Title: Superfund Cleanups and Infant Health

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Superfund Cleanups and Infant Health

By JANET CURRIE, MICHAEL GREENSTONE AND ENRICO MORETTI*

In 1980, outcry over the health effects of toxic waste in Love Canal, New York resulted in the Comprehensive Environmental Response, Compensation, and Liability Act, which became known as Superfund. Superfund was intended to provide a mechanism for initiating remedial clean-ups at the most dangerous hazardous waste sites. More than 1,500 sites are eligible for clean-ups, but due to budget constraints they have been completed at only half of them. Given the substantial cost and slow rate of clean up, there is considerable debate on whether it is in the public interest to continue the program in its current form (U.S. Environmental Protection Agency, 2006).

The question is controversial in part because there is a paucity of reliable information on the program's benefits. Some previous studies find poorer birth outcomes near a site while others do not (see Martine Vrijheid, 2000). However, evidence of a correlation between proximity to a site and poor birth outcomes does not necessarily represent a causal effect because populations living near hazardous waste sites are typically different from the general population, and their health outcomes are likely to differ even in the absence of negative health effects from exposure. For example, Michael Greenstone and Justin Gallagher (2008) found that residents of areas near hazardous waste sites are more likely to be poor and have lower levels of education than others.

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Our project is the first to examine the effect of site cleanups on infant health rather than simply focusing on proximity to a site. We focus on single births that occurred within 5km of a Superfund site between 1989 and 2003 in five large states (Florida, Michigan, New Jersey, Pennsylvania, and Texas). This large sample gives us statistical power to detect small effects. The basis of our "difference in differences" approach is to compare changes in birth outcomes before and after a site's clean-up among births to mothers who live within 2,000 meters of the site and among those who live between 2,000 and 5,000 meters away. Our approach is made feasible by access to confidential Vital Statistics data that includes the street address of the mother's residence.

II. DATA AND SAMPLE

The primary source of outcomes data for this study are individual Vital Statistics Natality records, which provide data on both birth outcomes and characteristics of the mother. We focus on births to mothers between 15 and 45. The five states we consider include data on 154 sites that were cleaned up between 1989 and 2003. The key data step is that we were able to use geocoded maternal residential address to identify mothers who lived within a given distance of a Superfund site. In addition to focusing on births within 5000 meters of a site, we further restrict the sample to births conceived between 4 years before the initiation of a site cleanup and 4 years after its completion. This provides a sample of roughly 621,409 births with 92,609 to mothers living within 2,000 meters of one of the 154 sites in the sample.

Data on Superfund sites comes from the Environmental Protection Agency (EPA) and includes the date when the site was added to the National Priority List, the date when cleanup was initiated, and the date when cleanup was completed. In addition, the EPA conducts a hazardous risk assessment for all sites, and this hazardous ranking system (HRS) allows us to identify the most dangerous sites.

III. ECONOMETRIC APPROACH

We estimate the following model::

(1) $\textit{Health Outcome}_{ijt} = \Upsilon_0 + \Upsilon_1 \textit{Close}_{ijt} + \Upsilon_2 \textit{During}_{ijt} + \Upsilon_3 \textit{After}_{ijt}$

$\quad\quad \mathrm{E}\ \Upsilon_4 \textit{Close}_{ijt} * \textit{During}_{ijt} + \Upsilon_5 \textit{Close}_{ijt} * \textit{After}_{ijt} + \Upsilon_6 \boldsymbol{X}_{ijt} + \boldsymbol{\alpha}_j + \boldsymbol{\delta}_t + \varepsilon_{ijt},$

where i indicates a birth, j is the mother's street address, and t denotes the year of birth. There are three key indicator variables in this specification. $\textit{Close}_{ijt}$ equals one if the mother resided within 2000 meters of a site where a clean-up was finished during the sample. $\textit{During}_{ijt}$ equals one if the the birth occurred during the site clean-up. $\textit{After}_{ijt}$ indicates that it occurred after the site clean-up was completed. The vector X_{ijt} of maternal and child controls includes: indicators for the mother's age (<20, 20-34, 35 plus, age missing); maternal education (less than high school, high school, some college, college, education missing); maternal race and ethnicity (African-American, non-Hispanic white, Hispanic, other, race and ethnicity missing); birth order (first, second, third, fourth, fifth or higher order births, and birth order missing); and maternal smoking (smokes, does not smoke, smoking status missing).

We present results that adjust for all time invariant or fixed neighborhood characteristics in two different ways. In the first, $\boldsymbol{\alpha}_j$ is implemented with a full set of indicators for each site. We also report on specifications that replace the site fixed effects with zip code fixed effects that are based on the zip code of the mother's residence. Additionally, we include a vector of indicators for the year, δ_t, which allow us to control for time trends non-parametrically. The estimates are qualitatively similar if year indicators are replaced with state by year ones. The ε_{it} is an idiosyncratic error term.

The coefficient of primary interest is Υ_5 which is a "difference in differences" estimator of the impact of a site's clean-up on infant health outcomes. It measures the change in outcomes after a site's clean-up, relative to before clean-up, among births to mothers that live within 2,000 meters of the site to those that live between 2,000 and 5,000 meters away. Although we don't emphasize it in the subsequent results, Υ_4 is also a difference in differences estimator of the impact of living near a site during cleanup.

The key identifying assumption is that any benefits to women more than 2000 meters away are smaller than the benefits to those closer to a site. This assumption is reasonable since the primary methods for Superfund sites to affect local residents are through direct contact with the site, migration of toxic dirt or fumes through the air, or invasion of the water supply for houses that rely on well water. This assumption would be violated if the clean-up causes mothers with different unobserved health endowments to move closer to the site. Indeed, the basis of the identification strategy is that differential changes in migration and child bearing do not occur within 5,000 meters of a site. The specifications with zip code fixed effects aim to probe the robustness of this assumption by restricting the identifying comparison to births within the same zip code that occur less than 2,000 away from a site versus, relative to more than 2,000 meters. As additional methods to guard against selective migration and child birth, we use the *X* vector to adjust for a wide range of observable determinants of infant health and restrict the sample to the period 4 years before the cleanup's initiation through four years after its completion.

Two other details merit noting. Models of dichotomous dependent variables were estimated using linear probability models. The variance-covariance matrix allows for clustering at the county-year level to allow for dependence of observations within these cells.

IV. RESULTS

Summary statistics for outcomes and some characteristics of infants are shown in Table 1. Columns (1) and (2) report the means of these variables in the four years preceding the initiation of the clean-up among births to mothers that live within 2000 meters and 2000-5000 meters of one of the Superfund sites. Column (3) reports the difference in these means after adjustment for year of birth fixed effects. The associated standard error clustered at the county by year level (reported in brackets).

Panel A shows that infants living close to a site before its clean-up are more likely to have a congenital anomaly. Otherwise, the birth outcomes are statistically indistinguishable. However, the differences in maternal characteristics shown in Panel B suggest that such a direct comparison may confound the impact of clean-ups with other determinants of infant health. For example, mothers closer to a site are less likely to have a college degree or to be older than 35 years of age. Additionally, they are substantially more likely to smoke. Hence, it is important to control adequately for maternal characteristics, and to explore the possibility that maternal characteristics change systematically following a site cleanup.

Column (4) of Table 1 presents some initial results on Superfund cleanups and the quality of the research design. The entries come from fitting a version of equation (1) that includes site and year fixed effects but does not adjust for the vector X of maternal and child controls; they are unadjusted difference in differences estimates. The most striking finding is that there is a statistically significant decline in congenital anomalies. Table 1 does not show any evidence of differential changes in the determinants of infant health. This finding is reassuring. Nevertheless, the subsequent analysis will adjust for all available covariates as well as estimating the effects of Superfund cleanups in more uniform samples of mothers.

Panel A of Table 2 shows estimates from the fitting of versions of equation (1) with site fixed effects in the (a) columns and zip code fixed effects in the (b) columns. There is continued evidence that Superfund cleanups reduce the incidence of congenital anomalies. The coefficients in columns (1a) and (1b) indicate a reduction of 20-25%, relative to the baseline levels shown in Table 1. There is little evidence of an impact on the incidence of low birth weight. In columns (3a) and (3b), the point estimates suggest a reduction in the incidence of prematurity but it would only reach levels of precision considered to be statistically significant with the zip code fixed effects. These results may indicate that the fetus is most vulnerable in the first trimester of pregnancy, when congenital anomalies are most likely to occur (see Gerald G. Briggs, Roger K. Freeman, and Sumner J. Yaffe (2008)), and less vulnerable in the later stages of pregnancy, when the fetus puts on most of its weight and preterm labor may occur.

There is a roughly 14% decline in infant mortality rates but it would not be judged to be statistically significant by conventional criteria. Deaths are 30% less likely than congenital anomalies and an order of magnitude rarer than the other negative birth outcomes, suggesting that we have less power to detect effects on deaths. Finally, we note that there is little evidence of a change in any of the birth outcomes during the cleanup.

Panel of Table 2 repeats the analysis for the subset of births near the Superfund sites believed to be the most dangerous, defined as those with HRS scores in the top third. This sample restriction reduces the estimated impact of the cleanups on the incidence of congenital anomalies, but the effect remains statistically insignificant in the specification with zip code fixed effects. The estimates of Υ_5 in the models for the incidence of low birth weight and prematurity all rise in absolute value and become statistically significant in the case of prematurity for the specification that includes zip code fixed effects.

Perhaps, the most noteworthy results are the economically meaningful and statistically significant decline in infant mortality after clean-up at these high HRS score sites. These estimates imply that the infant mortality rate declined by a substantial 4.5 infants per 1000 births. The magnitude of these estimated impacts appears too large; the overall mean is just 7.4 deaths per 1000 births. Nevertheless if this estimate is taken literally, it implies that 323 additional infants survived to 1 year near these 51 sites in the 4 years following their clean-up. It is also interesting that the reductions in infant mortality first appear during clean-up.

To explore the robustness of our estimates further, we estimated a series of models using more uniform samples. In particular we excluded smokers, fourth and higher order births, mothers less than 20 and older than 34, and mothers with less than 12 years of education from our samples. Due to the similarity of the results from the site and zip code fixed effects specifications, we only report on the former here. Column (1) repeats the column (1a) results from Table 2 as a basis of comparison. Columns (2) through (5) report estimates for white mothers from this uniform sample. The estimates are generally more than twice as large as the baseline ones in column (1), which suggests that the results for congenital anomalies are not driven by changes in the composition of mothers near a Superfund site after cleanup. A comparison of columns (2) and (3) shows that the estimated effect is robust to defining "close" as 1500m rather than 2000m. A comparison of columns (4) and (5) suggests that boys are more vulnerable to exposure to a Superfund site than girls and that they also have higher baseline rates of congenital anomalies. Column (6) fails to find an impact of cleanups among black infants, although the standard errors are more than three times larger than in the baseline sample since the sample is much smaller. Finally, we conducted this exercise for the other outcome variables and failed to find consistent evidence of an impact of Superfund cleanups on the incidence of low birthweight, prematurity, or infant mortality in these subsamples.

V. DISCUSSION AND CONCLUSIONS

This study is the first to examine the impact of cleanups of hazardous waste sites on infant health. Its advantages include the large sample size, the analysis of several aspects of fetal and infant health in the same framework, and the addition of extensive controls for characteristics of maternal neighborhoods in the form of site or zip code fixed effects.

Our estimates suggest that Superfund cleanups reduce the incidence of congenital anomalies by roughly 20-25%.[1] Further, there is some evidence that cleanups at the most dangerous sites may reduce infant mortality rates. However, the magnitude of our estimate underscores the need for further research. Finally, important differences in the health endowments of people who live near Superfund sites underscores the likelihood of confounding in cross-sectional analyses of the impacts of exposure.

There are a few broader lessons from this analysis. One appeal of infant health as an outcome is that it avoids the problem of a lack of information on the countless other environmental factors that may affect adult health, including, lifetime smoking behavior, lifetime exposure to ambient air pollution, and lifetime exposure to multiple hazardous waste sites. A limitation of our analysis is that

[1] In a cross-sectional analysis Paul Elliott, et al. (2001) finds that proximity to a hazardous waste site in Great Briain increases the incidence of congenital anomalies. Dolk et al. (1998) find a 33% increase in the risk on non-chromosomal anomalies for residents living within 3km of a hazardous waste site, which is quite similar to our estimate.

it cannot be informative about long run outcomes, like cancer. Further, there is no standard measure of the willingness to pay to avoid a congenital anomaly so it is difficult to develop a monetary benefit of these clean-ups.[2]

A primary limitation of our study is the fact that like many previous studies of hazardous waste sites we do not have a direct measure of exposure or the toxics that individuals were exposed to. Hence, our estimates cannot be used to identify the precise pathways or toxics through which proximity harms health. This is an important question for future research.

REFERENCES

Briggs, Gerald G., Roger K. Freeman, and Sumner J. Yaffe. 2008. *Drugs in pregnancy and lactation: a reference guide to fetal and neonatal risk*. 8th ed. Philadelphia: Lippincott Williams & Wilkins.

Henshaw, Stanley K. 1998. "Unintended Pregnancy in the United States." *Guttmacher Institute*, 30(1): 24-29+46.

Dolk, Helen, Martine Vrijheid, Ben Armstrong, Lenore Abramsky, Fabrizio Bianchi, Ester Garne, Vera Nelen, Elisabeth Robert, John E.S. Scott, David Stone, and Romano Tenconi. 1998. "Risk of Congenital Anomalies near Hazardous-Waste Landfill Sites in Europe: the EUROHAZCON Study." *Lancet*, 352: 423-427.

Elliott, Paul, David Briggs, Sara Morris, Cornelis de Hoogh, Christopher Hurt, Tina Kold Jensen, Ian Maitland, Sylvia Richardson, Jon Wakefield, and Lars Jarup. 2001. "Risk of Adverse Birth Outcomes in Populations Living near Landfill Sites." *British Medical Journal*, 323: 363-368.

Greenstone, Michael, and Justin Gallagher. 2008. "Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program," *Quarterly Journal of Economics*, 123(3): 951-1003.

U.S. Environmental Protection Agency. 2006. *Superfund's 25th Anniversary: Capturing the Past, Charting the Future*. http://www.epa.gov/superfund/25anniversary (accessed February 2, 2009).

Vrijheid, Martine. 2000. "Health Effects of Residence Near Hazardous Waste Landfill Sites: A Review of Epidemiologic Literature." *Environmental Health Perspectives*, 108(S1): 101-112.

[2] Our estimates imply that these cleanups averted 231 instances of congenital anomalies in the 44,580 infants born to mothers within a mile of Superfund site that had been cleaned up. Using Greenstone and Gallagher's cost of clean-up figures, the total cost of cleaning up these 146 sites was approximately $4 billion (2005 $s). Hence, the cost was approximately $117,000 per anomaly averted.

Table 1: Means of Key Variables in Births Data

	<2000 meters [1]	2000-5000 meters [2]	Diff-erence [3]	Diff-in-Diff [4]
A. Outcomes				
Cong. Anomalies	0.0118	0.0101	0.0018**	-0.0022**
			[0.0008]	[0.0010]
Low Birth Weight	0.0767	0.0742	0.0016	-0.0005
			[0.0035]	[0.0041]
Preterm	0.0869	0.0897	-0.0026	-0.0030
			[0.0032]	[0.0035]
Infant Death	0.0084	0.0085	-0.0001	-0.0011
			[0.0008]	[0.0010]
B. Mother Characteristics				
<=19 Years Old	0.1359	0.1367	0.0004	0.0021
			[0.0067]	[0.0071]
>=35 Years Old	0.1035	0.1135	-0.0114***	0.0062
			[0.0043]	[0.0052]
< High School Ed.	0.2512	0.2534	-0.0009	0.0100
			[0.0138]	[0.0115]
>= College Ed.	0.1856	0.2051	-0.0228**	0.0090
			[0.0111]	[0.0118]
African American	0.2491	0.2919	-0.0383	0.0062
			[0.0420]	[0.0322]
Hispanic	0.1973	0.1931	0.0028	0.0143
			[0.0340]	[0.0164]
Smoker	0.1556	0.1355	0.0194**	0.0013
			[0.0081]	[0.0054]
C. Child Characteristics				

Birth Order	1.9496	1.9791	-0.0280	0.0039
			[0.0305]	[0.0260]
Male	0.5115	0.5099	0.0014	-0.0064
			[0.0027]	[0.0047]

Notes: For Columns 1-3, only singleton births conceived in the 4 years before the initiation of a cleanup are included. The number of such births within 2000 meters of a cleanup site (Column 1) is 31,126; within 2000-5000 meters of a site (Column 2), it is 166,338. Column 3 reports the difference in means after adjustment for year of birth fixed effects. The standard error is clustered at the county by year level (in square brackets). In Column 4, the sample includes all singleton births conceived between 4 years prior to the initiation of a cleanup and 4 years after completion; 621,409 births. Column 4 reports the difference and differences estimator obtained by fitting a version of equation (1) that includes site and year fixed effects but does not adjust for the X vector. The standard error clustered at the county by year level is also reported (in square brackets). See the text for further details.

Table 2: Effects of Superfund Cleanups on Birth Outcomes

	Cong. Anom. [1a]	Cong. Anom. [1b]	Low BW [2a]	Low BW [2b]	Pre-mature [3a]	Pre-mature [3b]	Infant Death [4a]	Infant Death [4b]
A. Full Sample								
During*Close	-0.0009	-0.0011	0.0016	0.0013	0.0003	-0.0003	-0.0009	-0.0009
	[0.0011]	[0.0011]	[0.0027]	[0.0030]	[0.0025]	[0.0026]	[0.0011]	[0.0010]
After Cleanup*	-0.0022**	-0.0029***	-0.0020	-0.0033	-0.0036	-0.0051*	-0.0011	-0.0011
Close	[0.0010]	[0.0010]	[0.0030]	[0.0028]	[0.0026]	[0.0027]	[0.0010]	[0.0009]
Mean Dep. Var.:	0.0112	0.0112	0.0795	0.0795	0.0880	0.0880	0.0079	0.0079
R-squared	0.0061	0.0126	0.0412	0.0585	0.014	0.0181	0.0028	0.0069
# Obs.	601949	599289	617698	615037	617792	615131	617792	615131
B. Top HRS Sites (Sites in the Top 1/3 of HRS Scores)								
During*Close	-0.0014	-0.0021	0.0002	-0.0032	-0.0023	-0.0064	-0.0036**	-0.0032**
	[0.0014]	[0.0015]	[0.0044]	[0.0048]	[0.0040]	[0.0044]	[0.0015]	[0.0016]
							-	-
After Cleanup*	-0.0014	-0.0026*	-0.0048	-0.0080	-0.0041	-0.0092**	0.0045***	0.0044***
Close	[0.0017]	[0.0015]	[0.0049]	[0.0049]	[0.0036]	[0.0042]	[0.0015]	[0.0015]
Mean Dep. Var.:	0.0120	0.0120	0.0811	0.0811	0.0899	0.0899	0.0074	0.0074
R-squared	0.0060	0.0142	0.0445	0.0712	0.0122	0.0195	0.0024	0.0098
# Obs.	260168	258970	267623	266425	267686	266488	267686	266488
Site FE	Yes	No	Yes	No	Yes	No	Yes	No
Zip FE	No	Yes	No	Yes	No	Yes	No	Yes

Notes: The table reports the coefficients and standard errors (in square brackets) associated with $Close_{ijt}$*$During_{ijt}$ and $Close_{ijt}$*$After_{ijt}$ from the estimation of alternative versions of equation (1). Standard errors are clustered at the county-year level. The sample is limited to singleton births within 5,000 meters of a site conceived between 4 years prior to the initiation of a cleanup and 4 years after completion are included. "Close" is defined as within 2000 meters of the site. Regressions include controls for race, maternal age, maternal education, maternal smoking, child parity, child gender, year of birth, and zip code. *, **, and *** indicate significance at the 90%, 95%, and 99% levels. See the text for further details.

Table 3: Effects of Superfund Cleanups on Congenital Anomalies: Alternative Samples and Specifications

	[1]	[2]	[3]	[4]	[5]	[6]
During*Close	-0.0009	-0.0027	0.0002	-0.0038	-0.0017	-0.0027
	[0.0011]	[0.0017]	[0.0022]	[0.0026]	[0.0020]	[0.0031]
After Cleanup*	-0.0022**	-0.0055***	-0.0044**	-0.0068**	-0.0040**	-0.0021
Close	[0.0010]	[0.0018]	[0.0022]	[0.0027]	[0.0019]	[0.0034]
Mean Dep. Var.:	0.0112	0.0109	0.0109	0.0127	0.0089	0.0106
R-squared	0.0061	0.0070	0.0070	0.0099	0.0076	0.0143
# Obs.	601949	183693	183693	94245	89448	54485
Uniform Sample	No	Yes	Yes	Yes	Yes	Yes
Other Restriction	None	White	White	White, Male	White, Female	Black
Definition Close	2000m	2000m	1500m	2000m	2000m	2000m
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: See the notes to Table 2. In addition to those details, the "uniform" samples include only nonsmoking mothers with high school education or more who are between 20 and 34, and only children of parities 1, 2, or 3. *, **, and *** indicate significance at the 90%, 95%, and 99% levels. See the text for further details.