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ABSTRACT

We are the first to examine the effect of Superfund cleanups on infant health rather than focusing on proximity to a site. We study singleton births to mothers residing within 5km of a Superfund site between 1989-2003 in five large states. Our "difference in differences" approach compares birth outcomes before and after a site clean-up for mothers who live within 2,000 meters of the site and those who live between 2,000- 5,000 meters of a site. We find that proximity to a Superfund site before cleanup is associated with a 20 to 25% increase in the risk of congenital anomalies.

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 conducting remedial clean-ups at the most dangerous hazardous waste sites. Over the years, it became the largest and most expensive federal program to deal with toxic waste in the US. 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 (EPA, 2006).

While the costs of the programs are clear, its benefits are not well understood. Indeed, the policy 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.

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. 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 exact street address of the mother's residence. Our large sample gives us statistical power to detect small effects.

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 births 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) $Health\ Outcome_{ijt} = \mu_0 + \mu_1\ Close_{ijt} + \mu_2\ During_{ijt} + \mu_3\ After_{ijt}$

$+\mu_4\ Close_{ijt}*During_{ijt} + \mu_5 Close_{ijt}*After_{ijt} + \mu_6\ X_{ijt} + \alpha_j + \delta_t + \varepsilon_{ijt},$

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. $Close_{ijt}$ equals one if the mother resided within 2000 meters of a site where a clean-up was finished during the sample. $During_{ijt}$ equals one if the birth occurred during the site clean-up. $After_{ijt}$ 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, α_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. On the one hand, there are ten times as

many zip codes as sites so that zip code fixed effects may control more fully for the characteristics of local areas. On the other hand, the differences in exposure to Superfund site hazards between births within 2,000 meters and those 2,000 to 5,000 meters from a site are likely to be smaller within a zip code. 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 coefficient of primary interest is μ_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, μ_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 clean-up related benefits to women 2000 to 5000 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.

While migration in response to environmental amenities is itself an interesting question (see Currie, 2011), the assumptions necessary to identify health effects would be violated if the clean-up causes mothers with systematically different unobserved health endowments to move closer to the site. In order to guard against the possible effects of selective migration, 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. We also estimate models focusing on demographically uniform samples (e.g. white, non-smoking, 20-34 year old mothers with a high school education or more) to probe the robustness of the results to bias due to sorting on observable characteristics.

Finally, 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 to 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 is 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

Table I: 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** [0.0008]	-0.0022** [0.0010]
Low Birth Weight	0.0767	0.0742	0.0016 [0.0035]	-0.0005 [0.0041]
Preterm	0.0869	0.0897	-0.0026 [0.0032]	-0.0030 [0.0035]
Infant Death	0.0084	0.0085	-0.0001 [0.0008]	-0.0011 [0.0010]
B. Mother Characteristics				
<=19 Years Old	0.1359	0.1367	0.0004 [0.0067]	0.0021 [0.0071]
>=35 Years Old	0.1035	0.1135	-0.0114*** [0.0043]	0.0062 [0.0052]
< High School Ed.	0.2512	0.2534	-0.0009 [0.0138]	0.0100 [0.0115]
>= College Ed.	0.1856	0.2051	-0.0228** [0.0111]	0.0090 [0.0118]
African American	0.2491	0.2919	-0.0383 [0.0420]	0.0062 [0.0322]
Hispanic	0.1973	0.1931	0.0028 [0.0340]	0.0143 [0.0164]
Smoker	0.1556	0.1355	0.0194** [0.0081]	0.0013 [0.0054]
C. Child Characteristics				
Birth Order	1.9496	1.9791	-0.0280 [0.0305]	0.0039 [0.0260]
Male	0.5115	0.5099	0.0014 [0.0027]	-0.0064 [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.

differential changes in the determinants of infant health, which provides some support for the validity of the difference in differences design. However, Currie (2011) shows evidence that there is some sorting on observables following Superfund cleanups when the specification includes zip code fixed effects, rather than site fixed effects. Hence, 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 in the models with zip code fixed effects. The stronger results for congenital anomalies 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 B 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 μ_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.

Table II: 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 Clean*	-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 Clean*	-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 $Close_{iit}*During_{iit}$ and $Close_{iit}*After_{iit}$ 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.

Perhaps, the most noteworthy results are the 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. However, the magnitude of

these estimated impacts appears too large; the overall mean is just 7.4 deaths per 1000 births. It is possible that these results are driven by sorting, as Currie (2011) suggests that sorting following cleanups is stronger at more hazardous sites.

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.

Table III: 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
				White,	White,	
Other Restriction	None	White	White	Male	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.

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. When we conducted this exercise for the other outcome variables we did not find consistent evidence of an impact of Superfund cleanups on the incidence of low birthweight, prematurity, or infant mortality in these subsamples. Hence, only the estimates for congenital anomalies are robust to different specifications.

V. Discussion and Conclusions

This study is the first to examine the impact of cleanups of hazardous waste sites on infant health. Our estimates suggest that Superfund cleanups reduce the incidence of congenital anomalies by roughly 20-25%.[1] The finding of health benefits does not necessarily imply that it is in the public interest to continue the Superfund program in its current form. It might be more cost effective, for example, simply to ensure that people do not live near contaminated sites. Further research is clearly needed to determine whether the program is cost effective in improving health outcomes relative to possible alternative use of federal resources. Given the likelihood of a large heterogeneity in the toxicity level of the remaining sites, further research is also needed to determine how the expected benefits of the clean ups may vary across sites, as the program moves its focus from the sites with the highest levels of pollution to the sites with lower levels of pollution.

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[1] In a cross-sectional analysis Paul Elliott, et al. (2001) finds that proximity to a hazardous waste site in Great Britain 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.

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 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 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.

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[2] The estimates imply that these clean ups averted between 76 and 144 instances of congenital anomalies in the 26,238 infants born to mothers within 2000 meters 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 sites was approximately $4 billion (2005 $s). Hence, the cost per anomaly averted greatly exceeds standard estimates of the value of a statistical life (e.g., Ashenfelter and Greenstone 2004). Of course, this paper's focus on infants cannot measure any health improvements that occur later in life and we have explored only one dimension of possible health effects.

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