Going Beneath the Surface: Petroleum Pollution, Regulation, and Health

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Abstract

This paper quantifies the health impacts of petroleum leaks from underground storage tanks, the effectiveness of tank regulation, and the role of information as a policy tool in the same setting. Exposure to a leaking underground storage tank during gestation increases both the probability of low birth weight and preterm birth by 7-8 percent. Compliance with regulations requiring the adoption of preventative technologies mitigated the entire effect of leak exposure on low birth weight, and information increased avoidance and moving among highly educated mothers. Back-of-the-envelope calculations suggest the health benefits of preventative regulations exceed the upgrade cost to facilities.

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Environmental disasters like the Flint water crisis and the Love Canal tragedy have generated growing concern over human exposure to pollution. Governments can address pollution concerns by directing cleanup efforts ex-post or by encouraging preventative actions among firms or individuals. Governments may require firms to adopt preventative technologies to reduce future pollution or may provide warnings to the public to encourage individual avoidance behaviors. Previous research has been unable to compare the effects of mandated firm adoption of preventative technologies to the effects of information provision on human health within the context of a single and homogeneous point source of pollution.

The existing literature on the health impacts of pollution has been growing rapidly. Research has documented the impacts of a range of pollutants on human health (Currie et al., 2014). Some studies have also documented that various regulations can help mitigate the negative health effects of pollution (Foster et al., 2009; Greenstone and Hanna, 2014). Within the US, this research has focused mainly on the health impact of regulation targeting non-point source pollution, such as air pollution (Chay and Greenstone, 2003; Marcus, 2017). Other research has shown that pollution information shocks can mitigate the negative health effects by increasing avoidance behaviors (Neidell, 2004, 2009; Zivin et al., 2011; Moretti and Neidell, 2011). In addition, some research has shown greater avoidance among the highly educated in some research (Currie, 2011).

However, until now, the literature has lacked a unified setting with a homogenous pollution source in which to document and quantify the relative importance of these effects. For example, research has shown that Superfund sites harm health and that avoidance response is greatest among the highly educated, but these papers are unable to compare the avoidance response to the effect of preventative regulation (Currie et al., 2011; Currie, 2011). Similarly, Chay and Greenstone (2003), Currie and Walker (2011), and Greenstone and Hanna (2014) study the effect of policy and regulation on health, but they cannot compare these effects to the impact of information as a policy tool. It is often difficult to study the role of pollution information on individual avoidance behavior, as many sources of pollution are already visible or publicized widely.

This paper improves upon previous research by using a single setting, leaking underground storage tanks (LUSTs), to quantify the health impacts of pollution, the effectiveness of regulation, the impact of information, and heterogeneous responses to information. This allows a direct comparison of the relative benefits for different policy tools, as well as a comparison of these benefits to the health effects of pollution exposure. In this way, I quantify how well different policy tools mitigate the negative health effects of exposure, as well as which individuals benefit most from different policies.

Leaking underground storage tanks provide a useful context to explore the effects of regulation and information as policy tools to protect health. Leaks occur underground and are not well publicized, making it unlikely for nearby residents to know that pollution exists. Zabel and Guignet (2012) show that property values in three Maryland counties decline for only the most publicized LUST sites. This is consistent with the idea that, on average, residents have little knowledge of nearby leak sites. It is important to understand how information about a previously unknown pollution source impacts avoidance behaviors and health, and how these impacts compare to alternate policy tools, such as preventative technologies. As the environmental justice literature has consistently documented greater exposure to pollution sources among low socio-economic groups, resource constraints may play an important role in individuals' ability and willingness to exhibit costly avoidance behaviors in response to information (Currie, 2011; Brulle and Pellow, 2006; Bowen, 2002; Viscusi and Hamilton, 1999; Gupta et al., 1996). This may have important implications for the distribution of benefits when using information as a policy tool.

In addition to comparing the health effects of pollution to the impact of regulation and information, this paper also contributes to the literature as the first paper to quantify the impact of leaking underground storage tanks on health. Leaking underground storage tanks are a ubiquitous and important source of pollution throughout the US and globally. Prior to underground storage tank (UST) regulation, there were approximately 2 million UST systems in the US, primarily storing petroleum products at gas stations.[1] The bare-steel constructed tanks were very likely to corrode and leak after about 20 years, making leaks extremely prevalent. As of September 2015, the EPA has confirmed approximately 528,000 leaks in total, costing over $1 billion per year in state and federal remediation costs. For

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[1] UST regulation resulted in many tank closures and today there are about 575,000 underground storage tanks used nationwide, 80 percent of which are owned by the retail motor fuels sector. USTs can also be found at manufacturing plants, dry cleaners, farms, and other commercial and industrial facilities in the US.

comparison, there are only 1,323 Superfund sites on the National Priorities List, and 391 sites have been deleted as of January 2016. Data used in this study shows that about 60 percent of UST facilities have experienced at least one leak. Contamination from LUST sites is very localized, usually traveling distances less than 300 meters. Nevertheless, 21 percent of mothers in this study live within 300 meters of a tank. Even though these localized pollution sites have been overlooked by many researchers, they are prevalent and impact a large population, making it especially important to estimate their impact on health and the role of government responses in mitigating their effects.

In addition, LUSTs are an important source of sub-surface pollution, allowing this paper to contribute to a limited literature on the health impacts of groundwater and soil pollution in the US. Whereas previous research has made great progress in exploiting natural experiments to quantify the health impacts of air pollution (Currie and Walker (2011); Luechinger (2014); Lleras-Muney (2010); Schlenker and Walker (2015), for example), the health impacts of groundwater and soil pollution in the US have been understudied by economists (Keiser and Shapiro, 2019).[2]

This paper also contributes to our understanding of the human health impacts of exposure to petroleum pollution. Gasoline contains more than 150 chemicals. Yet, many of these chemicals have unknown or uncertain health effects. Most of the limited existing evidence is based on animal studies and the extent to which effects on animal health can be translated to human health is the subject of some debate. In addition, the few existing epidemiological studies focus mostly on correlations by looking at adult health conditions for gasoline-exposed workers. These studies focus on adult health rather than infant health and generally do not control for selection into job type and other important omitted variables, such as smoking. These studies often have ambiguous findings, possibly due to multiple confounders, inadequate methodology, and small sample size (Sharara et al., 1998). Given these limitations, this paper also contributes to a very small literature on the human health impacts of exposure to petroleum pollution with a more convincing research design.

I combine detailed data from several sources to overcome identification challenges. Be-

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[2] Cutler and Miller (2005) and Currie et al. (2013) consider the impact of drinking water quality on mortality and infant health. Keiser and Shapiro (2016) estimate the impact of the US Clean Water Act on water pollution and home values, but do not consider health impacts.

cause LUST pollution is very localized, I use confidential Vital Statistics birth data from Pennsylvania, Florida, and New Jersey containing mothers' addresses to identify precise proximity to leak sites. To determine leak exposure during gestation, I use reported leak start and end dates from state databases. I show that endogenous residential sorting biases simple cross-sectional comparisons, since low-SES individuals are more likely to live near leaking tanks and to be in poor health for reasons unrelated to pollution. To overcome this challenge, I include maternal fixed effects and compare birth outcomes across siblings, using variation in gestational exposure to leaks driven by leak timing, rather than changes in maternal residential location. While maternal fixed effects capture all time-invariant characteristics, estimates could still be biased if time-varying unobservables vary systematically with leak timing. Therefore, I estimate the relative difference in sibling outcomes between exposed and unexposed siblings born to mothers within two narrow distance bands from a leak site. Mothers farther from the site act as a control group to account for any time-varying factors impacting all mothers near the leak. In order for these results to be biased, time-varying unobservable characteristics must vary systematically with leak timing, but differentially for mothers within these two narrow distance bands. Since leaks are underground and not well publicized, residents are unlikely to know of a leak when it occurs, which mitigates bias from avoidance behaviors.

I find that leak exposure during gestation increases both the probability of low birth weight and preterm birth by about 7-8 percent, prior to the regulation. This impact on low birth weight is similar in magnitude to the effect of the food stamp program and the adoption of E-ZPass (Almond et al., 2011; Currie and Walker, 2011). Evidence from mothers outside the public water supply areas and from water quality violations suggests that groundwater contamination is likely one channel, though not the only channel, through which these effects operate.[3]

After demonstrating that leaks harm infant health, I then estimate whether UST regulations successfully protected health. The EPA set technical standards for tanks, which

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[3] It is important to note the limitations in comparing heterogeneous treatment effects across these areas for example, as the underlying populations may differ in important ways that are relevant for the treatment effect. I address this by testing that the results are robust to including interactions of the main coefficients with additional demographic characteristics.

required owners to remove, upgrade, or replace their existing USTs by 1998 to comply with spill, overfill and corrosion protection. These regulations reduced the probability of fetal exposure to a leak by 16.5 percent relative to the pre-regulation mean. Conditional on exposure, facility-level tank upgrades entirely eliminated the effect of leak exposure on low birth weight. The results suggest that these preventative technologies were successful in protecting infant health along both the extensive and intensive margins.

Next, I explore avoidance behaviors in response to two types of leak information: direct notifications and local newspaper coverage. Avoidance behaviors might include drinking bottled water, avoiding contact with soil and groundwater, or even moving to a new residential location. The estimates indicate that local newspaper coverage reduces the negative health effects of exposure, especially for high-educated white individuals. This is consistent with findings in other settings that show information about pollution induces avoidance behaviors that protect health (Neidell, 2004, 2009; Zivin et al., 2011; Moretti and Neidell, 2011). I also find evidence that highly educated mothers exhibit an even more extreme avoidance behavior – moving – in response to information about leaks, which has implications for the distributional effects of information. Unlike most previous research that has documented aggregate neighborhood changes following pollution cleanup (Cameron and McConnaha, 2006; Banzhaf and Walsh, 2008; Gamper-Rabindran and Timmins, 2011; Currie, 2011), this paper focuses on responses to information. Currie (2011) also focuses on the information channel to show that neighborhood demographics change after increased reporting requirements for persistent bioaccumulative toxins (PBTs), which may be due to differential changes in the demographics of households moving into or out of the area. This paper shows complementary individual-level evidence that highly educated mothers move away from even very localized pollution sites after becoming informed.

Finally, I compare the costs and benefits of these different policy tools. Both information and preventative regulation mitigate the negative health effects of leaking underground storage tanks. Back-of-the-envelope calculations suggest the health benefits of preventative regulations account for 105-125 percent of the one-time upgrade cost to facilities. While information provision is a very inexpensive policy tool, the increased responsiveness of highly educated mothers to information suggests there may be distributional consequences of information that exacerbate the existing inequality in pollution exposure. In addition, placing avoidance costs on individuals leads firms to undervalue the costs of pollution, weakening incentives for firms to make efficient investments in risk reducing technology.

The rest of the paper proceeds as follows. Section 1 provides background on petroleum products and their impact on health, leaking underground storage tanks, and UST regulations. Section 2 describes the data. Section 3 describes the empirical strategy and estimates the health impact of leak exposure. Section 4 explores whether regulations protected health. Section 5 explores the role of information and avoidance behaviors. Sections 6 and 7 provide a cost-benefit analysis, discussion, and conclusion.

1 Background

1.1 Petroleum Products & Health

Petroleum products released underground may impact health through two main channels. First, vapor intrusion occurs when toxic vapors rise through soil and collect in confined spaces, such as basements, parking garages, or sewer lines. Second, leaks can contaminate soil and groundwater. Exposure to contaminated groundwater occurs through inhalation of volatile chemicals during showering, contact with chemicals during bathing or showering, and ingestion of chemicals through drinking contaminated groundwater. Over 75 percent of leaking UST sites involve groundwater contamination, and a spill of one gallon of gasoline can render 1 million gallons of water undrinkable (Cech, 2010).

While we know that UST sites leak and leak often, it is still difficult to determine the severity of leaks. The degree to which leaking tanks impact soil, groundwater, and air quality depends on groundwater velocity and flow direction, soil permeability, sorption of chemicals to solids, dispersion, water table depth, chemical contents of leak, size of leak, and many other factors. Because leaks are underground, mapping the extent of contamination is especially difficult and requires on-site sampling. Therefore, existing research has focused on case studies or a relatively small sample of sites. To my knowledge, this paper is the first to study the impact of these leaks in a large sample.

Half of the US population, and almost 100 percent of rural areas, rely on groundwater for drinking water. Although community water systems treat much of this water, small water systems often have few monitoring and notification systems to detect contaminants. About 39 million people drink water provided by "very small" (serving 500 or less people) or "small" (serving 501-3,300 people) water systems. In addition, 45 million people (14 percent) supply their own water for domestic use in the US, according to the USGS. About 98 percent of self-supplied water comes from fresh groundwater wells (Dieter et al., 2018). Many of the harmful chemicals found in petroleum products can pass undetected in air and water supplies. Chemicals are often clear or colorless and are dangerous to health at levels below their odor and taste thresholds (see Table A5).

Although petroleum products may harm health across all age groups, this study focuses on newborns for two main reasons. First, the study of health effects among adults is complicated because cumulative exposure matters. Poor health today may reflect both pollution exposure today and exposure that occurred in the distant past, and it is difficult to obtain a complete residential history for adults. Unlike adult health, birth outcomes can be linked directly to pollution exposure during gestation. Second, fetal health is sensitive to conditions in utero and these in utero shocks can have long-term consequences.[4]

Gasoline contains more than 150 chemicals. Many of these chemicals have unknown or uncertain health effects. Chemicals such as benzene, toluene, MTBE, and lead are suspected of adversely affecting child development and damaging the reproductive system. According to the National Institute of Health (NIH), repeated high exposure to gasoline can cause lung, brain, and kidney damage, and may damage the developing fetus in pregnant women. Some of the chemicals found in petroleum products, such as toluene, are fetotoxic agents, which cause generalized growth retardation and reduced maternal food consumption.

Laboratory experiments with pregnant animals and epidemiological studies suggest a possible link between various chemicals found in petroleum products and poor birth outcomes (Caprino and Togna, 1998; ATSDR, 2007; Hudak and Ungváry, 1978; Xing et al., 2010; Wang et al., 2000; Sharara et al., 1998; Donald et al., 1991). Specifically, benzene, toluene, xylenes,

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[4] See Currie et al. (2014) for a review of the literature on the short and long-term effects of early life pollution exposure.

and cadmium have been associated with reduced fetal body weight and delayed development in utero, which could result in lower birth weight. Shortened gestational age due to exposure to benzene and toluene could result in a higher chance of preterm birth. Various chemicals, including benzene, toluene, xylenes, tertiary amyl methyl ether (TAME), methanol, and cadmium, have also been linked with chromosomal abnormalities, skeletal anomalies, and other birth defects.

1.2 Leaking Underground Storage Tanks

Initially, there were about 2 million USTs across the nation, and the EPA estimated that over 95 percent held petroleum products.Approximately 80 percent of USTs were constructed from bare-steel tanks, which were very likely to corrode and leak (EPA, 1988). In general, leaks can occur as a result of corrosion, ground subsidence, defective piping, improper installation, or spills during refilling and maintenance. As of September 2015, the EPA has confirmed approximately 528,000 leaks in total throughout the US.

Unlike many other pollution sites, leaking USTs are less likely to be observed by nearby residents. If residents observe physical signs of contamination, this would likely prompt them to file a complaint. Data from Pennsylvania indicates that only about 8.6 percent of leak notifications originate from complaints to the department. The majority of notifications come from tank owners and operators (42.0%) or tank installers and inspectors (42.3%). In addition, Zabel and Guignet (2012) find that only the most publicized LUST sites have any impact on housing values. Using newspaper articles covering leaking underground storage tanks from local and regional sources, the ratio of articles to leaks is approximately 1 to 20. These observations suggest that residents are unlikely to know about pollution at the average LUST site. However, we might expect to find evidence of avoidance behaviors when sites are publicized or residents are notified of a leak.

1.3 UST Regulation

In response to public concern over the increasing threat to groundwater from leaking underground storage tank systems, a federal program was created to regulate USTs containing petroleum and certain hazardous substances. In 1988, the EPA put into effect the UST regulation (40 CFR Part 280), which set minimum standards for new tanks and required owners and operators of existing tanks to comply with requirements for specific preventative technologies. Table A2 in the appendix provides a detailed history of UST regulation in the US.[5]

First, existing USTs were required to use a leak detection system within five years of the 1988 regulation, depending on the age of the tank. In order to reduce leaks, owners and operators had to comply with new requirements for spill, overfill, and corrosion protection by upgrading, replacing, or closing their existing tanks by December 1998. While corrosion protection was likely to reduce the number of leaks, spill and overfill protection were targeted at reducing the severity of leaks. The estimated cost for a three-tank system was \$15,000 - \$33,000 to remove, \$12,700 to upgrade, or \$80,000-\$100,000 to replace all the tanks, according to the EPA.

In addition, the regulations set forth corrective action and closure requirements, and required owners to demonstrate financial responsibility for cleanup and damages in the event of a leak.[6] Record-keeping was required for leak detection reports, compliance with spill, overfill, and corrosion protection, tank repairs, and tank closures. Penalties for non-compliance could be up to \$10,000 per violation per day past the deadline for each tank.

2 Data

In this section, I describe the main sources of data used in this paper. The appendix provides additional details and describes supplementary data used in the analysis, including public water supply data, public direct notification data, newspaper data, and census data.

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[5] Although it is outside the scope of this paper, leaking underground storage tanks are also a concern internationally. Most of the European Union member states, for example, adopted requirements for the construction, installation, or operation of UST systems in the 1990s (see Barker and Marples (2001) for a comparison of US and EU UST regulations). However, these standards differ across countries and the health threats are likely to differ due to differences in geography, water table depth, soil type, source water monitoring, etc.

[6] See Boyd (1997) and Boyd and Kunreuther (1995) for a detailed description of financial responsibility rules and a discussion of challenges to optimal policy design in the context of leaking underground storage tanks.

Vital Statistics Birth Data

Data from individual Vital Statistics Natality records for 1989 to 2008 provide information on birth outcomes and maternal characteristics.[7] I calculate precise proximity of mothers to underground storage tanks using confidential data containing mothers' street addresses from Florida, New Jersey, and Pennsylvania. These states were chosen due to the availability of the necessary LUST data and availability of maternal addresses in the birth record. To compare siblings, I link mothers over time using a unique identifier generated from each individual's social security number in Pennsylvania and using first name, maiden name, date of birth, and race in New Jersey and Florida.

This rich source of geographic information on individuals over time provides an opportunity to investigate detailed residential sorting and moving behaviors of individuals. Maternal addresses offer several advantages over previous studies that use housing prices or decennial Census data to determine sorting behaviors. Whereas housing price data is only observed when houses are sold, maternal location is observed even if the previous house remains unsold or was abandoned. Maternal location data also captures renters, who are more affected by leak sites. Since renters are unburdened by home ownership, they may have a lower cost of moving. Unlike Census data, maternal location data is observed at a very fine scale in both space and time. The main limitations of these data are that the exact timing of the move between births is unknown and that only moves occurring between the first and last observed birth are captured.

The Vital Statistics Natality data also provide a rich source of demographic information, including mother's age, marital status, smoking behaviors, education, race and ethnicity; the child's gender, gestation, and birth order; and whether it was a multiple birth. I limit the sample to singleton births and mothers between the ages of 15 and 45.

Laboratory research, as described in section 1, suggests petroleum products may impact birth weight, gestation, APGAR score, congenital anomalies, or abnormal conditions.[8] In

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[7] The main results use data up until 2008 because the only available data on leaks in NJ was last updated on March 9, 2009. The analysis of direct notifications in FL uses data until 2012 to maximize sample size.

[8] APGAR score is a summary measure of initial infant health status. It ranges from 0 to 10 and is calculated from five separate tests (each receiving a score from 0 to 2) of newborn health: heart rate, respiratory effort, muscle tone, reflex irritability, and color. This study uses the 5-minute APGAR score, conducted 5 minutes after birth. Congenital anomalies exclude chromosomal congenital anomalies. Abnormal conditions include Hyaline Membrane Disease/Respiratory Distress Syndrome, assisted ventilation, and seizures. These

addition to studying these outcomes individually, I create a summary measure of newborn health where k indexes the following binary health outcomes (x): low birth weight, preterm birth, low APGAR score, congenital anomaly, and abnormal condition. Each variable is oriented such that higher values indicate worse health outcomes. The index aggregates information across related outcomes, allowing for an estimate of the impact on overall infant health and reducing the number of statistical tests performed so as to reduce the chance of false positives. I use the standardized mean value, where the original data have been normalized by the mean ($\overline{x_k}$) and standard deviation ($\hat{\sigma}_k$) of the variable, as in Kling et al. (2007).[9] The results are robust to alternate indexes, including the sum of binary poor health outcomes scaled by the total outcomes and the first principle component.

$$IndexZ = \frac{1}{K}\sum_{k=1}^{K}\frac{x_k - \overline{x_k}}{\hat{\sigma}_k} \tag{1}$$

UST Data

Underground storage tank databases for each state provide facility addresses for all registered tanks. I obtain information on all known tank leaks from each state, including the confirmed release date and case closure date.[10]Throughout this paper, I refer to the confirmed release date as the leak start date. This is not a perfect measure since it is possible that the leak begins earlier than this date. It also takes time for the contamination to travel through the sub-surface to a distance that would affect nearby residents. I address these timing concerns in section 3.4 and show that the timing of poor health outcomes coincides with the leak start date. I consider the leak end date to be when the case reaches a status indicating cleanup activities are complete.[11] Table 1 provides summary statistics on facilities and leaking UST

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conditions were chosen in part due to consistent recording across states and time, and also because of their potential to be affected. Following commonly used medical classifications, low birth weight is defined as birth weight below 2,500 grams, preterm birth is defined as a gestation less than 37 weeks, and low APGAR score is defined as a 5-minute APGAR score below 7.

[9] This index can be interpreted as the average of results for separate measures, scaled to standard deviation units. Kling et al. (2007) also estimate the mean effect size using a seemingly unrelated regression approach (SUR) to estimate the covariance of the effects. Both approaches yield identical treatment effects when there are no missing values and no regression adjustment. In this paper, I focus on the index for simplicity.

[10] Data on NJ releases came from the EPA's 2011 National LUST Cleanup Backlog study. Thanks to Will Anderson and Susan Burnell from the Office of Underground Storage Tanks for sharing these data.

[11] Each state records different possible statuses. For PA, end dates occur when the status indicates cleanup

sites used in this analysis. There are 113,646 facilities with about 3 tanks per facility. About 60 percent of facilities experience a leak, and conditional on having at least one leak, facilities experience 1.2 leaks on average. Figure A3 shows the locations of all 80,599 leaks recorded in the data from 1989 to 2009. Leaks are dispersed widely across each state with higher concentrations in areas with high population density. Based on a small subset of data from Pennsylvania, the average leak size is about 524 gallons. Although the leak size is missing for too many observations to be used in the analysis, leaks can be large enough to pose a threat to health.

To examine the impact of UST regulation, I construct a measure of facility compliance based on installation and removal dates of tanks at each facility in Florida and Pennsylvania. New Jersey is excluded from this analysis since installation and removal dates are not available. To comply with the 1998 technical requirements, facilities had to either replace or upgrade their existing tanks by December 22, 1998. For the former, I define the facility compliance date as the date of new tank installation if the new tank was installed within half of a year from the last tank removal that occurred before the deadline. For the latter, I do not observe the retrofitting of old tanks. So I define the facility compliance date as the deadline, December 22, 1998, if the facility had existing tanks and was still in operation after the deadline.

3 Health impacts of leak exposure

3.1 Estimation strategy

The environmental justice literature has argued that minorities and the poor are disproportionally exposed to environmental pollution. Consistent with this hypothesis, I find that low-SES mothers are more likely to live near pollution sites. Mothers living very near tanks are more likely to be younger, smokers, unmarried, non-white, and low educated, as seen in

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completed, inactive, interim or remedial actions initiated, or administrative close out. For FL, end dates occur when the status indicates no further action (NFA) complete, NFA with conditions, cleanup not required, report of discharge received, remediation by natural attenuation, or SRCR complete. For NJ, closure dates are reported in the data received from the EPA's Backlog study. Sites where no cleanup is required are excluded from the analysis. Only sites with complete leak timing data are included in the analysis.

Table A4. Figure 1 shows maternal and neighborhood demographic characteristics by distance to sites that ever or never experience a leak. Interestingly, the gradients are generally flat for mothers near non-leaking sites, while mothers near leaking sites are less white, lower educated, younger and more likely to live in neighborhoods with low median incomes, high poverty, and many renters. These gradients with distance to leaking sites exist even after conditioning on facility, such that, holding the facility-specific location constant, mothers living nearest to the facility are more disadvantaged (see Figure A4 and Table A3 in the appendix).

Since infants born to more disadvantaged mothers are more likely to have worse health outcomes even in the absence of pollution exposure, a simple cross-sectional analysis would be biased. Therefore, I include maternal fixed effects and exploit variation in exposure over time to address this key identification problem. Within-mother estimates compare birth outcomes across siblings, where siblings are either exposed or unexposed to a leak in utero. Maternal fixed effects capture all time-invariant characteristics, such as race, education, permanent income, fixed neighborhood characteristics, etc.

The remaining threat to identification is time-varying unobservable characteristics (e.g. local economic conditions) that vary systematically with the observed leak timing. To address this concern, I compare mothers within two small radii of the leaking site, 300 and 600 meters. These distances are consistent with observed petroleum plume lengths.[12] Mothers within 300 meters are most likely to experience negative health effects, while mothers 300-600 meters will serve as a control group to account for any time-varying characteristics that impact all mothers near the leak. Table A4 in the appendix shows characteristics of mothers within these small radii and for the full sample.

The basic empirical specification to estimate the impact of reported leak exposure during

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[12] Connor et al. (2015) provides a review and summary of published scientific surveys showing that the observed lengths of benzene and MTBE plumes are relatively consistent among various regions and hydrogeologic settings. The median plume lengths for a concentration of 5μg/L were 54m and 83m for benzene and MTBE, respectively. The 90th percentile plume lengths were 129m and 161m for benzene and MTBE, respectively. Therefore, the choice of 300m as the treatment group is conservative since many plumes will not travel this distance, suggesting that the results may be underestimates of the true effect of exposure. Table A6 in the appendix shows results for alternate distances to define the treatment group: within 100m, 200m, 300m, 400m, and 500m. Point estimates are larger for mothers living very near leak sites and diminish as the distance increases.

gestation on infant health is as follows:

$$Y_{ijym} = \beta_0 + \beta_1 Near_{ij} \times Exp_{ij} + \beta_2 Exp_{ij} + B' X_{ij} + \gamma_j + \lambda_y + \mu_m + \varepsilon_{1ijym} \tag{2}$$

for each infant i, born to mother j, in year y, and month m. X_{ij} is a vector of maternal and child characteristics including smoking status, maternal education, marriage status, age, age squared, birth parity dummies, child gender, and missing indicators. The specification also includes mother fixed effects, γ_j, year dummies, λ_y, and month dummies, μ_m. Standard errors are clustered at the mother level. The sample is limited to births occurring prior to the 1998 regulation deadline. Mothers with only one observed birth are kept in the sample to help identify fixed effect coefficients. The variable $Near_{ij}$ equals one if the mother lives within 300 meters of the leak site and zero if the mother lives 300-600 meters from the leak site. The coefficient of interest, β_1, estimates the within-mother impact of exposure during gestation by comparing exposed versus unexposed siblings within 300 meters of the site, relative to the same sibling difference slightly farther from the site.

Exposure, Exp_{ij}, is based on reported leak timing relative to the period of gestation. I use two different measures of exposure based on leaks occurring within 600 meters of each mother. First, a binary exposure variable equals one if a reported leak occurs during gestation. Since leak duration may matter, the second measure is the mean days of gestational exposure across all reported leaks. Results are similar for exposure measures based on the maximum days of exposure across all leaking tanks during gestation, and based on the number of sites reported leaking during gestation. Because measures of exposure use gestation length in their construction, they are endogenous. Births with shorter gestation are less likely to be exposed to a leak, simply because they spend less time in utero, and yet they are more likely to experience negative health outcomes. To avoid this mechanical relationship, I instrument for true exposure using hypothetical exposure based on a full, 39-week, gestation period. The 39-week exposure measures are unrelated to true gestational length. In addition, to address the possibility of endogenous exposure driven by maternal moving behaviors, I use exposure based on a mother's first observed location. Table A12 shows that results are similar when the sample is limited to non-moving mothers. In this way, variation in leak exposure is driven by the timing of leaks, rather than mothers' moving behavior. I study moving behaviors in response to leaks and leak information separately in section 5.

In order for the results to be biased, time-varying unobservable characteristics must differ systematically with leak timing but differentially for mothers within these two narrow distance bands. Since I do not observe all time-varying characteristics, it is impossible to prove this assumption holds. However, I can show that time-varying observable characteristics are not driving the results. Table 2 estimates equation 2 with time-varying characteristics as outcome measures and controls for age, parity, year, month, and maternal fixed effects. The results show there is no statistically significant relationship between observable time-varying characteristics and gestational leak exposure within 300 meters. The magnitudes of the effects are small, suggesting that these point estimates are also economically insignificant.

3.2 Results: Health effects of exposure

Panel A of Figure 2 shows graphical evidence of the impact of leaking underground storage tanks on infant health. Index Z is a summary measure of poor health outcomes at birth, as defined in section 2. The figure plots point estimates of the coefficient on exposure for each of 40 distance bins after controlling for maternal and child characteristics, mother fixed effects, year dummies, and month dummies. The dashed line smooths these point estimates to depict the general shape of the response function. In utero exposure to a reported leak increases poor health outcomes for distances close to the leaking tank. The impact of exposure on poor health is largest for those living closest to the tank and diminishes as distance increases. Effects are concentrated at distances consistent with summary of observed petroleum plume lengths in Connor et al. (2015). If health effects were found for much farther distances, this would call into question the validity of the results since petroleum plumes rarely travel farther than 300 meters. However, the figure shows that the effect of leak exposure is close to zero for distances farther than 300 meters. Other birth outcomes follow a similar pattern and are shown in Figure 3.

Panel B of Figure 2 shows the analogous graph for time-varying maternal characteristics. Following the method for creating the health index, I calculate a standardized mean value index of maternal characteristics using the following binary indicators associated with poor infant health: smoking status, unmarried, risky pregnancy, and no prenatal visits.[13] The figure plots point estimates of exposure by distance bin after controlling for age, parity, year, month, and maternal fixed effects. Changes in time-varying maternal characteristics cannot explain the impact of leak exposure on health. The point estimates do not follow the same pattern and show no relationship between distance and exposure. Figure A6 in the appendix shows additional graphs of specific time-varying maternal characteristics. Consistent with results presented in Table 2, there is no evidence of a relationship between exposure and distance for these outcomes. This suggests that the results are not driven by other time-varying characteristics.

Before presenting the main results, I demonstrate the inherent bias in the cross-sectional estimates and illustrate the need for maternal fixed effects in this specification. Table 3 shows a comparison of specifications with and without maternal and child controls for low birth weight (see Table A8 in the appendix for all outcomes). The first two columns do not include any fixed effects. Comparing the cross-sectional estimates in columns 1 and 2, the coefficient of interest changes by an order of magnitude when maternal and child controls are added, suggesting that these estimates are quite biased.[14] Columns 3 and 4 show the same specifications with the addition of facility fixed effects. The coefficient of interest still changes by about an order of magnitude with the addition of controls. Finally, columns 5 and 6 show estimates with maternal fixed effects. The coefficient of interest is stable across specifications with and without controls, suggesting that maternal fixed effects capture almost all of the characteristics causing bias in the OLS specification. For this reason, the preferred specification includes maternal fixed effects in the results that follow.

Table 4 shows estimates from equation 2 of the health impact of exposure to a reported leak. Panel A includes exposure duration in days, while Panel B includes a binary exposure

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[13] An alternate way to calculate this index is to use the predicted value of a regression of the poor infant health index on maternal characteristics. Figure A5 shows that the pattern of result is similar for this predicted index.

[14] In addition to coefficient movements, it is important to take into account movements in R-squared values. Following Oster (2014), who formalizes a bounding argument for omitted variable bias under the proportional selection relationship, the bias-adjusted coefficient in this specification is 4.95 (assuming the unobservables are not more important than observables in explaining the treatment, and with the upper bound on R-squared as 0.6). This coefficient leads to a completely different conclusion so the OLS specification is strongly biased. Similarly, the bias-adjusted coefficient in the facility fixed effects specification is 1.92, suggesting facility fixed effect specification is still strongly biased.

variable. The former captures both the extensive and intensive margins, while the latter captures only the extensive margin. The first three columns show the impacts on the summary measures of health, and columns 4-8 show the impacts on low birth weight, preterm birth, APGAR score, congenital anomalies, and abnormal conditions. The impact on all three summary health measures is positive and significant. Infants born near a leaking tank during gestation experience worse health outcomes relative to their unexposed siblings. The effects on low birth weight and preterm birth, columns 4 and 5, are also positive and significant. Looking at Panel B, exposure increases low birth weight by 0.60 percentage points, or about 8 percent from the mean. Exposure increases preterm birth by 0.69 percentage points, or about 7 percent from the mean. Exposure also lowers the APGAR score by 0.01 points on a scale from 0 to 10, where lower scores indicate worse health. This is a very small decrease, only 0.13 percent from the mean.

3.3 Groundwater as a mechanism

Although exposure can occur through inhalation of toxic vapors and soil exposure, contaminated groundwater is of particular concern. To test the importance of this pathway, I first estimate the effects for individuals living outside of public water supply (PWS) areas. Because individuals living outside of the PWS area generally obtain their water for drinking, bathing, and cooking from wells, larger health impacts for this population are consistent with exposure through groundwater contamination. Data on public water supply areas are available for New Jersey and Pennsylvania only (see appendix for data detail). Figure A2 shows the spatial distribution of leaks in relation to public water supply areas. While the majority of leaks occur within these areas, a large number of leaks occur in areas without public water supply.

Results in Table 5 show the health effects separated by whether or not the mother lives within a public water supply area. Even though the sample size is restricted to only Pennsylvania and New Jersey, reported leak exposure occurring both inside and outside of PWS areas still significantly harms health. The point estimates for leak exposure occurring outside of PWS areas suggest large health effects. For example, reported leak exposure outside of PWS areas is associated with a 38 and 40 percent increase in the probability of low birth weight and preterm birth, respectively. An equality test shows whether the health impacts are statistically significantly larger for non-PWS areas compared to PWS areas. Even though the small sample of mothers living outside PWS areas limits statical power, for preterm births, the effects are statistically significantly larger outside PWS areas.

It is important to note, however, that these health impacts may be larger in non-PWS areas either due to groundwater contamination or due to larger impacts among certain demographic groups that may be more prevalent in rural areas, such as low SES individuals. Table A7 in the appendix includes additional controls to account for potential heterogeneous effects of exposure across demographic groups. Effects of exposure are still statistically significantly larger outside PWS areas for both low birth weight and preterm birth.

Second, I explore whether reported leaks near public supply wells increase PWS water quality violations (see appendix for data source and variable construction details). I estimate a hazard model, because it is likely to take an unknown amount of time for the petroleum product to travel from the leak site to the water supply intake location, meaning that leaks and violations are not necessarily contemporaneous. Petroleum products are most likely to cause a maximum contaminant level (MCL) violation for volatile organic chemicals (VOCs). Therefore, I consider the relationship between leaks near PWS source wells and VOC violations. I use other violation types as placebo tests. Table 6 estimates the following stratified Cox Proportional Hazard model:

$$h_p(t|leak, pop) = h_{0p}(t) exp\left[\theta_1 leak(t) + \theta_2 pop\right] \tag{3}$$

where p indexes strata defined by type of PWS system (community, non-transient community, and transient non-community). The specification controls for population and standard errors are clustered at the PWS system level.

First, columns 1-2 of Table 6 show OLS coefficients. Column 1 shows that a leak near the source well increases the probability of a VOC violation by about 0.5 percentage points. Column 2 includes a lag indicator for the presence of a leaking tank in the previous year. The results suggest that leaks occurring in the past statistically significantly increase the probability of a VOC violation in the current year.

Columns 3-9 report the results from the hazard model shown in equation 3. Columns 3-5 show the change in the hazard of a VOC violation with three different measures of a reported leak. The variable of interest in column 3 is an indicator equal to one when a leak occurs near a source well for each PWS. The variable of interest in column 4 is equal to one if any leak has occurred in the past, and column 5 uses the cumulative number of leaks that have occurred. The coefficients in columns 3-5 are all positive and significant, suggesting that leaks near PWS source wells increase the hazard of a VOC violation. The parameter estimates indicate the increase in expected log of the relative hazard for a one unit increase in the predictor, holding population constant. In column 3, a nearby leak increases the expected log of the relative hazard of a VOC violation by 2.38 for water systems with source wells near a leak as compared to those not near a leak. Converting this to a hazard ratio, it suggests that the expected hazard of a VOC violation is 10.8 times higher in water systems with a source well near a leak.

By contrast, this relationship does not hold for other types of violations. Columns 6-9 show leaks do not significantly increase the hazard of non-VOC violations, inorganic chemical (IOC) violations, turbidity violations, or nitrate violations. Since petroleum leaks should not impact these other types of violations, it suggests that the results on VOC violations are not operating through another channel correlated with leaks.

Together, these findings suggest that groundwater is likely one channel through which health effects occur, but not necessarily the only channel. Since health impacts occur among individuals both inside and outside PWS areas, I use the combined sample in the main specification and in the results that follow.

3.4 Robustness of the main results

Table 7 shows a selection of robustness checks for the health impacts of leaking underground storage tanks. Column 1 replicates the baseline results for comparison. Columns 2-4 show robustness of the findings to alternative time controls. While the main specification includes year dummies and month dummies separately, column 2 includes year-month specific dummies to control non-parametrically for time trends. Columns 3 and 4 include county-specific and urban area-specific linear time trends, respectively, to account for any regional or cityspecific trends in the data. Point estimates are very stable across these specifications and remain statistically significant.

One concern is that if a leak begins prior to the recorded start date, births occurring prior to the official leak start date would be mistakenly classified as unexposed. This would cause the previous estimates to be attenuated. Column 5 excludes births occurring up to 6 months prior to the reported leak start date. Point estimates remain similar and statistically significant across outcomes. Figure A9 shows the coefficient of interest for years before and after the reported leak start date. Health effects worsen for individuals near the leak at the same time as the recorded leak start date, as seen by the upward shift in coefficient estimates after the start date. Variation in leak duration is likely to contribute to the larger confidence intervals throughout the post-period.

Another concern may be that exposure differentially impacts births by parity, which could be driving the results. Column 6 includes interactions between each parity group and the exposure measure as controls. The coefficient remains stable and significant. Moreover, Table A11 interacts the outcome of interest with each parity group to show that the results are not driven by any particular parity group. In addition, there are no detectable effects of leak exposure on birth spacing or the gender ratio (results available upon request).

The last two columns include more flexible controls for age. Given the existence of differential age trajectories in poor birth outcomes across racial groups, column 7 tests the robustness of the results to the inclusion of race-specific quadratics in age. Column 8 includes age dummies to control more flexibly for the non-linear relationship between maternal age and health at birth. The coefficients of interest remain stable and significant.

In addition, individuals living in high-rise apartment buildings are less likely to be exposed to leaks through soil contamination or vapor intrusion. These individuals are also more likely to be served by public water supply systems, which mitigates the possibility of contamination through groundwater. It would be reassuring to find that the main results are not driven by high density urban areas with many renters. In Table A14, we can see that there is no significant effect on health for areas with high density and many renters.

Finally, Table A13 shows additional placebo tests. I estimate the impact of exposure at farther distances, which should not experience health effects. In the final column, birth injury is chosen as a placebo outcome since the risk of birth injury is unlikely to change with exposure. For both placebo tests, the estimated coefficients are not statistically significant, as expected.

4 Health impacts of UST Regulation

4.1 Estimation strategy

Having established that reported leaks harm infant health, I now turn to investigate the effectiveness of regulations in mitigating these health effects. The UST regulations implemented new technical standards to reduce the risk and severity of leak exposure. I consider the effect of UST regulations on both the extensive and intensive margins of exposure.

First, I estimate the overall effect of the UST regulation on reported leak exposure. I use the full sample of births and estimate the following empirical specification:

$$Exposed_{ijym} = \delta_0 + \delta_1 PostDeadline_{ijym} + \gamma_j + \varepsilon_{2ijym} \tag{4}$$

for each infant i born to mother j. The outcome variable is equal to one if a leak is reported within 300 meters during the pregnancy and zero otherwise. $PostDeadline$ is equal to one for conceptions occurring after the deadline for compliance with spill, overfill, and corrosion protection, December 22, 1998. The specification also includes maternal fixed effects. Standard errors are clustered at the mother level.

Second, I estimate the effect of UST regulation on the severity of reported leak exposure. I estimate the health impacts of reported leak exposure before and after facility compliance with the new technical standards. If preventative technologies were successful in reducing size, duration, or distance of petroleum leaks, human exposure to petroleum pollution is less likely and newborns that were in utero during a leak will have better health outcomes after adoption of the new technologies.

The empirical specification is as follows:

$$\begin{aligned} Y_{ijfym} =& \alpha_0 + \alpha_1 Near_{ij} \times Exp_{ij} \times Reg_{fym} + \\ & \alpha_2 Near_{ij} \times Exp_{ij} + \alpha_3 Near_{ij} \times Reg_{fym} + \alpha_4 Exp_{ij} \times Reg_{fym} + \\ & \alpha_5 Exp_{ij} + \alpha_6 Near_{ij} + \alpha_7 Reg_{fym} + A' X_{ij} + \gamma_j + \lambda_y + \mu_m + \varepsilon_{3ijfym} \end{aligned} \tag{5}$$

for each infant i, born to mother j, near facility f, in year y, and month m. The variables $Near_{ij}$ and Exp_{ij} are defined as in equation 2. Reg_{fym} is an indicator equal to one if the individual is born after the facility has complied spill, overfill and corrosion protection. I use tank-level data from Pennsylvania and Florida to construct facility-level compliance dates for each deadline to meet the new technical standards, as described in section 2. X_{ij} is the same vector of maternal and child characteristics defined in equation 2. The specification includes maternal fixed effects, γ_j, as well as year dummies, λ_y, and month dummies, μ_m.[15] Standard errors are clustered at the mother level. As before, I instrument for true exposure using hypothetical exposure based on a full, 39-week gestation period to avoid the mechanical relationship between gestation length and actual exposure. This specification estimates a triple difference, where the coefficient of interest, α_1, measures the impact of exposure to a reported leak during gestation (relative to no exposure), for a mother living near (relative to far from) a tank, after the upgrade (relative to before).

4.2 Results: Health impact of regulations

Figure 4 shows the probability of exposure to a reported leak within 300 meters during pregnancy over time. The increase in exposure to reported leaks during the early 1990s is related to increased compliance with reporting requirements. There is a steady decline in the probability of exposure after the spill, overfill, and corrosion protection deadline, December 22, 1998. It is not surprising that there is no immediate decline in exposure at the deadline, since many pre-existing leaks are not yet remediated. As old leaks are remediated and fewer new leaks arise, the overall chance of exposure decreases steadily after the deadline.

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[15] Tables A9 and A10 in the appendix show an analysis of the bias in ols estimates. Estimates are similar when only controlling for facility fixed effects.

Columns 1-2 in Table 8 show estimate equation 4 with and without maternal fixed effects. These results indicate that the probability of exposure declined by about 1.7 percentage points after the regulation deadline. This is a 16.5 percent decline in the probability of exposure relative to the pre-policy mean.

Next, I consider the effect of UST regulation on the severity of reported leak exposure before and after facility compliance, by looking at the impact on health among those exposed. Figure 5 shows that the spill, overfill, and corrosion requirements had a large and long-term impact on low birth weight. The treated group includes individuals near and exposed to reported leaks, while the control group contains other individuals within 600 meters of the tank. Event time (in days) is calculated as the difference between the date of birth and the facility-level date of compliance, as defined in section 2. Time zero is the facility level date of compliance, which is based on the time of new tank installation. However, old tanks may have been removed as early as the first vertical line (a half-year prior), based on the definition of facility compliance in section 2.

Prior to the facility upgrade, individuals near the site and exposed to a leak experience worse health outcomes on average. Once removal of old tanks begins, there is a sharp improvement in health among the treated group. Since facilities must close at some point during a tank upgrade/removal, part of the immediate health improvement may be driven by a reduction in air pollution while the facility is out of operation.[16] However, if this were the only factor driving the improvement in health, we would expect the poor health outcomes to return to their previous level after the facility resumes operation. This does not appear to be the case. Alternatively, excavation of leaking tanks may reveal more information about the extent of sub-surface pollution and may prompt authorities to provide an alternate water source to nearby residents, which could explain the sharp health improvement. The graph also shows that the treated group experiences a downward trend after the upgrade, indicating that additional health improvements occur over a longer time horizon. This is not surprising since leak remediation may be a slow process.

One concern is that a facility upgrades could change the type of mothers giving birth.

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[16] On the other hand, one might expect construction to have some negative impacts on health, such as air pollution from operation of heavy machinery. However, this effect does not dominate in the data.

Figure A7 in the appendix shows event study graphs analogous to Figure 5 for various maternal characteristics. There is no discernible or consistent pattern that could explain the health effects seen in Figure 5. Figure A8 compares all mothers near and far from facilities to show broader neighborhood changes following upgrades. There are no shifts in demographic characteristics for residents near tanks after facilities upgrades. Overall trends show decreasing percentages of white mothers, but increasing education levels over time for mothers both near and far from tanks, reflecting a general trend. Unlike other pollution settings, such as Superfund sites, I detect no strong evidence of gentrification after facility upgrades.

Columns 3-11 in Table 8 estimate equation 5. Exposure is measured as the binary indicator. Compliance with this regulation reduces the harmful effects of reported leak exposure. Column 4 indicates that facility upgrades reduced the effect of leak exposure on low birth weight by 1 percentage point, or 15.0 percent from the mean. Although the magnitude of the point estimate is slightly larger than the negative health impact of leak exposure, it is not statistically significantly larger. Results for preterm birth are imprecisely measured, but the point estimate indicates regulations reduced the harmful effects of leaks by about half, or 0.3 percentage points. Column 5 also shows that facility upgrades eliminated the harmful effects of leaks on APGAR. These results suggest that the adoption of spill, overfill and corrosion protection ultimately mitigated the entire impact of leaking tanks on low birth weight.

5 Information and avoidance behaviors

In a setting where pollution is unobserved by local residents, one low-cost initiative policymakers might consider to protect health from the harmful effects of pollution is to provide information to the public in order to encourage avoidance behaviors. More generally, it is important to understand the role of information in inducing avoidance behaviors when sites are small, pollution is localized, and nearby residents are unlikely to know of pollution. Avoidance could include, for example, finding another source of water for domestic use, such as bottled water, or avoiding contact with soil and groundwater. Such behaviors would reduce the harmful health effects of leaks. Mothers could also avoid exposure by temporarily or permanently moving. This section examines the impact of information about leaks on both the probability of moving and health outcomes.

I use two sources of information on leaks: direct notifications and newspaper coverage. First, data from Florida includes the facility-specific date of public leak notification (see appendix for detail). To explore the impact of direct notifications, I compare infants born to mothers before and after they are notified of a nearby leak. This analysis includes infants born from 2005-2012 in Florida.The restricted sample size may cause these estimates to be under-powered.

Second, I collect data on newspaper articles covering leaking underground storage tanks (see appendix for detail).

5.1 Avoidance and health

I look for evidence that non-moving mothers exhibit avoidance behaviors in response to information. I consider the reduced-form effect of reported leak exposure on health with and without information. The empirical specification is as follows:

$$\begin{aligned} Y_{ijym} =& \pi_0 + \pi_1 Near_{ij} \times Exp_{ij} \times Info_{ijym} + \pi_2 Near_{ij} \times Exp_{ij} + \pi_3 Exp_{ij} \times Info_{ijym} \\ & + \pi_4 Near_{ij} \times Info_{ijym} + \pi_5 Exp_{ij} + \pi_6 Info_{ijym} + \Pi' X_{ij} + \gamma_j + \lambda_y + \mu_m + \varepsilon_{4ijym} \end{aligned} \tag{6}$$

for each infant i, born to mother j, in year y, and month m. X_{ij} is the same vector of maternal and child characteristics defined in equation 2. The specification also includes mother fixed effects, γ_j, year dummies, λ_y, and month dummies, μ_m. Two types of information are considered: direct notifications and newspaper coverage. Since leak sites with a direct notification are a subset of all leak sites, the empirical specification differs slightly due to collinearity: for direct notifications $Near_{ij} \times Info_{ijym}$ and $Info_{ijym}$ are excluded. In addition, the newspaper analysis includes an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with $Near_{ij} \times Exp_{ij}$, Exp_{ij}, and $Near_{ij}$. Standard errors are clustered at the mother level. Exposure is measured as a binary indicator and information is either a measure of direct notifications or newspaper coverage. The coefficient of interest, π_1, indicates the health impact of living near a leaking tank and being exposed in utero after the mother has some information about the leak. If information about a nearby leak prompts mothers to practice avoidance behaviors, such as drinking bottled water or avoiding contact with soil and groundwater, π_1 should indicate a health improvement.

Table 9 shows estimates from equation 6. Panels A and B show the results for newspaper coverage and direct notifications, respectively. The coefficients in Panel A indicate that local newspaper coverage of a nearby leak significantly decreases low birth weight. The coefficients for the health index and preterm birth are also negative, but imprecisely estimated. As there was no measurable health effect of leak exposure on congenital anomalies or abnormal conditions, it is unsurprising that newspaper coverage has no effect on these health outcomes. Newspaper coverage is associated with a 1.5 percentage point (22 percent) decline in the probability of low birth weight for infants in utero near a leak. While this point estimate is larger than what we might have expected based on the magnitude of the negative health effects of leaks, it is not statistically significantly larger. Alternatively, this slightly larger magnitude may be driven by an overreaction to the leak information if mothers take additional measures to protect health during pregnancy. In fact, past research has shown that individuals are likely to overreact to low probability events (Sunstein and Zeckhauser, 2011).

Panel B shows the reduced-form impact of direct notification on health. Unlike information from newspaper coverage, there is little evidence that direct notifications protect health. Only for congenital anomalies is there a statistically significant improvement in health, but the magnitude is unreasonably large relative to the mean. Although insignificant, other point estimates indicate that notification worsens health. Standard errors are large due to the data restriction to births in Florida between 2005 and 2012. Importantly, notification data come from the time period after regulations requiring preventative technologies. Since results shown previously indicate that facility upgrades almost entirely eliminated the health effects of leak exposure, it is perhaps not surprising that there is little evidence of health improvement after notification in the post-regulation period.

Table 10 explores whether newspaper coverage has heterogeneous impacts by maternal characteristics. The coefficient of interest is interacted with indicators for race, ethnicity, and education. Improvements among high-educated white mothers drive the reduction in poor health at birth after news coverage. Column 2 includes interactions with race indicators, where the omitted group is white mothers. The results suggest that white mothers respond most to information. Columns 3 and 4 show interactions with indicators for Hispanic and education levels, respectively. The response of Hispanic mothers is not significantly different from non-Hispanics. The interactions with education show larger reductions in poor health for more educated individuals. Finally, column 5 shows that the effects are driven primarily through high-educated, white mothers.

5.2 Avoidance and moving

Next, I examine whether information about leaks increases the probability of moving for mothers living very close to leaking tanks. The empirical specification is as follows:

$$Move_{ijym} = \phi_0+\phi_1 Near_j \times Info_{ijym}+\phi_2 Near_j+\phi_3 Info_{ijym}+\Phi' Z_{ij}+\gamma_c+\lambda_y+\mu_m+\varepsilon_{5jym} \quad (7)$$

for each infant i, born to mother j, in year y, and month m. Z_{ij} is a vector of maternal and child characteristics including smoking status, maternal education, maternal race, marital status, age, age squared, birth parity, child gender, and missing indicators. The specification also includes county fixed effects, γ_c, year dummies, λ_y, and month dummies, μ_m. The regression also includes an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with $Near_j$. Standard errors are clustered at the county level. Information is a measure of local newspaper coverage. The outcome variable is an indicator equal to one if a mother changes residential location before her next observed birth. The coefficient of interest, ϕ_1, indicates whether a mother living near a site is more likely to move when she has some information about the leak.

Table 11 shows the results from estimation of equation 7. Column 1 shows a positive but insignificant impact of information on the probability of moving. In addition, the magnitude of the point estimate suggests informed mothers near reported leak sites are only about 1.1

percent more likely to move before their next birth. There is little evidence that the average mother moves in response to information.

Columns 4-7 of Table 11 estimate heterogeneous effects by race, ethnicity, and education. While there are no statistically significant patterns by race or ethnicity, education seems to play an important role. Column 4 shows that highly educated mothers are statistically significantly more likely to move in response to information. Mothers who have a bachelors degree or higher are about 3 percentage points more likely to move than mothers that did not complete high school. High school graduates are about 0.8 percentage points more likely to move. When separated by race, point estimates indicate there is a gradient in education for both whites and non-whites. However, these interactions are only statistically significantly different from zero for whites. White mothers with a bachelors degree or higher are 2.5 percentage points more likely to move after receiving information, which is a 7 percent increase from the average group-specific probability of moving, 32 percent.

Figure 6 shows the results graphically by education for nonparametric quantiles of distance. The figure shows coefficients from estimation of the following specification:

$$\begin{aligned} Move_{ijym} =& \chi_0 + \sum_{l=1}^{3}\sum_{k=1}^{8} K' Dist_{jk} \times Info_{ijym} \times Educ_{jl} + \sum_{k=1}^{7} \Omega' Dist_{kj} + \\ & X' Z_{ij} + \gamma_c + \lambda_y + \mu_m + \varepsilon_{6jym} \end{aligned} \tag{8}$$

where k indexes distance quantiles and l indexes education levels. Low education includes mothers who did not complete high school, medium education includes mothers completing high school and/or some college, high education includes college graduates and higher education. Other terms are defined as in equation 7.[17] Figure 6 confirms that highly educated mothers living near leaking tanks respond the most to news of leaking tanks.

Moving is a costly and somewhat extreme avoidance behavior. Highly educated mothers are more likely to have a higher income, making it easier to pay the large fixed cost of moving. I discuss the implications of this finding for policy-makers in the next section.

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[17] The regression also includes an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with Near, education levels, and Near interacted with education levels.

6 Effect magnitude and cost-benefit analysis

This paper contributes to the cost-benefit calculation by quantifying the health effects from leak exposure and the health improvements from new UST technical standards. Prior to regulation, I find that reported leak exposure during gestation increases the probability of low birth weight by 8.7 percent (0.600 pp) and preterm birth by 7.4 percent (0.687 pp). To put the magnitude of the effect on low birth weight into perspective, I first compare it to other policies that improve low birth weight. Second, I compare the benefits of reduced low birth weight with the cost of leak cleanup and the cost of tank upgrades. Finally, I discuss the consequences of using information as a policy-lever.

The magnitude of the effect of leak exposure is similar to several other policies that impact low birth weight. For example, an additional year of maternal education decreases low birth weight by 10 percent (Currie and Moretti, 2003). Participation in WIC decreases low birth weight by 11 percent for low educated women (Hoynes et al., 2011). Alternatively, the food stamp program decreases low birth weight by 7 percent among white mothers, and 5-11 percent among black mothers (Almond et al., 2011). In this sense, gestational exposure to leaking tanks has approximately the same effect as an additional year of maternal education, WIC participation, or receiving food stamps.

Relative to other environmental exposures, the impacts of leaking tanks on low birth weight are also similar in magnitude. For example, Currie et al. (2013) find exposure to chemicals in the drinking water during pregnancy increases the probability of low birth weight by 6.5 percent, with larger effects for low educated mothers. The adoption of E-ZPass decreased low birth weight and prematurity by about 11 and 12 percent, respectively, for mothers living within 2km of a toll plaza (Currie and Walker, 2011). In addition, Currie et al. (2009) estimate a 1 unit change in mean carbon monoxide during the last trimester of pregnancy increases the risk of low birth weight by 8 percent.

However, the additional costs of low birth weight due to leaking tanks are small relative to the cost of cleanups. Based on the average number of births in gestation near reported leaks per year, leaking underground storage tanks increase the number of low birth weight infants by 154 each year in the sample states (FL, NJ, PA). Estimates from Almond et al. (2005) indicate that low birth weight increases hospital costs by $8,319 and one-year mortality by 37 per 1,000 births. I also calculate the longer-run effect of low birth weight on lifetime earnings using point estimates from Oreopoulos et al. (2008) that suggest low birth weight reduces earnings by 3.8 percent and the US Census Bureau's average synthetic work-life earnings of $1.8 million. In the sample states, this translates into excess hospital costs of $1.28 million per year, excess mortality costs of $37.0 million per year, and reduced lifetime earnings of $10.7 million per year.[18] These infant health effects account for about 10 percent of the average yearly cost of leak cleanups in these states, $490 million.[19]

On the other hand, facility compliance with spill, overfill, and corrosion protection requirements successfully mitigated the entire effect of reported leak exposure on low birth weight. These cost savings are large relative to the cost of tank upgrades. Upgrades reduced the number of low birth weight infants by 200 per year in Pennsylvania and Florida, saving about $1.7 million per year in excess hospital costs, $48.2 million per year in reduced one-year mortality, and $13.9 million per year in lifetime earnings. The upgrade cost to facilities in Pennsylvania and Florida was between $539-$639 million.[20] With a 20-year tank life and a 7 percent discount rate, the discounted value of the reduction in low birth weight accounts for about 105-125 percent of the one-time facility upgrade cost.

It is important to note that this is not a full accounting of either the costs or benefits of such regulation. It does not take into account other costs of the regulation, such as the cost for enforcement, inspections or training, the closure costs from facilities forced out of business, or the cost to consumers of the LUST gasoline tax ($0.001/gal). Similarly, while I have measured the effect of reported leaks on one dimension of human health, infant birth outcomes, I have not taken into account the effect of unreported leaks, or the effect on

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[18] Excess hospital cost is a weighted average of the fixed-effects estimates for the average cost of raising births from each birth weight segment to above the low birth weight threshold. Excess mortality is calculated analogously, based on the fixed-effects spline estimates. I use average synthetic work-life earnings values by education level to created a national average weighted by the proportion of the population with each level of education. Mortality costs use the EPA's official value of a statistical life, $6.45 million.

[19] There were an average of 2,893 leaks per year in the sample states. The average cost per cleanup was $169,500, based on an equally weighted average of the cost of four leak types: small extent soil only ($25,300), large extent soil only ($114,000), small extent groundwater ($110,500), and large extent groundwater ($428,200) (Industrial Economics, 2015).

[20] For a 3 tank facility, the cost to upgrade all tanks was $12,700 and the cost to replace all tanks was $80,000-$100,000. In these data, 10,908 facilities upgraded tanks and 5,009 facilities replaced tanks in PA and FL, using definitions in section 2.

other health outcomes (e.g. cancer, hospital admissions, adult health and mortality) or the environment. For example, water quality has been linked with long-run outcomes such as digestive cancer (Ebenstein, 2012). In addition, these estimates do not include all longer-term effects of birth outcomes. In addition to earnings, higher birth weight has been linked with improved cognitive development, IQ, educational attainment, and reduced welfare take-up (Figlio et al., 2014; Black et al., 2007; Oreopoulos et al., 2008). A full accounting of the benefits would take all of these factors into account. Nevertheless, the infant health benefits from preventative technology measured here more than make up for the one-time facility upgrade cost.

Finally, we can consider the tradeoffs associated with the provision of information as a policy option. Although information provision is inexpensive and the previous evidence suggests that individuals do exhibit avoidance behaviors in response to information, there are some important drawbacks to consider. First, previous results indicate that informing the public of pollution has distributional consequences that could exacerbate the inequality of environmental exposure to pollution. In particular, I show that mothers with high education are more likely to move in response to information. It is likely that mothers with high education are more financially able to change location. To the extent that policy-makers care about the reduction of environmental inequalities in pollution exposure, this would not be ideal. Second, this policy option would put the burden of avoidance costs on individuals, rather than on the polluter. Placing pollution costs on the public is particularly undesirable since it leads firms to undervalue the costs of pollution relative to the social costs, which weakens the incentive for firms to make efficient risk reducing investments (Boyd, 1997; Boyd and Kunreuther, 1995).

7 Conclusion

Leaking underground storage tanks provide a unified and homogenous context to quantify the health impacts of pollution, the effectiveness of regulation, the impact of information, and explore heterogeneous responses to information. LUSTs have been a pervasive, yet understudied, source of pollution throughout the US. These sites are one example of many small and localized pollution sources that have been overlooked by researchers, but have the potentially to harm human health. This paper shows that exposure to a reported leak in utero increases the probability of low birth weight and preterm birth by about 7-8 percent, among mothers living near the leak.

Next, I explore the effectiveness of preventative regulation relative to the health impacts of LUSTs. Given the increasing amount of environmental regulation in the US and globally, identifying the full health effects of pollution and the ability of regulation to successfully diminish these effects is critical. Ultimately, compliance with the 1998 technical standards entirely mitigated the effect of a leak on low birth weight. In terms of protecting human health, these regulations were quite successful. These findings are timely given the EPA's recent revision of the original 1988 UST regulation, effective as of October 13, 2015. These revisions update the regulation to reflect current technology and practices, increase emphasis on proper operation and maintenance of UST equipment, expand coverage of the regulation to Indian country, and remove past deferrals for emergency generator tanks, field constructed tanks, and airport hydrant systems.

Finally, this paper examines avoidance behaviors in response to leak information. This setting is uniquely suited to study avoidance behaviors since underground leaks are less observable to nearby residents. I find that individuals respond to local newspaper coverage. Information mitigates the negative health effects of exposure, which is consistent with mothers exhibiting some avoidance behaviors, such as drinking bottled water. Interestingly, information also increases the odds that a well-educated mother moves away from the leak site, which is an even more extreme form of avoidance. The propensity to relocate among highly educated mothers may help explain the broad inequalities observed in pollution exposure. In the presence of such inequality, low-SES individuals derive a disproportionate share of the health benefits from regulations requiring the adoption of new preventative technologies, such as the UST regulation studied here.

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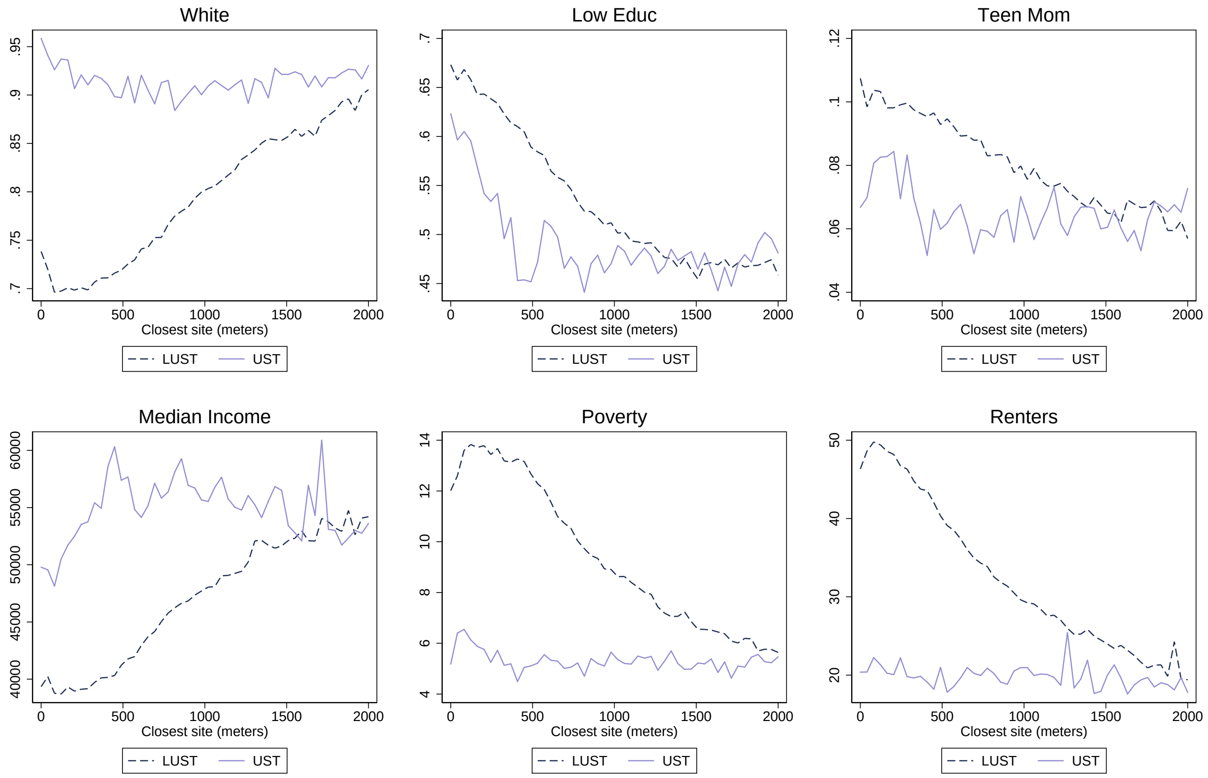
Figures

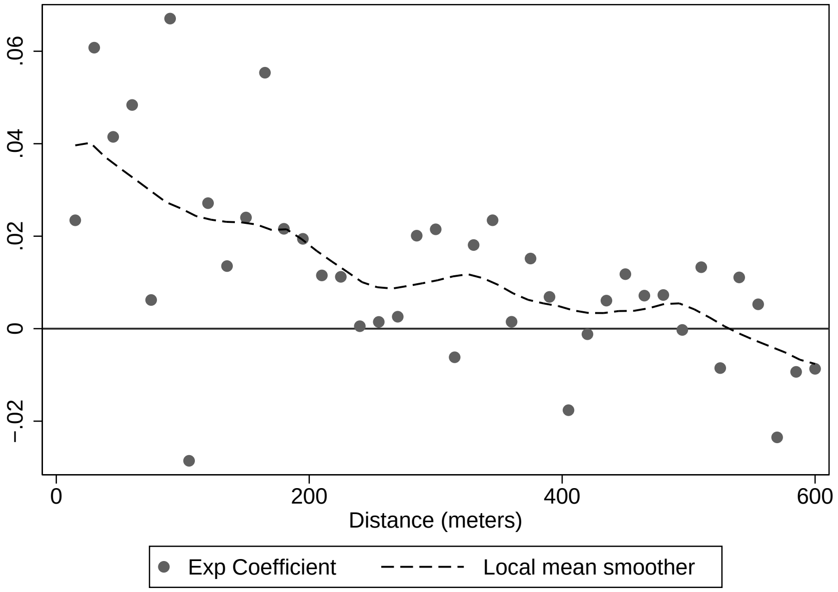
Figure 1: Mother and neighborhood characteristic gradients with distance



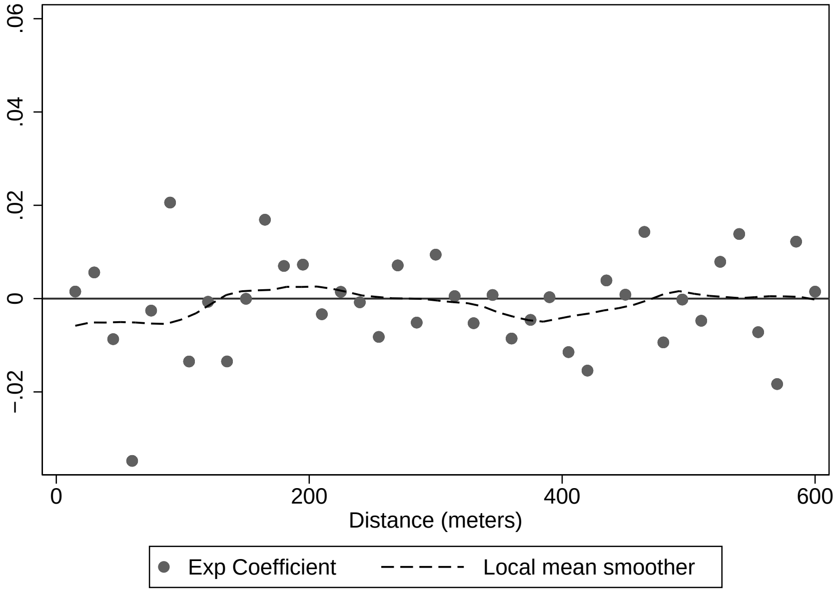
Notes: Maternal characteristics by distance, smoothed using “lpoly” (degree 0, bandwidth 15). LUST observations include mothers who live near a site that leaked and UST observations include mothers that live near a site that did not leak. Sample includes mothers giving birth prior to the 1998 regulation. Neighborhood characteristics from the 2000 Census tract level data.

Figure 2: Impact of leak exposure by distance

(a) Index of Poor Health



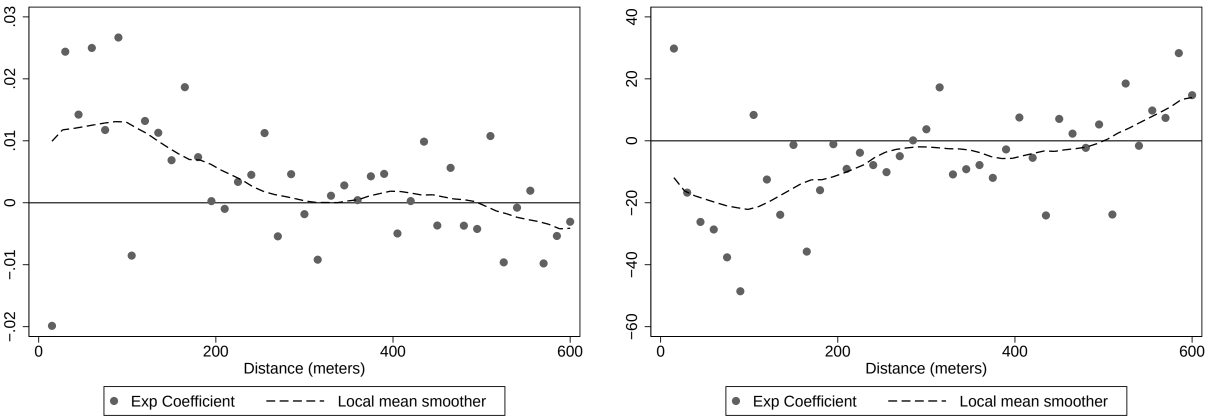
(b) Index of Time-varying Characteristics



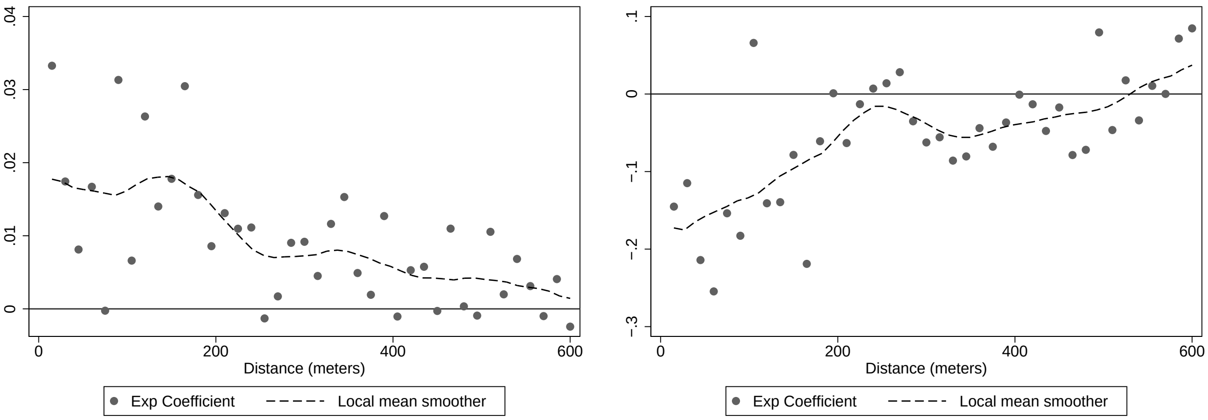
Notes: Plots point estimates of gestational leak exposure for each of 40 distance bins after controlling for age, parity, year, month, and maternal fixed effects. Panel A also includes controls for time-varying maternal and child characteristics, as in equation 2. The health index is the standardized mean value of low birth weight, preterm birth, low APGAR score, congenital anomaly, and abnormal condition. The time-varying maternal characteristic index is the standardized mean value of smoking status, marital status, risky birth, and no prenatal visits. The local mean smoother uses "lpoly" with degree of 0 and bandwidth of 35. Sample includes births occurring before the 1998 regulations.

Figure 3: Birth outcomes by exposure and distance

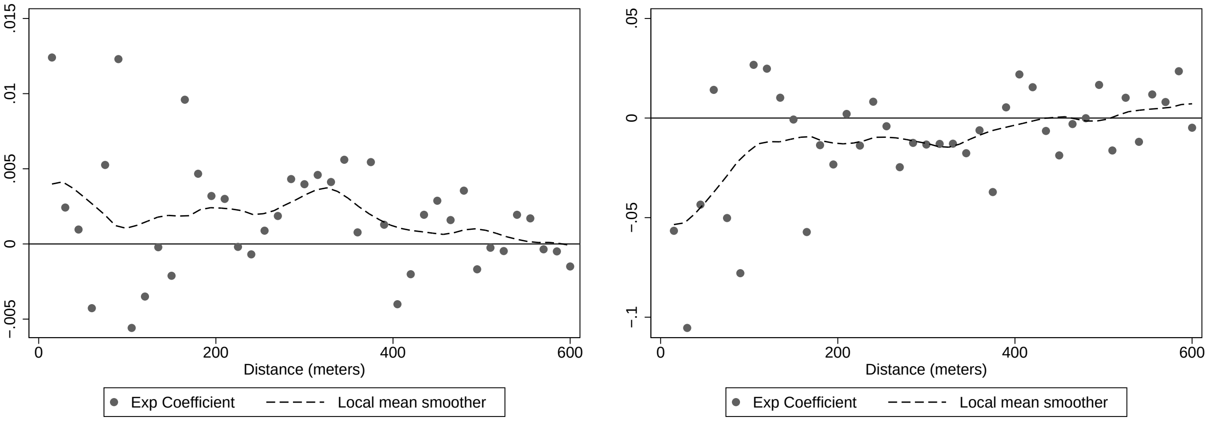
(a) Low Birth Weight (d) Birth Weight



(b) Preterm (e) Gestation

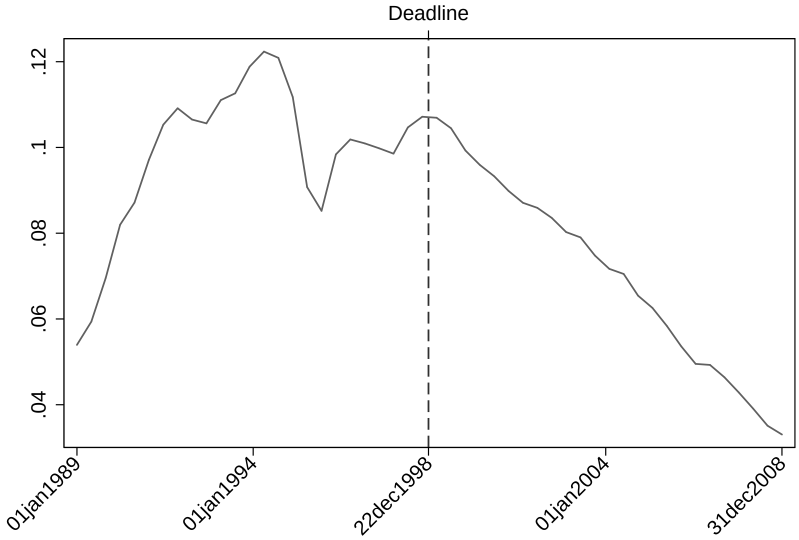


(c) Low APGAR (f) APGAR



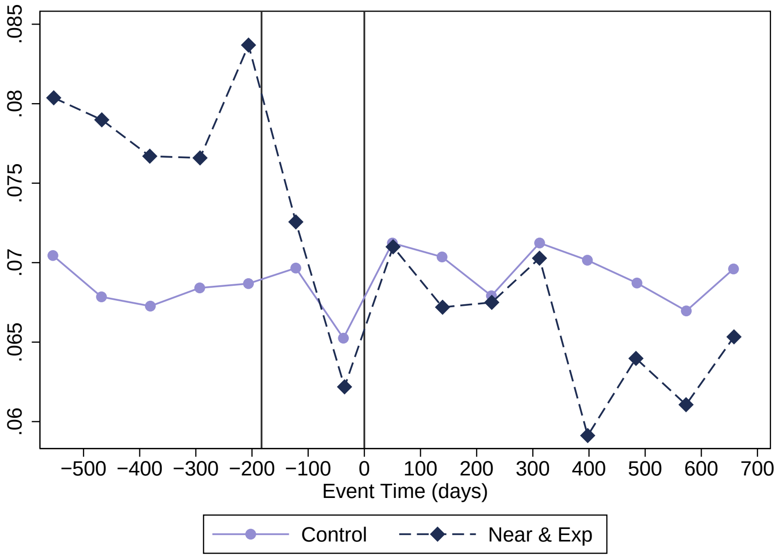
Notes: Plots point estimates of gestational leak exposure for each of 40 distance bins after controlling for maternal and child characteristics, mother fixed effects, year dummies, and month dummies. The local mean smoother uses "lpoly" with degree of 0 and bandwidth of 35. Sample includes births occurring before the 1998 regulations.

Figure 4: Exposure to leaks over time



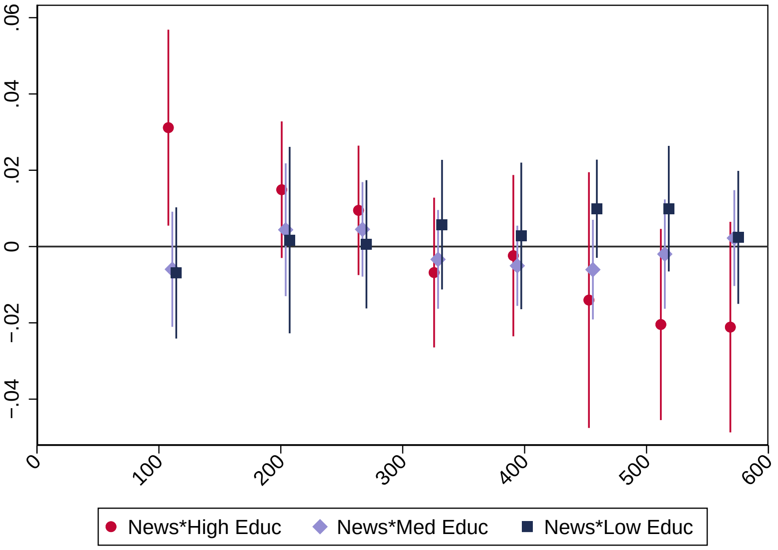
Notes: Fraction of births exposed to a leak within 300m during pregnancy, smoothed using "lpoly" (degree 0 and bandwidth 50). Date refers to date of conception. Vertical line at the deadline to comply with spill, overfill, and corrosion protection, December 22, 1998.

Figure 5: Low Birth Weight Relative to Compliance with Spill, Overfill and Corrosion Protection



Notes: Event time (in days) is calculated as the difference between the date of birth and the date of facility upgrade. The date of facility upgrade is the date of new tank installation if the new tank is installed within half of a year from the last tank removal before the deadline, December 22, 1998. If the facility had existing tanks and is still open after the deadline, I define the date of facility upgrade to be the deadline. The first vertical line identifies the earliest time at which old tanks were removed (a half year) before the new tanks were installed at time 0, which is marked by the second vertical line. The diamonds represent individuals who live within 300m of the facility and were exposed to a leak. The control group includes individuals farther away (300-600m) or unexposed. The outcome is low birth weight. The sample contains data from PA and FL and is limited to non-movers.

Figure 6: Moving in response to newspaper coverage of leaks



Notes: Coefficients and 99 percent confidence intervals are shown from equation 8. News is measured as an indicator for any news coverage of local leaking underground storage tanks. High education, medium education, and low education are indicators for mothers with a college degree or higher, a high school degree or some college, and less than a high school degree, respectively. The outcome, moving, is equal to one if a mother moves to a new location by the next observed birth.

Tables

Table 1: Summary Statistics: Facilities & Leaks

Total facilities	113,646
Total leak incidents	80,599
Percent of facilities leaking	59.6
Number leaks per leaking facility	1.2
Tanks per facility	3.2
Mean facility capacity (gal)	17,439
Mean tank capacity (gal)	4,887
Mean gallons per leak	524

Table 2: Time-varying maternal characteristics

	Time-varying maternal characteristics				
	Mom Char Index (1)	Smoker (2)	Unmarried (3)	Risky (4)	No Prenatal Visits (5)
Near × Exp	0.243	-0.0985	0.0878	0.325	0.0192
	(0.389)	(0.221)	(0.240)	(0.278)	(0.134)
Observations	658,148	658,148	658,148	658,148	617,314
Number of Moms	296,722	296,722	296,722	296,722	279,733
Outcome Mean	-	15.4	37.3	12.1	1.83
% Change	-	-0.640	0.235	2.68	1.05

Notes: All coefficients and standard errors are scaled up by 100. Exposure is measured as a binary indicator. Specification includes maternal age, age-squared, parity dummies, year dummies, month dummies, and maternal fixed effects. Risky indicates the presence of any maternal risk factor, including diabetes, hypertension, previous poor outcomes, etc. The index is the standardized mean value of the following variables: smoker, unmarried, risky, and no prenatal visits. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: Bias with and without FE: Exposure analysis

	Low Birth Weight					
	OLS (1)	OLS (2)	Facility FE (3)	Facility FE (4)	Mom FE (5)	Mom FE (6)
Near × Exp	-0.371***	-0.0666	-0.0675	-0.00981	0.576***	0.586***
	(0.129)	(0.127)	(0.145)	(0.141)	(0.205)	(0.205)
Exp	-0.0420	-0.0399	0.189*	0.153	-0.0702	-0.0828
	(0.0778)	(0.0779)	(0.111)	(0.109)	(0.130)	(0.129)
Near	0.595***	0.187**	0.125	0.0182		
	(0.0785)	(0.0773)	(0.0990)	(0.0951)		
Observations	692,845	692,845	692,845	692,845	692,845	692,845
R-squared	0.001	0.035	0.0420	0.0583	0.570	0.572
Controls	no	yes	no	yes	no	yes
Number of FE			16,150	16,150	311,144	311,144

Notes: Exposure is measured as a binary variable based on a hypothetical 39 week gestation. All specifications include year and month dummies. Columns with controls include child gender, parity indicators, maternal education, marital status, smoking status, age, age-squared, indicators for race, and indicators for missing values of gender, education, marriage and smoking status. Standard errors are in parentheses. Coefficients and standard errors scaled by 100. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Health impact of leak exposure: Pre-1998

	Index Z (1)	Low BW (2)	Preterm (3)	APGAR (4)	Cong.Anom. (5)	Abnorm (6)
Panel A. Days Exposed						
Near×Exp	0.00533***	0.00233***	0.00214**	-0.00540*	0.000214	0.000453
	(0.00203)	(0.000857)	(0.00103)	(0.00278)	(0.000379)	(0.000465)
Panel B. Exposure Dummy						
Near×Exp	1.491***	0.600***	0.687***	-1.193*	0.0687	0.120
	(0.486)	(0.207)	(0.246)	(0.665)	(0.0899)	(0.111)
Observations	694,033	693,159	694,033	688,851	694,033	694,033
Number of Moms	311,395	311,040	311,395	309,481	311,395	311,395
% Change	-	8.67	7.39	-0.133	6.69	6.49

Notes: Shows results from estimation of equation 2. Coefficients and standard errors scaled by 100. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. The sample is restricted births occurring before the 1998 UST regulation deadline. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Health impact of leak exposure: Non-PWS areas

	Index Z (1)	Low BW (2)	Preterm (3)	APGAR (4)	Cong.Anom. (5)	Abnorm (6)
Panel A. Days Exposed						
Near×Exp×PWS	0.00611**	0.00206**	0.00162	-0.00435	0.000386	0.00107**
	(0.00247)	(0.00104)	(0.00117)	(0.00337)	(0.000500)	(0.000505)
Near×Exp×Non-PWS	0.0193**	0.00836**	0.0100***	-0.0143	0.000626	0.00218
	(0.00910)	(0.00348)	(0.00373)	(0.0124)	(0.00205)	(0.00196)
Equality test	0.151	0.0728	0.0262	0.426	0.907	0.573
Panel B. Exposure Dummy						
Near×Exp×PWS	1.339**	0.387	0.522*	-0.730	0.100	0.243**
	(0.577)	(0.246)	(0.275)	(0.789)	(0.115)	(0.119)
Near×Exp×Non-PWS	3.980*	1.688**	2.169**	-4.371	0.0705	0.366
	(2.131)	(0.840)	(0.893)	(2.803)	(0.469)	(0.468)
Equality test	0.218	0.125	0.0688	0.198	0.949	0.793
Observations	475,470	474,676	475,470	471,516	475,470	475,470
Number of Moms	212,395	212,074	212,395	210,950	212,395	212,395
PWS Mean	-0.00325	0.0704	0.0822	9.008	0.0130	0.0148
Non-PWS Mean	-0.0514	0.0437	0.0531	9.039	0.0134	0.0135
% Change PWS	-	5.49	6.34	-0.0811	7.72	16.4
% Change Non-PWS	-	38.7	40.9	-0.484	5.28	27.0

Notes: Sample is restricted to mothers living in Pennsylvania and New Jersey. Coefficients and standard errors scaled by 100. Specification controls for a differential baseline impact of exposure for mothers inside and outside PWS areas. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. P-values are shown to test the equality of coefficient estimates for mothers inside and outside public water supply areas. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: PWS violations after nearby leak

	VOC (1)	VOC (2)	VOC (3)	VOC (4)	VOC (5)	Placebo violations Non-VOC (6)	IOC (7)	Turbidity (8)	Nitrate (9)
LUST	0.00455**	0.00109	2.380***			-0.137	0.354	0.536	0.212
	(0.00202)	(0.000803)	(0.391)			(0.147)	(0.448)	(0.333)	(0.484)
LUST lag		0.00381***							
		(0.00139)							
Any Leak				2.270***					
				(0.405)					
Num Leaks					0.00318***				
					(0.00118)				
Observations	96,580	96,580	99,935	99,935	99,935	52,149	100,146	98,704	91,601

Notes: Columns 1-2 show OLS results with controls for population and water system type. Columns 3-9 show results from estimation of the Cox Proportional Hazard Model in equation 3. Regressions control for population and are stratified by PWS type. Standard errors are clustered by PWS System. Coefficient estimates can be converted to hazard ratios by taking the exponent of the estimate. Columns 6-9 show results for volatile organic chemical (VOC), non-VOC, inorganic chemical (IOC), turbidity, and nitrate violations of maximum contaminant levels. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Robustness of main results

	Baseline (1)	Year-month dummies (2)	County trends (3)	UA trends (4)	Exclude pre-leak (5)	Par×Exp controls (6)	Age×Race controls (7)	Age dummies (8)
Panel A. Index Z								
Near × Exp	1.491***	1.497***	1.485***	1.440***	1.493***	1.492***	1.473***	1.482***
	(0.486)	(0.486)	(0.485)	(0.496)	(0.520)	(0.486)	(0.486)	(0.486)
Observations	694,033	694,033	694,033	668,711	629,944	694,033	694,003	694,033
Number of Moms	311,395	311,395	311,395	300,337	284,348	311,395	311,381	311,395
Panel B. Low Birth Weight								
Near × Exp	0.600***	0.604***	0.596***	0.552***	0.544**	0.602***	0.594***	0.597***
	(0.207)	(0.207)	(0.206)	(0.211)	(0.221)	(0.207)	(0.207)	(0.207)
Observations	693,159	693,159	693,159	667,859	629,140	693,159	693,129	693,159
Number of Moms	311,040	311,040	311,040	299,991	284,020	311,040	311,026	311,040
Panel C. Preterm Birth								
Near × Exp	0.687***	0.688***	0.684***	0.652***	0.785***	0.690***	0.674***	0.684***
	(0.246)	(0.246)	(0.246)	(0.251)	(0.263)	(0.246)	(0.246)	(0.246)
Observations	694,033	694,033	694,033	668,711	629,944	694,033	694,003	694,033
Number of Moms	311,395	311,395	311,395	300,337	284,348	311,395	311,381	311,395

Notes: Column 1 shows the baseline results. Columns 2-4 include year-month dummies, county specific linear time trends, and urban area specific linear time trends, respectively. Column 5 excludes births occurring up to 6 months prior to the leak start date. Column 6 includes interactions between each parity group and exposure as controls. Column 7 includes race-specific quadratics in age, and column 8 controls for age dummies. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. Coefficients and standard errors scaled by 100. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8: Health impact of regulations

	Exposed (1)	Exposed (2)	Index Z (3)	Low BW (4)	Preterm (5)	APGAR (6)	Cong.Anom. (7)	Abnorm (8)
Post-deadline	-2.535***	-1.707***						
	(0.0195)	(0.0399)						
Near×Exp×Reg			-1.789	-1.047**	-0.294	2.845*	0.0356	0.143
			(1.219)	(0.530)	(0.665)	(1.690)	(0.224)	(0.379)
Near×Exp			2.489**	0.893**	0.531	-1.820	0.0355	0.449
			(1.010)	(0.439)	(0.551)	(1.401)	(0.186)	(0.314)
Exp×Reg			1.211*	0.791***	0.571	-0.958	0.171	-0.355*
			(0.693)	(0.301)	(0.378)	(0.961)	(0.128)	(0.216)
Exp			-1.405**	-0.587**	-0.348	0.585	-0.203*	-0.0317
			(0.576)	(0.251)	(0.314)	(0.800)	(0.106)	(0.179)
Near×Reg			0.00177	0.265	0.587	-0.292	-0.195	-0.102
			(0.823)	(0.357)	(0.449)	(1.138)	(0.151)	(0.256)
Reg			-0.517	-0.446*	-0.208	-0.600	-0.0330	0.0150
			(0.617)	(0.268)	(0.337)	(0.855)	(0.114)	(0.192)
Observations	8,014,803	7,672,848	472,634	465,196	472,634	460,746	472,634	472,634
Number of Moms		5,101,423	236,317	232,598	236,317	230,373	236,317	236,317
% Change	-26.5	-16.5	-	-15.1	-2.89	0.319	4.12	5.21

Notes: The outcome variable for columns 1-2 is equal to 1 if a leak occurs within 300m during the pregnancy and post-deadline is equal to 1 for conceptions occurring after the deadline for compliance with spill, overfill, and corrosion protection, December 22, 1998. Column 2 includes maternal fixed effects. Columns 3-11 show results from estimation of equation 5 where exposure is measured as a binary indicator and regressions include maternal and child controls, year dummies, month dummies, and maternal fixed effects. The sample for columns 3-11 includes moms near facilities that upgrade in PA and FL with 2 observed births. Coefficients and standard errors scaled by 100. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Information and the health effects of a leak

	Index Z (1)	Low BW (2)	Preterm (3)	APGAR (4)	Cong.Anom. (5)	Abnorm (6)
Panel A. Newspaper Coverage						
Near×Exp×News	-2.400	-1.528**	-0.968	-0.752	0.0750	-0.611
	(1.763)	(0.726)	(0.912)	(2.316)	(0.316)	(0.426)
Observations	694,033	693,159	694,033	688,851	694,033	694,033
Number of Moms	311,395	311,040	311,395	309,481	311,395	311,395
Outcome Mean	0.00136	0.0692	0.0930	8.989	0.0103	0.0184
% Change	-	-0.221	-0.104	-0.000837	0.0729	-0.331
Panel B. Direct Notifications						
Near×Exp×Notified	0.0359	2.309	1.248	3.102	-2.186**	1.868
	(6.045)	(2.167)	(3.368)	(6.767)	(1.003)	(1.978)
Observations	139,045	139,032	139,045	138,602	139,045	139,045
Number of Moms	63,830	63,825	63,830	63,653	63,830	63,830
Outcome Mean	0.0459	0.0734	0.132	8.858	0.00587	0.0332
% Change	-	0.315	9.43	0.350	-372.1	56.3

Notes: Shows results from estimation of equation 6. Exposure is measured as a binary indicator. The sample for Panel A includes births before the 1998 UST regulations and includes an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with Near×Exp, Exp, and Near. The sample for Panel B includes births in Florida from 2005-2012. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. Standard errors are clustered at the mother level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 10: News and heterogeneous health effects of a leak

	Low Birth Weight				
	(1)	(2)	(3)	(4)	(5)
Near×Exp×News	-1.528**	-2.351***	-0.889	0.811	
	(0.726)	(0.729)	(0.922)	(1.501)	
×Black		2.482*			
		(1.453)			
×Asian		2.533			
		(3.083)			
×Other Race		20.42*			
		(10.47)			
×Hispanic			-1.220		
			(1.052)		
× HS Grad				-2.340	
				(1.562)	
× College Grad+				-3.353**	
				(1.671)	
White & < HS					-0.797
					(1.647)
White & HS Grade					-2.140**
					(0.866)
White & College Grad+					-2.529**
					(1.019)
Non-white & < HS					3.249
					(2.698)
Non-white & HS Grad					-0.203
					(1.634)
Non-white & College Grad+					-2.321
					(3.284)
Observations	693,159	693,129	693,159	666,544	666,520
Number of Moms	311,040	311,026	311,040	300,146	300,135

Notes: Exposure is a binary indicator. The reference group is white mothers for column 2, Non-Hispanic mothers for column 3, and mothers with less than a high school degree for column 4. Coefficients and standard errors scaled by 100. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. Columns 2-5 include controls for Near×Exp and Exp interacted with each demographic characteristic. The sample includes births before the 1998 UST regulations and regressions include an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with Near×Exp, Exp, Near, and interactions of these variables with demographic characteristics. Standard errors are clustered at the mother level. *** p<0.01, ** p<0.05, * p<0.1

Table 11: Information and avoidance by moving

	Move before next birth				
	(1)	(2)	(3)	(4)	(5)
Near × News	0.601	0.670	0.637	-0.367	
	(0.428)	(0.540)	(0.469)	(0.586)	
× Black		-0.267			
		(0.638)			
× Asian		0.480			
		(1.367)			
× Other Race		-0.818			
		(1.199)			
× Hispanic			-0.168		
			(0.625)		
× HS Grad				0.742*	
				(0.439)	
× College Grad+				2.951***	
				(0.954)	
× White & College Grad +					2.517***
					(0.768)
× White & HS Grad					0.436
					(0.484)
× White & < HS					-1.063
					(0.712)
× Non-white & College Grad					1.431
					(1.044)
× Non-white & HS Grad					0.333
					(0.498)
× Non-white & < HS					0.405
					(0.740)
Observations	1,268,157	1,268,157	1,268,157	1,242,765	1,242,765
Outcome Mean	0.442				
% Change	1.36				

Notes: Shows results from estimation of equation 7. The reference group is white mothers for column 2, Non-Hispanic mothers for column 3, and mothers with less than a high school degree for column 4. Each regression includes maternal and child controls, year dummies, month dummies, and county fixed effects. Regressions also include an indicator for mothers living in a county where information on historic newspaper articles is not available, as well as interactions of this indicator with Near, demographic characteristics, and Near interacted with demographic characteristics. Standard errors are clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

For Online Publication

Appendix

Additional Data

Public Water Supply Areas

A public water system (PWS) provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year. Public water systems may be publicly or privately owned. This paper utilizes GIS data from New Jersey and Pennsylvania on community water systems, which supply water to the same population year-round.Unfortunately, the Florida Department of Environmental Protection (FL DEP) does not maintain community water supply service areas for the state, so any analysis utilizing PWS areas will exclude Florida.

Community water service area boundaries for New Jersey come from the New Jersey Department of Environmental Protection (NJ DEP) (Carter et al., 2004).[21] New Jersey Public Community Water Supply Purveyor service areas boundaries were collected and digitized to enable long term water supply planning, and to aid in emergency management during drought.The Pennsylvania Department of Environmental Protection (PA DEP) also provides a digitized map of the boundaries of the current public water supplier's (PWS) service areas (PADEP, 2015). These data contain over 90 percent of active service boundary areas for Pennsylvania public community water supplies. As part of Pennsylvania's State Water Plan, this data is used to determine non-public water supply areas (i.e. self-supplied), the population served, and water supply demand. Figure A1 shows PWS areas for both Pennsylvania and New Jersey.

PWS Water Quality violations and source well data

For Pennsylvania, I obtain data on PWS water quality violations and well location data. Water quality violation data from the PA DEP includes all PWS violations of any Maximum Contaminant Level (MCL). I exclude bottled water, bulk water, retail water, and vended water systems from the analysis. Table A1 shows violation data summary statistics for the volatile organic chemicals (VOCs) regulated by the PA DEP and the MCL for each. VOC violations are the most likely type of violation to occur as a result of leaking petroleum products. Pennsylvania wells data comes from the Pennsylvania Groundwater Information System (PaGWIS), which contains water well latitude and longitude for a large number of wells in the state.[22] I link PWS wells to PWS areas based on overlapping geographies. This will be measured with some error since PWS services may draw water from a well outside of their own PWS area and I cannot identify which of these wells service which PWS area. I assume that a PWS well located within a PWS area services that area. I link leaking underground storage tanks within 600 meters to PWS wells to explore the relationship of leaks near PWS supply wells with PWS water quality violations.

Direct Notifications

Since 2005, Florida has maintained a database with information on public notification of possible contamination for routine site cleanups. In emergency situations, the public is notified immediately and these emergency notifications would not show up in these data. According to conversations with the FL DEP, most sites do not require immediate emergency notification so the standard procedures are followed. Exceptions might include some roadside spills (from truck accidents, etc.) which are addressed immediately by response crews. These data identify the date of initial notice of contamination beyond property boundaries,

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[21] 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 NJ DEP and is not state-authorized.

[22] Records submitted by drillers have been added to PaGWIS starting in 1969, but data entry varied substantially over time. Due to insufficient staff, no records were entered for several years, creating a large backlog. Although some of these data have subsequently been entered into the system and electronic submission of new records is now mandatory, large gaps still exist. PA is estimated to have over 1 million domestic water wells, but there are only 440,000 records in PaGWIS.

which is required during the assessment phase of a cleanup. I use these data to explore the impact of public notification on avoidance behaviors.

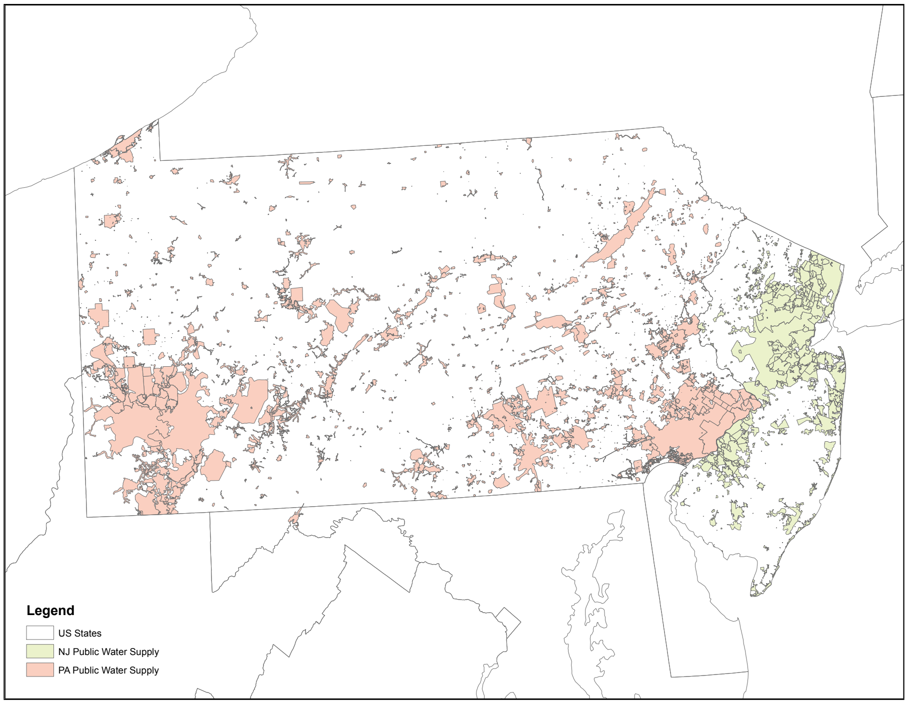
Newspaper Data

Information on newspaper coverage of leaking tanks comes from Access World News, a comprehensive collection of full-text news sources with over 528 million current and archived news articles from as early as 1978. Access World News provides extensive coverage at every geographic level, including many hard-to-find local and regional sources that are unavailable elsewhere. This access to local news articles is crucial for determining information available to mothers about local leaking underground tanks. News articles containing the phrase "leaking underground tank" are considered coverage of a nearby leak site. Other key words, such as "underground storage tank leak", or inclusion of additional terms such as "water", produce similar results. Newspaper articles for a 9 month gestation period are linked to mothers based on county of residence and month of conception. I create an indicator for any newspaper coverage during the fixed, hypothetical 9 month period of gestation.

Census Data

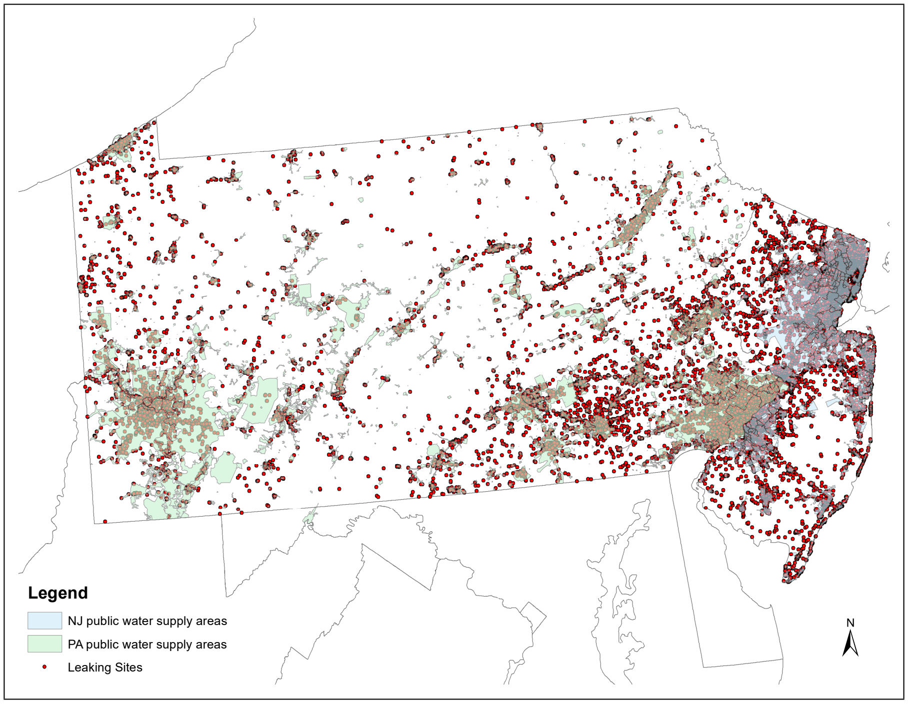
Tract level data from the 2000 Census provide further information on the neighborhood characteristics. Variables of interest include median house value, median income, unemployment rate, poverty rate, percent foreign, and percent renters.

Figure A1: Public water supply areas in PA and NJ



Notes: Community water service area boundaries for New Jersey come from the NJ DEP (Carter et al., 2004). The PA DEP provides a digitized map of the boundaries of the current public water supplier's (PWS) service areas (PADEP, 2015).

Figure A2: Public water supply areas and leaks in PA and NJ



Notes: Community water service area boundaries for New Jersey come from the NJ DEP (Carter et al., 2004). The PA DEP provides a digitized map of the boundaries of the current public water supplier's (PWS) service areas (PADEP, 2015).

Table A1: PWS water quality VOC violations

VOCs	Number of violations	Percent of violations	Avg. Duration (months)	MCL (mg/L)
BENZENE	29	3.97	3.62	0.005
CARBON TETRACHLORIDE	8	1.10	2.88	0.005
o-DICHLOROBENZENE	0	0.00		0.600
PARA-DICHLOROBENZENE	1	0.14	3.00	0.075
1,2-DICHLOROETHANE	12	1.64	3.00	0.005
1,1-DICHLOROETHYLENE	93	12.74	3.29	0.007
cis-1,2-DICHLOROETHYLENE	19	2.60	3.47	0.070
trans-1,2-DICHLOROETHYLENE	4	0.55	3.00	0.100
DICHLOROMETHANE	11	1.51	4.64	0.005
1,2-DICHLOROPROPANE	5	0.68	3.00	0.005
ETHYLBENZENE	1	0.14	3.00	0.700
MONOCHLOROBENZENE	0	0.00		0.100
STYRENE	0	0.00		0.100
TETRACHLOROETHYLENE	153	20.96	3.82	0.005
TOLUENE	0	0.00		1.00
1,2,4-TRICHLOROBENZENE	0	0.00		0.070
1,1,1-TRICHLOROETHANE	31	4.25	3.00	0.200
1,1,2-TRICHLOROETHANE	15	2.05	3.00	0.005
TRICHLOROETHYLENE	316	43.29	3.07	0.005
VINYL CHLORIDE	30	4.11	3.00	0.002
XYLENES (Total)	0	0.00		10.00

Notes: Maximum Contaminant Levels (MCLs) as of April 2006 and MCL violation data were obtained from the Pennsylvania Department of Environmental Protection, Division of Drinking Water Management.

Regulation History

Table A2: History of UST Regulation

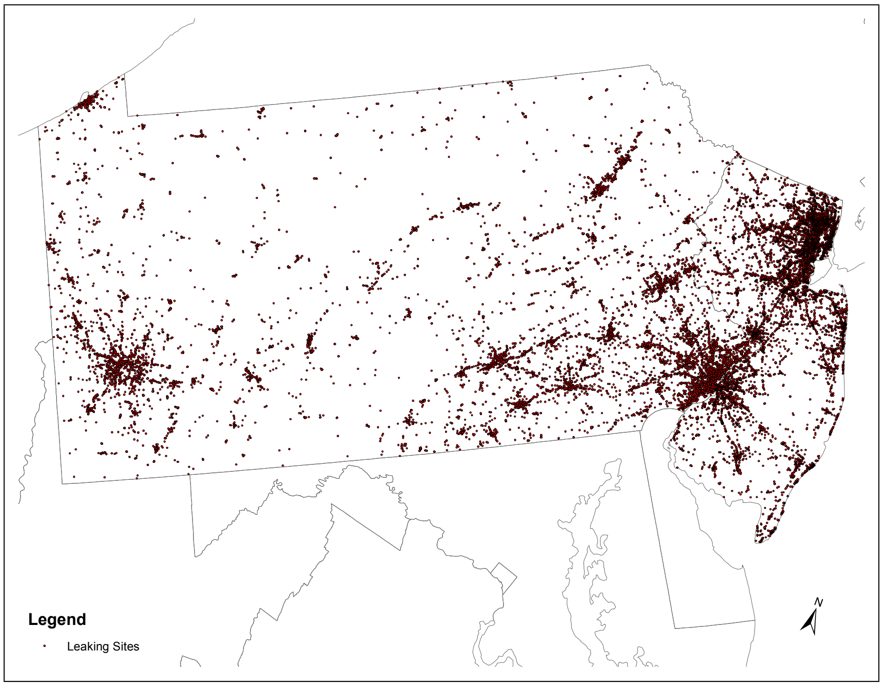
1984	Subtitle I added to the Solid Waste Disposal Act (SWDA) through the Hazardous and Solid Waste Amendments • Created a federal program to regulate USTs containing petroleum and certain hazardous chemicals • Directed EPA to set operating requirements and technical standards
1986	Subtitle I amended through the Superfund Amendments Reauthorization Act • Authorized EPA to respond to petroleum spills and leaks • Directed EPA to establish financial responsibility requirements of UST owners • Created a Leaking Underground Storage Tank (LUST) Trust Fund (to oversee and enforce cleanups, and to pay for cleanups when the owner or operator is unknown, unwilling, or unable to respond or when emergency action is required)
1988	EPA issues UST Regulations • Technical standards require leak detection, leak prevention, and corrective action • New tanks must meet all technical standards, but tanks installed prior to December 22, 1988 have until December 22, 1998 to be upgraded, replaced, or closed • Requires all UST owners and operators to demonstrate financial responsibility for taking corrective action, and for compensating thrid parties for bodily injury and property damage from releases
2005	Energy Policy Act of 2005 amended Subtitle I of the SWDA • Added new leak detection and enforcement provisions • Required all regulated USTs to be inspected every 3 years • Expanded use of the LUST Trust Fund
2009	American Recovery and Reinvestment Act of 2009 • Provided a one-time supplemental appropriation of $200 million from the LUST Trust Fund to EPA for cleaning up leaks from federally regulated USTs
2015	The 2015 UST Regulation updated the 1988 UST Regulation • Added periodic operation and maintenance requirements for UST systems • Added requirements to ensure UST compatibility before storing certain biofuel blends • Removed past deferrals for emergency generator tanks, airport hydrant systems, and field-constructed tanks • Expanded coverage of the regulation to Indian country

Source: EPA's Office of Underground Storage Tanks: www.epa.gov/ust.

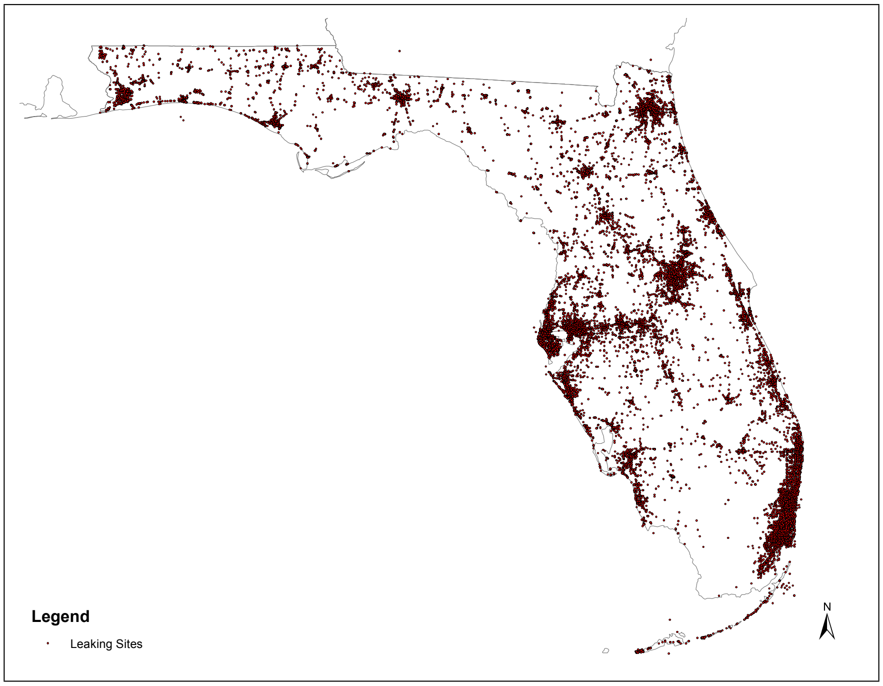
Additional Figures & Tables

Figure A3: Leaking underground storage tanks

(a) Pennsylvania and New Jersey

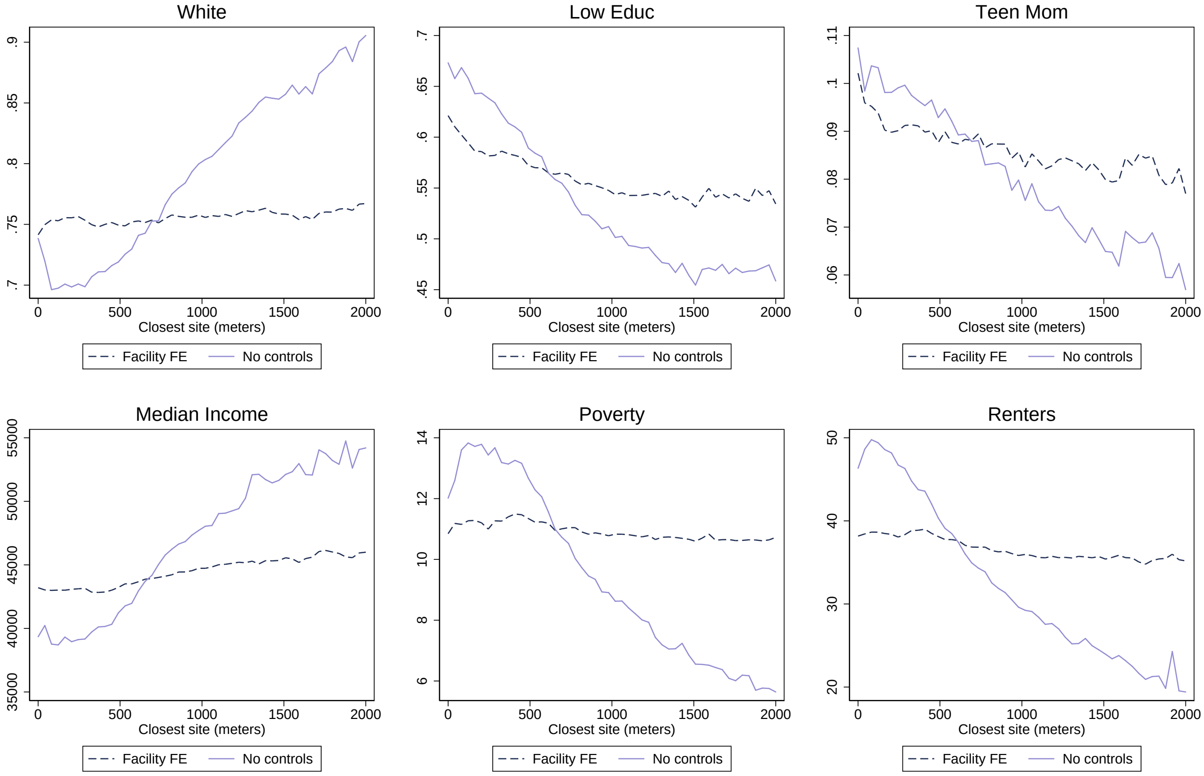


(b) Florida



Notes: Figures show location of all facilities that ever report a leak.

Figure A4: Demographic gradients controlling for facility fixed effect



Notes: Pre-1998 maternal characteristics by distance, smoothed using “lpoly” (degree 0, bandwidth 15). Includes mothers who live near a site that leaked.

Table A3: Demographic gradients controlling for facility fixed effect

	(1) Black	(2) Black	(3) Low Educ	(4) Low Educ	(5) Teen Mom	(6) Teen Mom
Distance	-0.109***	-0.00955***	-0.132***	-0.0700***	-0.0250***	-0.0135***
	(0.000597)	(0.00218)	(0.000738)	(0.00204)	(0.000421)	(0.000750)
Observations	2,282,224	2,279,744	2,240,436	2,237,961	2,283,129	2,280,647
R-squared	0.014	0.418	0.014	0.154	0.002	0.054
Facility FE		yes		yes		yes

Notes: Coefficients and standard errors are scaled by 1000. Distance is measured in meters to the closest tank that experienced a leak. Standard errors are clustered by facility when facility fixed effects are included. p<0.01, p<0.05, p<0.1

Table A4: Summary statistics: Mothers living near USTs

	Distance from leaking UST			
	<300m	300-600m	>600m	Total
Age	27.22	27.52	28.36	27.98
	(6.102)	(6.138)	(6.059)	(6.103)
Smoker	0.145	0.136	0.115	0.125
	(0.352)	(0.343)	(0.319)	(0.331)
Married	0.542	0.578	0.686	0.637
	(0.498)	(0.494)	(0.464)	(0.481)
Hispanic	0.362	0.385	0.422	0.404
	(0.480)	(0.487)	(0.494)	(0.491)
White	0.687	0.695	0.796	0.754
	(0.464)	(0.460)	(0.403)	(0.430)
Black	0.243	0.240	0.156	0.190
	(0.429)	(0.427)	(0.362)	(0.392)
< HS	0.0559	0.0435	0.0316	0.0382
	(0.230)	(0.204)	(0.175)	(0.192)
Some HS	0.165	0.150	0.110	0.128
	(0.372)	(0.357)	(0.313)	(0.334)
HS Grad	0.363	0.346	0.306	0.325
	(0.481)	(0.476)	(0.461)	(0.468)
Some College	0.198	0.216	0.247	0.232
	(0.398)	(0.411)	(0.431)	(0.422)
College Grad	0.122	0.144	0.192	0.170
	(0.327)	(0.351)	(0.394)	(0.375)
College+	0.0632	0.0754	0.0980	0.0871
	(0.243)	(0.264)	(0.297)	(0.282)
Prenatal Visits	10.47	10.76	11.35	11.07
	(4.054)	(4.027)	(3.829)	(3.928)
Observations	1,477,344	2,412,394	5,854,076	9,743,814

Notes: Average characteristics of mothers with standard deviations in parentheses. Distance (in meters) is measured with respect to the nearest leaking underground storage tank. Observations include all mothers with each distance range.

Table A5: Select chemicals found in underground storage tanks

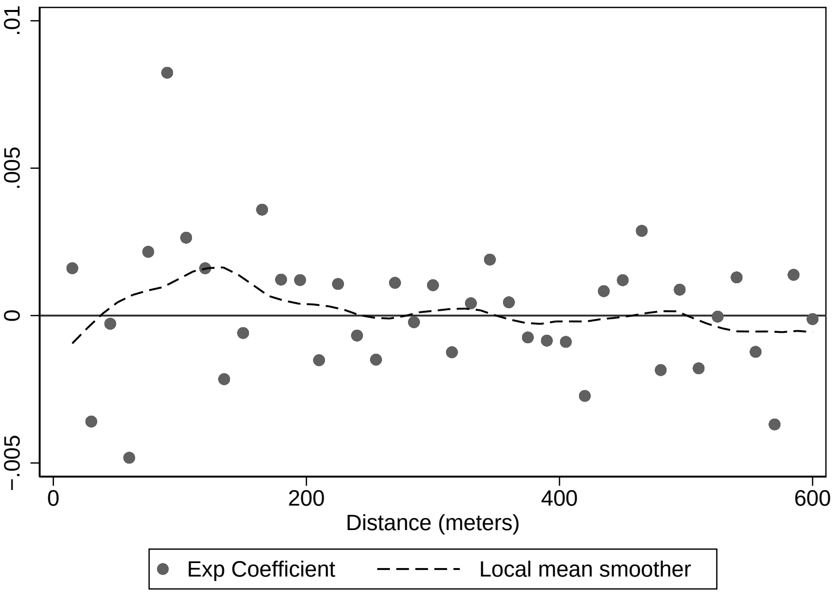
	Color	Odor	Odor threshold		Taste threshold	Class	MCLG	MCL
			Water	Air				
Benzene	Clear/colorless	Aromatic	2.0 mg/L	34 - 119 mg/L	0.5 - 4.5 mg/L	VOC	0 mg/L	0.005 mg/L
Toluene	Colorless	Sweet, pungent	0.024 - 0.17 mg/L	2.14 mg/L	No data	VOC	1 mg/L	1 mg/L
Xylenes (mixed)	Clear	Sweet	No data	1.0 mg/L	No data	VOC	10 mg/L	10 mg/L
Ethylbenzene	Colorless	Sweet, gasoline-like	0.029 - 0.140 mg/L	2.3 mg/L	No data	VOC	0.7 mg/L	0.7 mg/L
MTBE	Colorless	Terpene-like	680 ppb	No data	No data	Oxygenate		
Naphthalene	White	Tar, mothballs	0.021 mg/L	0.44 mg/m^3	No data	PAH		
1,2 Dichloroethane	Colorless	Pleasant odor	20 mg/L	12 - 100 mg/L	No data	VOC	0 mg/L	0.005 mg/L

Notes: The Maximum Contaminant Level Goal (MCLG) is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals. The Maximum Contaminant Level (MCL) is the highest level of a contaminant that is allowed in drinking water and is an enforceable standard. MCLGs and MCLs are from the EPA's National Primary Drinking Water Regulations.

Source: Toxicological profiles, Agency for Toxic Substance & Disease Registry.

[a] Solubility in water at 20°C

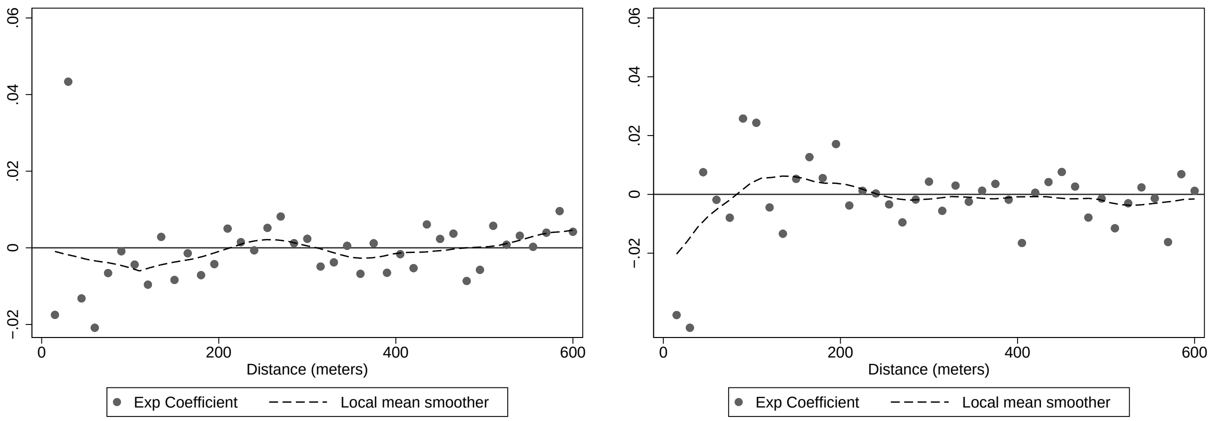
Figure A5: Time-varying maternal characteristics by exposure and distance: Predicted Index



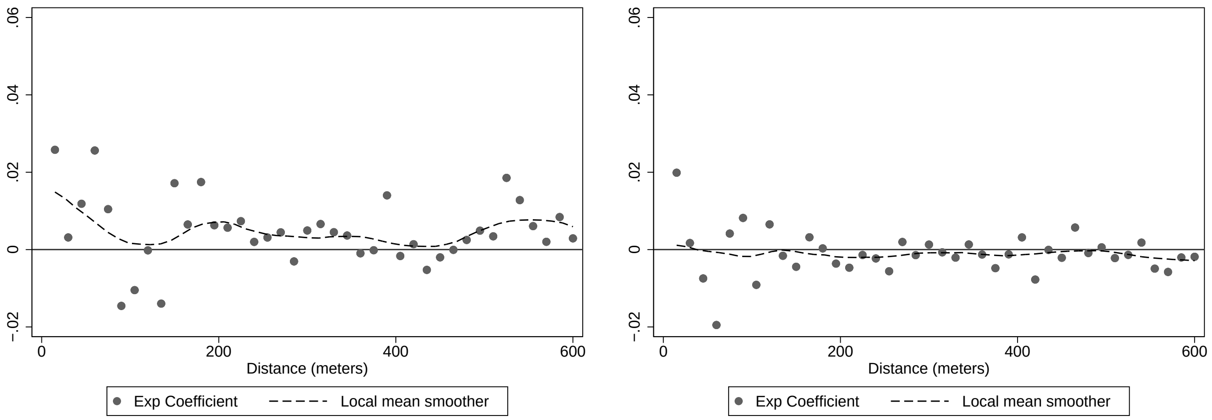
Notes: Plots point estimates of gestational leak exposure for each of 40 distance bins after controlling for age, parity, year, month, and maternal fixed effects. The local mean smoother uses "lpoly" with degree of 0 and bandwidth of 35. Sample includes births occurring before the 1998 regulations.

Figure A6: Time-varying maternal characteristics by exposure and distance

(a) Smoking (c) Risky



(b) Unmarried (d) No Prenatal Visits



Notes: Plots point estimates of gestational leak exposure for each of 40 distance bins after controlling for age, parity, year, month, and maternal fixed effects. The local mean smoother uses "lpoly" with degree of 0 and bandwidth of 35. Sample includes births occurring before the 1998 regulations.

Table A6: Health impact of leak exposure by alternate distances

	Low Birth Weight				
Near:	<100m (1)	<200m (2)	<300m (3)	<400m (4)	<500m (5)
Near × Exp	0.902*	0.832***	0.471**	0.328*	-0.0453
	(0.513)	(0.262)	(0.189)	(0.173)	(0.233)
Observations	758,298	758,298	758,298	758,298	758,298
Number of Moms	342,912	342,912	342,912	342,912	342,912
Outcome Mean	0.0666	0.0666	0.0666	0.0666	0.0666
% Change	13.5	12.5	7.07	4.92	-0.680

Notes: For all columns the control group includes individuals within 1000m of a leak site, rather than within 600m as shown in the main results. Coefficients and standard errors scaled by 100. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. The sample is restricted births occurring before the 1998 UST regulation deadline. *** p<0.01, ** p<0.05, * p<0.1

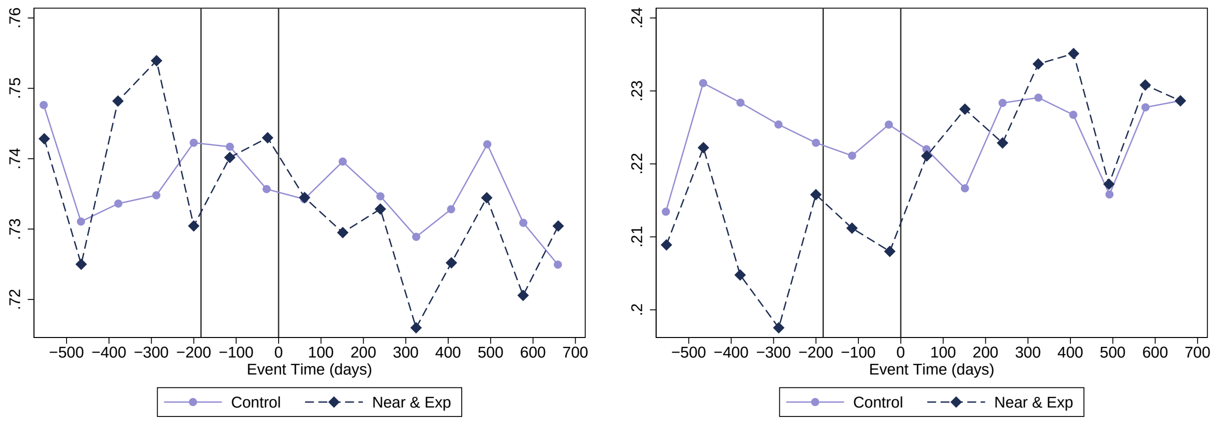
Table A7: Health impact of leak exposure: Non-PWS area robustness

	Index Z (1)	Low BW (2)	Preterm (3)	APGAR (4)	Cong.Anom. (5)	Abnorm (6)
Panel A. Days Exposed						
Near×Exp×PWS	0.0122**	0.00622**	0.00443	0.000130	0.00117	0.00126
	(0.00613)	(0.00265)	(0.00292)	(0.00862)	(0.00115)	(0.00121)
Near×Exp×Non-PWS	0.0271**	0.0138***	0.0131***	-0.0116	0.00148	0.00279
	(0.0110)	(0.00442)	(0.00478)	(0.0153)	(0.00236)	(0.00233)
Equality test	0.110	0.0362	0.0230	0.359	0.883	0.447
Panel B. Exposure Dummy						
Near×Exp×PWS	2.786*	1.462**	1.436**	0.239	0.209	0.420
	(1.444)	(0.631)	(0.688)	(2.029)	(0.267)	(0.283)
Near×Exp×Non-PWS	5.830**	2.997***	3.257***	-3.493	0.197	0.705
	(2.606)	(1.063)	(1.140)	(3.503)	(0.546)	(0.556)
Equality test	0.167	0.0777	0.0477	0.199	0.980	0.558
Observations	475,470	474,676	475,470	471,516	475,470	475,470
Number of Moms	212,395	212,074	212,395	210,950	212,395	212,395
PWS Mean	-0.00676	0.0691	0.0809	9.014	0.0129	0.0147
Non-PWS Mean	-0.0519	0.0435	0.0527	9.041	0.0134	0.0136
% Change PWS	-	21.2	17.7	0.0265	16.2	28.6
% Change Non-PWS	-	69.0	61.7	-0.386	14.7	51.7

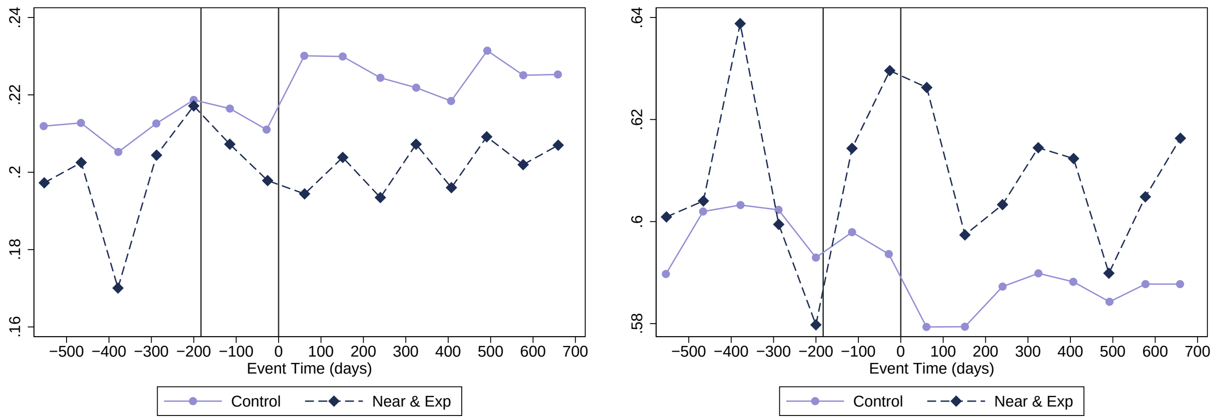
Notes: Sample is restricted to mothers living in Pennsylvania and New Jersey. Coefficients and standard errors scaled by 100. Specification controls for a differential baseline impact of exposure for mothers inside and outside PWS areas. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. Additional controls include Near×Exp and Exp interacted with education, race, and smoking status. P-values are shown to test the equality of coefficient estimates for mothers inside and outside public water supply areas. *** p<0.01, ** p<0.05, * p<0.1

Figure A7: Event study of facility upgrades: mother characteristics

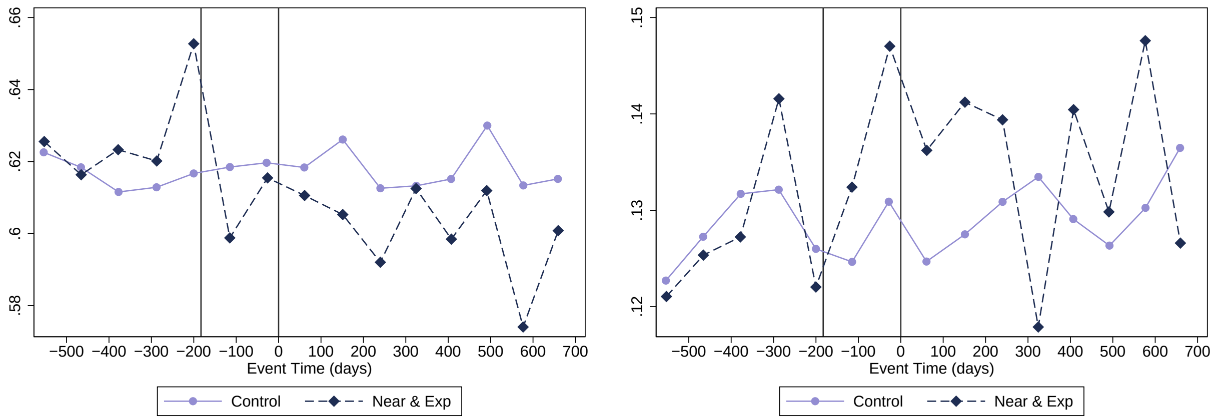
(a) White (d) Black



(b) High Educ (e) Low Educ

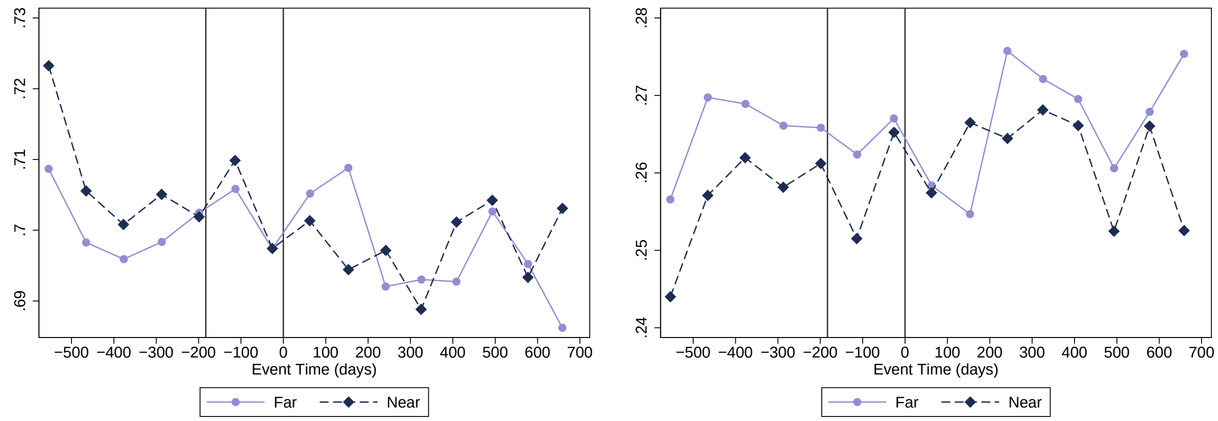


(c) Married (f) Teen Mom



Notes: Event time (in days) is calculated as the difference between the date of birth and the date of facility upgrade (defined in section 2). The first vertical line identifies the earliest time at which old tanks were removed (a half year) before the new tanks were installed at time 0, which is marked by the second vertical line. The diamonds represent individuals who live within 300m of the facility and were exposed to a leak. The control group includes individuals farther away (300-600m) or unexposed. The sample contains data from PA and FL and is limited to non-movers.

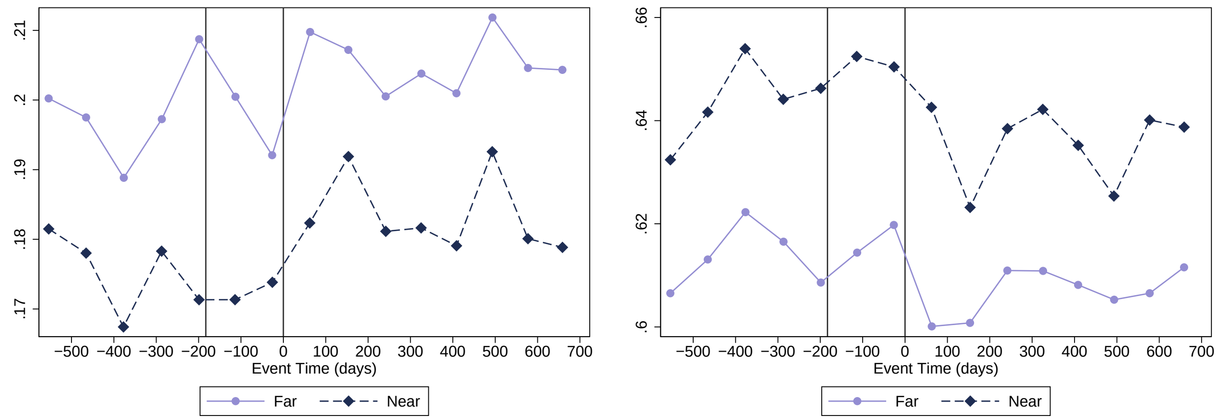
Figure A8: Event study of facility upgrades: all mothers near vs. far


(a) White

(d) Black

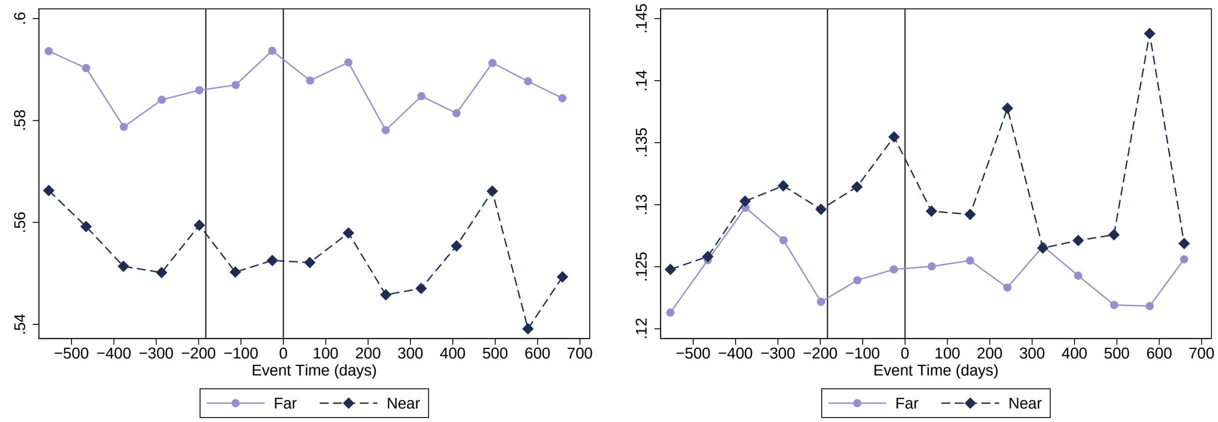
(b) High Educ

(e) Low Educ



(c) Married

(f) Teen Mom



Notes: Event time (in days) is calculated as the difference between the date of birth and the date of facility upgrade (defined in section 2). The first vertical line identifies the earliest time at which old tanks were removed (a half year) before the new tanks were installed at time 0, which is marked by the second vertical line. Near includes mothers living within 300m and far includes mothers 300-600m. The sample contains data from PA and FL and includes movers and non-movers.

Table A8: Bias with and without FE: Exposure analysis, all outcomes

	OLS (1)	OLS (2)	Facility FE (3)	Facility FE (4)	Mother FE (5)	Mother FE (6)
Panel A. Index Z						
Near × Exp	-0.524*	0.146	0.182	0.316	1.438***	1.472***
	(0.297)	(0.294)	(0.338)	(0.333)	(0.482)	(0.482)
Panel B. Low birth weight						
Near × Exp	-0.371***	-0.0666	-0.0675	-0.00981	0.576***	0.586***
	(0.129)	(0.127)	(0.145)	(0.141)	(0.205)	(0.205)
Panel C. Preterm birth						
Near × Exp	-0.136	0.275*	0.153	0.225	0.659***	0.676***
	(0.151)	(0.149)	(0.170)	(0.167)	(0.244)	(0.244)
Panel D. APGAR score						
Near × Exp	-0.157	-0.887**	-0.225	-0.367	-1.160*	-1.188*
	(0.398)	(0.395)	(0.445)	(0.441)	(0.661)	(0.659)
Panel E. Congenital anomalies						
Near × Exp	0.00347	0.00490	0.0296	0.0327	0.0681	0.0691
	(0.0502)	(0.0502)	(0.0556)	(0.0556)	(0.0891)	(0.0891)
Panel F. Abnormal conditions						
Near × Exp	-0.0203	0.0190	0.0784	0.0852	0.118	0.119
	(0.0667)	(0.0666)	(0.0713)	(0.0711)	(0.110)	(0.110)
SE Cluster Level			Facility	Facility	Mother	Mother
Controls	no	yes	no	yes	no	yes

Notes: Exposure is measured as a binary variable based on a hypothetical 39 week gestation. All specifications include year and month dummies. Columns including controls also include indicators for missing values for gender, education, marriage and smoking status. Standard errors are in parentheses. Coefficients and standard errors scaled by 100. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A9: Bias with and without FE: Regulation analysis

	Low Birth Weight					
	OLS (1)	OLS (2)	Facility FE (3)	Facility FE (4)	Mother FE (5)	Mother FE (6)
Near×Exp×Reg	-0.939***	-0.880***	-0.813***	-0.785***	-1.057*	-1.044*
	(0.210)	(0.207)	(0.229)	(0.226)	(0.540)	(0.539)
Near×Exp	0.422***	0.524***	0.492***	0.479***	0.935**	0.891**
	(0.156)	(0.154)	(0.173)	(0.170)	(0.443)	(0.442)
Exp×Reg	0.534***	0.423***	0.0562	0.150	0.770**	0.789***
	(0.118)	(0.118)	(0.139)	(0.137)	(0.304)	(0.303)
Near×Reg	0.235*	0.232*	0.247*	0.233*	0.307	0.265
	(0.129)	(0.128)	(0.141)	(0.139)	(0.374)	(0.373)
Exp	-0.358***	-0.371***	-0.143	-0.264**	-0.589**	-0.585**
	(0.0882)	(0.0891)	(0.114)	(0.112)	(0.250)	(0.250)
Reg	-0.0714	-0.0873	0.0404	-0.0484	-0.427	-0.445*
	(0.0984)	(0.0978)	(0.132)	(0.128)	(0.271)	(0.270)
Near	0.175**	-0.0163	0.0580	-0.00722		
	(0.0892)	(0.0882)	(0.101)	(0.0978)		
Observations	1,161,071	1,161,071	1,161,071	1,161,071	1,161,071	1,161,071
R-squared	0.000	0.021	0.0227	0.0360	0.859	0.860
Controls	no	yes	no	yes	no	yes
Number of FE			17,374	17,374	928,473	928,473

Notes: Exposure is measured as a binary variable based on a hypothetical 39 week gestation. All specifications include year and month dummies. Columns with controls include child gender, parity indicators, maternal education, marital status, smoking status, age, age-squared, indicators for race, and indicators for missing values of gender, education, marriage and smoking status. Standard errors are in parentheses. Coefficients and standard errors scaled by 100. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A10: Bias with and without FE: Regulation analysis, all outcomes

	OLS (1)	OLS (2)	Facility FE (3)	Facility FE (4)	Mother FE (5)	Mother FE (6)
Panel A. Index Z						
Near × Exp × Reg	-1.188***	-1.107**	-1.151**	-1.132**	-1.807	-1.783
	(0.453)	(0.450)	(0.491)	(0.484)	(1.228)	(1.226)
Panel B. Low birth weight						
Near × Exp × Reg	-0.939***	-0.880***	-0.813***	-0.785***	-1.057*	-1.044*
	(0.210)	(0.207)	(0.229)	(0.226)	(0.540)	(0.539)
Panel C. Preterm birth						
Near × Exp × Reg	-0.713***	-0.597**	-0.505*	-0.511*	-0.287	-0.293
	(0.249)	(0.247)	(0.268)	(0.263)	(0.670)	(0.669)
Panel D. APGAR score						
Near × Exp × Reg	0.648	0.475	0.285	0.221	2.827*	2.839*
	(0.612)	(0.608)	(0.663)	(0.656)	(1.690)	(1.687)
Panel E. Congenital anomalies						
Near × Exp × Reg	0.0156	-0.0102	-0.0386	-0.0448	0.0338	0.0356
	(0.0744)	(0.0744)	(0.0776)	(0.0774)	(0.225)	(0.224)
Panel F. Abnormal conditions						
Near × Exp × Reg	0.0134	0.0205	-0.108	-0.102	0.140	0.144
	(0.132)	(0.132)	(0.146)	(0.146)	(0.373)	(0.373)
SE Cluster Level			Facility	Facility	Mother	Mother
Controls	no	yes	no	yes	no	yes

Notes: Exposure is measured as a binary variable based on a hypothetical 39 week gestation. All specifications include year and month dummies. Columns including controls also include indicators for missing values for gender, education, marriage and smoking status. Standard errors are in parentheses. Coefficients and standard errors scaled by 100. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A11: Robustness to interaction with parity indicators

	Low Birth Weight					
Parity X =	1^{st}	2^{nd}	3^{th}	4^{th}	5^{th}	6^{th}+
	(1)	(2)	(3)	(4)	(5)	(6)
Near × Exp × Parity X	-0.0623	-0.156	0.224	-0.269	0.717	1.253
	(0.207)	(0.182)	(0.253)	(0.422)	(0.754)	(0.999)
Near × Exp	0.617***	0.657***	0.553***	0.624***	0.575***	0.561***
	(0.214)	(0.220)	(0.215)	(0.209)	(0.207)	(0.207)
Observations	693,159	693,159	693,159	693,159	693,159	693,159
Number of Moms	311,040	311,040	311,040	311,040	311,040	311,040

Table A12: Health impact of leak exposure: Non-movers only

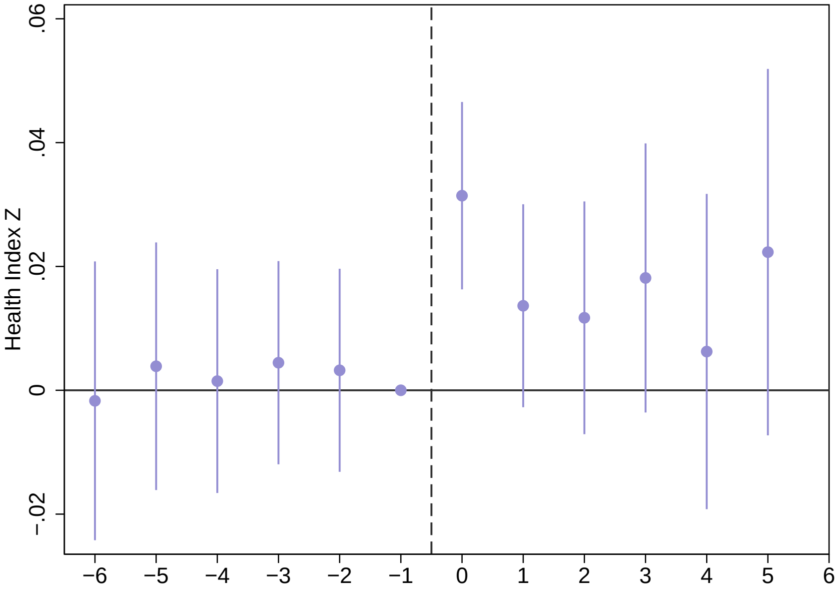
	Index Z	Low BW	Preterm	APGAR	Cong.Anom.	Abnorm
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Days Exposed						
Near×Exp	0.00564**	0.00236**	0.00206*	-0.00847***	0.000182	0.000257
	(0.00235)	(0.000994)	(0.00119)	(0.00322)	(0.000438)	(0.000520)
Panel B. Exposure Dummy						
Near×Exp	1.418**	0.580**	0.693**	-1.378*	0.0627	0.0558
	(0.560)	(0.239)	(0.284)	(0.768)	(0.103)	(0.123)
Observations	399,359	398,796	399,359	395,845	399,359	399,359
Number of Moms	186,465	186,219	186,465	185,018	186,465	186,465
% Change	-	8.57	7.56	-0.153	5.74	3.17

Notes: Shows results from estimation of equation 2. Coefficients and standard errors scaled by 100. Each regression includes maternal and child controls, year dummies, month dummies, and maternal fixed effects. The sample is restricted to non-movers and births occurring before the 1998 UST regulation deadline. *** p<0.01, ** p<0.05, * p<0.1

Table A13: Placebo tests

	Placebo Distance: 900-1200m vs. 1200-1500m			Placebo Outcome: Birth Injury
	Index Z	Low BW	Preterm	
	(1)	(2)	(3)	(4)
Near × Exp	0.377	-0.0343	0.401	-0.0216
	(0.495)	(0.206)	(0.253)	(0.0337)
Observations	270,073	269,816	270,073	694,033
Number of Moms	125,649	125,538	125,649	311,395

Figure A9: Timing relative to leak start date



Notes: Plots coefficients and 90% confidence intervals from a single regression for individuals living near the leak in periods before and after the leak start date. Each coefficient represents a period of 365 days relative to leak start date. Includes controls for maternal and child characteristics, mother fixed effects, year dummies, period dummies, and month dummies. Sample includes births occurring before the 1998 regulations.

Table A14: Health impact of leak exposure: Urban vs. Rural

	Index Z (1)	Low BW (2)	Preterm (3)	APGAR (4)	Cong. Anom. (5)	Abnorm (6)
Panel A. Days Exposed						
Near×Exp×Urban	0.00415	0.00159	0.000940	-0.000642	0.000400	0.000202
	(0.00343)	(0.00153)	(0.00180)	(0.00476)	(0.000597)	(0.000713)
Near×Exp×Rural	0.00624***	0.00262***	0.00240**	-0.00843***	0.000237	0.000605
	(0.00227)	(0.000930)	(0.00113)	(0.00307)	(0.000428)	(0.000546)
Equality test	0.582	0.531	0.458	0.133	0.806	0.626
Panel B. Exposure Dummy						
Near×Exp×Urban	0.891	0.174	0.329	0.125	0.122	0.0761
	(0.813)	(0.365)	(0.427)	(1.135)	(0.140)	(0.170)
Near×Exp×Rural	1.844***	0.770***	0.772***	-2.061***	0.0696	0.156
	(0.547)	(0.225)	(0.272)	(0.737)	(0.103)	(0.131)
Equality test	0.290	0.129	0.342	0.0776	0.740	0.684
Observations	692,463	691,590	692,463	687,293	692,463	692,463
Number of Moms	310,725	310,370	310,725	308,815	310,725	310,725
Rural Mean	-0.00629	0.0626	0.0877	8.985	0.0105	0.0198
Urban Mean	0.0226	0.0873	0.108	8.999	0.00977	0.0147
% Change Rural	-	0.123	0.0881	-0.00229	0.0665	0.0790
% Change Urban	-	0.0199	0.0306	0.000139	0.125	0.0517

Note: “Urban” areas are defined as those with both population density and the percent renters above the 75th percentile, based on census tract level data from the 2000 Census. “Rural” areas are defined as all other areas.