and their children from contaminated water.

We find that living in a water district with contaminated water during pregnancy is associated with an increase in low birth weight of 14.55% among less educated mothers. Similarly, potential exposure to contaminated water increases the incidence of prematurity by 10.3% among less educated mothers. Since not every mother in an affected water district is likely to be exposed to contaminated water, these estimates suggest large negative effects

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[13]Larger effects may also exist for these subsets of the population because of poorer maternal health that is more susceptible to the effects of contamination.

among those women who are actually exposed to water contaminated by chemicals during pregnancy.

Acknowledgments

Appendix

TABLE A1

First-stage regressions corresponding to table 3

Second-stage outcome	(2) LBW	(4) LBW	(6) Premature	(8) Premature
1st-stage outcome				
Chem in 39 weeks	0.9960***	0.9960***	0.9960***	0.9960***
	(0.0001)	(0.0004)	(0.0001)	(0.0004)
1st-stage outcome				
Contam. in 39 weeks	0.9956***	0.9955***	0.9956***	0.9955***
	0.000105	(0.0004)	0.000105	(0.0004)
No. observations	521978	521978	521978	521978
Full-gestation IV	x	x	x	x
Mom FE		x		x
Year*month FE	x	x	x	x
Cluster SE on mom		x		x

NOTES: Column numbers refer to the analagous column numbers in table 3.

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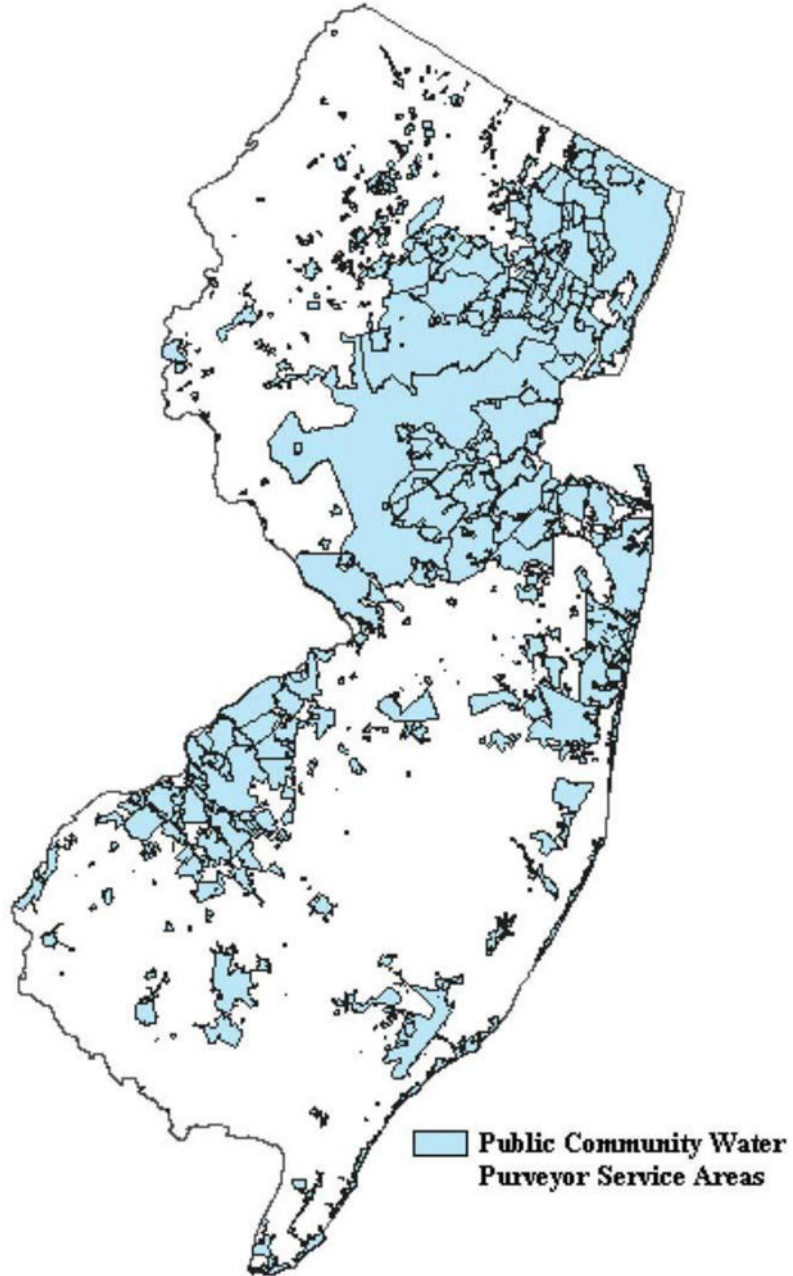
(State Boundary Shown for Reference Only)

FIGURE 1.
New Jersey water districts

TABLE 1

Sample means for all mothers and those potentially exposed

	All	Any contam.	Any chem.	Switchers Any contam.	Switchers Any chem.
No. of observations	521978	42256	35557	80507	68308
Low birth weight	0.0521	0.0578	0.0613	0.0578	0.0608
	(0.0003)	(0.0011)	(0.0013)	(0.0008)	(0.0009)
Preterm (<37 wks)	0.0739	0.0776	0.0811	0.0779	0.0802
	(0.0004)	(0.0013)	(0.0014)	(0.0009)	(0.0010)
Mom's age					
<19	0.0336	0.0461	0.0519	0.0530	0.0591
	(0.0002)	(0.0010)	(0.0012)	(0.0008)	(0.0009)
19–24	0.2029	0.2753	0.3017	0.2886	0.3144
	(0.0006)	(0.0022)	(0.0024)	(0.0016)	(0.0018)
25–34	0.5699	0.5256	0.5091	0.5186	0.5008
	(0.0007)	(0.0024)	(0.0027)	(0.0018)	(0.0019)
35+	0.1935	0.1530	0.1372	0.1398	0.1257
	(0.0005)	(0.0018)	(0.0018)	(0.0012)	(0.0013)
Mom's race					
African-American	0.1691	0.2235	0.2474	0.2242	0.2446
	(0.0005)	(0.0020)	(0.0023)	(0.0015)	(0.0016)
Hispanic	0.2317	0.3310	0.3589	0.2986	0.3223
	(0.0006)	(0.0023)	(0.0025)	(0.0016)	(0.0018)
Non-Hisp. white	0.5166	0.4011	0.3566	0.4306	0.3928
	(0.0007)	(0.0024)	(0.0025)	(0.0017)	(0.0019)
Mom's education					
No HS diploma	0.1521	0.2407	0.2685	0.2263	0.2498
	(0.0005)	(0.0021)	(0.0024)	(0.0015)	(0.0017)
HS	0.2780	0.2405	0.3302	0.314	0.3241
	(0.0006)	(0.0023)	(0.0025)	(0.0016)	(0.0018)
Some college	0.4228	0.3498	0.3237	0.3587	0.3374
	(0.0007)	(0.0023)	(0.0025)	(0.0017)	(0.0018)

	All	Any contam.	Any chem.	Switchers Any contam.	Switchers Any chem.
College or adv.	0.1308	0.0806	0.0657	0.0835	0.0701
	(0.0005)	(0.0013)	(0.0013)	(0.0010)	(0.0010)
Mother smokes	0.0774	0.0917	0.0952	0.0885	0.0903
	(0.0004)	(0.0014)	(0.0016)	(0.0010)	(0.0011)
Mother is married	0.6950	0.5728	0.5311	0.5864	0.5511
	(0.0006)	(0.0024)	(0.0026)	− 0.0017	− 0.0019
Mother moved	0.3719	0.3369	0.3118	0.3854	0.3606
	(0.0007)	(0.0023)	(0.0025)	− 0.0017	− 0.0018

NOTES: Standard errors in parentheses. Switchers refer to siblings in families where one child was exposed and the other was not. 'Mother moved' is equal to one if the mother moved at least once between births.

TABLE 2

Effects of comtamination during first birth on the probability of moving before second birth

Interaction	High school None	or less	Black	Hispanic	Over 35	Teen mom	Smoking
A: Any chem.	0.0098	0.0248[+]	0.0133	0.0176	0.0049	0.0120	0.0094
	(0.0076)	(0.0137)	(0.0103)	(0.0108)	(0.0076)	(0.0083)	(0.0077)
* Mom has CHAR		−0.0266[+]	−0.0176	−0.0211	0.0474[**]	−0.0244	0.0048
		(0.0142)	(0.0225)	(0.0154)	(0.0152)	(0.0182)	(0.0188)
B: Any contam.	0.0123[+]	0.0265[**]	0.0155[+]	0.0178[**]	0.0088	0.0139[**]	0.0120[+]
	(0.0066)	(0.0108)	(0.0086)	(0.0089)	(0.0066)	(0.0069)	(0.0066)
* Mom has CHAR		−0.0276[**]	−0.0174	−0.0167	0.0307[**]	−0.0198	0.0042
		(0.0123)	(0.0206)	(0.0147)	(0.0146)	(0.0177)	(0.0167)
No. observations	189705	189705	189705	189705	189705	189705	189705

NOTES: The sample consists of women who had two births in New Jersey between 1997–2007. The dependent variable is an indicator equal to 1 if the mother moved between the first and second births in the sample. The key independent variable is contamination during the first pregnancy. Exposure to contaminants during pregnancy is instrumented with potential exposure during the 39 weeks following conception. All regressions include year*month fixed effects and the following indicators measured at first birth: Mother's age (19–24, 25–34, 35+, missing); mother's race: (non-Hispanic white, non-Hispanic black, Hispanic, missing); mother's education (<12, 12, some college, college+, missing); mother smoked; risk factors for the pregnancy parity; mother married, married missing, child male, weather controls. Robust standard errors are clustered on the water system.

[+]
p < 0.10,

[**]
p < 0.05,

[***]
p < 0.001

TABLE 3

Effects of drinking water contamination on low birth weight and prematurity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	LBW	LBW	LBW	LBW	LBW	Premature	Premature	Premature	Premature	Premature
Any chem.	− 0.0001	0.0016	0.0018	0.0034 **	0.0037 ***	− 0.0042 ***	− 0.0008	− 0.0015	0.0021	0.0023
	(0.0012)	(0.0012)	(0.0017)	(0.0017)	(0.0017)	(0.0014)	(0.0014)	(0.0019)	(0.0019)	(0.0024)
Any contam.	− 0.0006	0.0012	0.0016	0.0032 **	0.0034 ***	− 0.0041 ***	− 0.0004	− 0.0015	0.0024	0.0025
	(0.0011)	(0.0011)	(0.0015)	(0.0015)	(0.0013)	(0.0013)	(0.0013)	(0.0017)	(0.0017)	(0.0020)
No. observations	521978	521978	521978	521978	521978	521978	521978	521978	521978	521978
Full-gestation IV		x		x	x		x		x	x
Mom FE			x	x	x			x	x	x
Year*month FE	x	x	x	x	x	x	x	x	x	x
Cluster SE on mom			x	x				x	x	
Cluster SE on water	district*year	x	x		x			x		x

NOTES: The sample consists of births matched to at least one sibling. Exposure to contaminants during pregnancy is instrumented with potential exposure during the 39 weeks following conception. All regressions include year*month fixed effects and the following indicators: mother's age (19–24, 25–34, 35+, missing); mother's race: (non-Hispanic white, non-Hispanic black, Hispanic, missing); mother's education (<12, 12, some college, college+, missing); mother smoked; risk factors for the pregnancy parity; mother married, married missing, child male, weather controls.

+
p < 0.10,

**
p < 0.05,

***
p < 0.001

TABLE 4

Effects on low birthweight for mothers with different characteristics (models with mother fixed effects and 39 weeks IV)

Mom CHAR:	HS or less	Black	Hispanic	Over 35	Teen mom	Smoking
Panel A: Cluster S.E. on Mother						
Any chem.	−0.0010	0.0018	0.0033+	0.0034+	0.0035**	0.0032+
	(0.0021)	(0.0018)	(0.0020)	(0.0018)	(0.0017)	(0.0017)
* Mom CHAR	0.0098**	0.0075	0.0003	0.0009	−0.0101	0.0067
	(0.0034)	(0.0048)	(0.0037)	(0.0075)	(0.0197)	(0.0124)
Any contam.	−0.0003	0.0021	0.0033+	0.0031**	0.0033**	0.0029+
	(0.0019)	(0.0016)	(0.0018)	(0.0016)	(0.0015)	(0.0015)
* Mom CHAR	0.0085**	0.0057	−0.0001	0.0018	−0.0043	0.0105
	(0.0031)	(0.0046)	(0.0035)	(0.0062)	(0.0194)	(0.0110)
No. observations	521978	521978	521978	521978	521978	521978
Panel B: Cluster S.E. on water district and year						
Any chem.	−0.0008	0.0020	0.0037+	0.0036**	0.0037**	0.0034**
	(0.0018)	(0.0017)	(0.0019)	(0.0017)	(0.0017)	(0.0017)
* Mom CHAR	0.0097***	0.0077**	−0.0001	0.0009	−0.0104	0.0069
	(0.0022)	(0.0036)	(0.0029)	(0.0051)	(0.0132)	(0.0101041)
Any contam.	−0.0001	0.0023	0.0036**	0.0033**	0.0035+	0.0031+
	(0.0015)	(0.0014)	(0.0016)	(0.0014851)	(0.0015)	(0.0015)
* Mom CHAR	0.0086***	0.0060+	−0.0004	0.0018	−0.0046	0.01067
	(0.0021)	(0.0035)	(0.0027)	(0.0042656)	(0.0134)	(0.0089193)
No. observations	521978	521978	521978	521978	521978	521978

NOTES: See table 3 notes. Mother characteristics are measured as of the first birth. Robust standard errors are clustered on the mother.

TABLE 5

Effects on prematurity for mothers with different characteristics (models with mother fixed effects and 39 weeks IV)

Mom CHAR:	HS or less	Black	Hispanic	Over 35	Teen mom	Smoking
Panel A: Cluster S.E. on mother						
Any chem.	− 0.0020	− 0.0003	0.0023	0.0024	0.0021	0.0014
	(0.0024)	(0.0020)	(0.0022)	(0.0020)	(0.0019)	(0.0019)
* Mom CHAR	0.0090**	0.0111**	− 0.0005	− 0.0044	− 0.0029	0.0192
	(0.0038)	(0.0052)	(0.0042)	(0.0089)	(0.0246)	(0.0122)
R-squared	0.0000	− 0.0000	− 0.0000	− 0.0000	− 0.0000	− 0.0000
Any contam.	− 0.0005	0.0005	0.0028	0.0027	0.0024	0.0018
	(0.0022)	(0.0018)	(0.0020)	(0.0018)	(0.0017)	(0.0017)
* Mom CHAR	0.0068+	0.0097+	− 0.0015	− 0.0056	− 0.0084	0.0166
	(0.0035)	(0.0049)	(0.0039)	(0.0075)	(0.0239)	(0.0109)
No. observations	521978	521978	521978	521978	521978	521978
Panel B: Cluster S.E. on water district and year						
Any chem.	− 0.0018	− 0.0002	0.0025	0.0025	0.0023	0.0016
	(0.0024)	(0.0022)	(0.0026)	(0.0024)	(0.0024)	(0.0023)
* Mom CHAR	0.0091***	0.0115***	− 0.0007	− 0.0044	− 0.0031	0.0197**
	(0.0028)	(0.0046)	(0.0032)	(0.0061)	(0.0183)	(0.0087)
Any contam.	− 0.0004	0.0006	0.0030	0.0029	0.0026	0.0019
	(0.0020)	(0.0019)	(0.0022)	(0.0021)	(0.0020)	(0.0020)
* Mom CHAR	0.0069**	0.0100**	− 0.0017	− 0.0056	− 0.0087	0.0171**
	(0.0027)	(0.0044)	(0.0030)	(0.0051)	(0.0176)	(0.0077)
No. observations	521978	521978	521978	521978	521978	521978

NOTES: See table 3 notes. Mother characteristics are measured as of the first birth. Robust standard errors are clustered on the mother.