Effect of oil spills on infant mortality in Nigeria

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Oil spills can lead to irreversible environmental degradation and are a potential hazard to human health. We study how onshore oil spills affect neonatal and infant mortality by combining spatial data from the Nigerian Oil Spill Monitor with Demographic and Health Surveys. To identify a causal effect, we compare siblings born to the same mother, conceived before and after a nearby oil spill. We find that nearby oil spills that occur before conception increase neonatal mortality by 38.3 deaths per 1,000 live births, which corresponds to an increase of around 100% on the sample mean. The effect is fairly uniform across girls and boys, socio-economic backgrounds, and locations. We show that this effect is not driven by events related to oil production or violent conflict. Rather, our results are consistent with medical and epidemiological evidence showing that exposure to hydrocarbons can pose risks to fetal development. We provide further evidence suggesting that the effects of oil spills on neonatal mortality persist for several years after the occurrence of an oil spill.

onshore oil spills | infant mortality | neonatal mortality | Nigeria | sibling comparisons

A large literature in the social sciences argues that oil, gas, and other natural resources may be a curse rather than a blessing for economic and political development (1). The negative effects of natural resources on economic development, corruption, and democratic institutions seem to be strongest in weakly institutionalized countries (2–4), where the political elite is not accountable to their citizens and the state often unable or unwilling to keep transnational extractive corporations accountable (5). In these countries, the extraction of oil and gas also typically brings a host of negative side effects at the local level, including irreversible environmental degradation and hazards to human health.

In Nigeria, which is Africa's most populous country and its largest oil producer, frequent oil spills resulting from pipeline vandalism, theft, and poor maintenance are a major source of environmental pollution. When crude oil or other petroleum products leak into the environment, the different compounds (depending on their physical properties) evaporate into the air, are absorbed by the soil, or enter ground and surface water. Oil spills also often lead to fires, which release respirable particulate matter (PM) into the air. Hazards to human health may result from dermal contact with soil and water; ingestion of contaminated drinking water, crops, or fish; or inhalation of vaporized product or PM and partly burned hydrocarbons produced by fires. In addition, onshore oil spills may have indirect health effects via damage of livelihood resources, such as diminished yields from degraded agricultural land and fishing grounds (6, 7). While various studies that document significant levels of water and soil contamination in the Niger Delta highlight the potential health hazards of such contamination (6, 8, 9), there is so far no causal evidence on how onshore oil spills affect actual human health outcomes.

In this paper, we study the causal effects of onshore oil spills before a child's conception on neonatal and infant mortality. The focus on neonatal and infant mortality is interesting in and of itself. In addition, these mortality rates serve as leading indicators that allow tracking human health more generally.

We combine data from the Nigerian Oil Spill Monitor (10) and the Nigeria Demographic and Health Survey (DHS) 2013 (11). The Nigerian Oil Spill Monitor provides information on oil spills recorded by the National Oil Spill Detection and Response Agency (NOSDRA). We use the information on the geo-coordinates and dates of the 5,296 oil spills recorded for the time period from January 2005 to July 2014. The Nigeria DHS 2013 provides the complete birth histories of 23,364 Nigerian mothers and information on the survival of their children, as well as the geo-coordinates of their places of residence (which are displaced by up to 10 km for confidentiality reasons). We focus on the 2,744 mothers living in the 130 different survey clusters at a reported distance of less than 10 km from the closest oil spill recorded between January 2005 and 1 y after the DHS interviews. Fig. 1 presents a map of Nigeria showing the locations of the oil spills and the clusters of the Nigeria DHS 2013. The shaded areas represent the union of all circles with a 10-km radius around the oil spills in our records. Our dataset (12) is based on the 130 survey clusters located within these areas, which are the focus of our analysis.

Our empirical strategy relies on sibling comparisons; i.e., we compare mortality rates across infants of the same mother, some conceived before the first nearby oil spill in our records and some conceived thereafter. We thereby control for a vast number of unobserved factors that may otherwise be spuriously correlated with both infant mortality and oil spills. We moreover control for various birth characteristics and allow for location-specific time trends.

Previous research on the topic is scant. The study most closely related to ours focuses on the Ecuadorian Amazon basin and compares pregnancy outcomes between women

Significance

Onshore oil spills can lead to irreversible environmental degradation and potentially pose hazards to human health, but scientific evidence on their health effects is lacking. We fill this gap by studying the causal effects of onshore oil spills on neonatal and infant mortality rates. We compare siblings conceived before and after nearby oil spills and find that nearby oil spills double the neonatal mortality rate. Given that oil spills occur with high frequency in the densely populated areas along pipelines in Nigeria, they are the cause of an alarming ongoing human tragedy. Our results suggest that efforts to prevent oil spills in the Niger Delta could save the lives of thousands of newborns every year.

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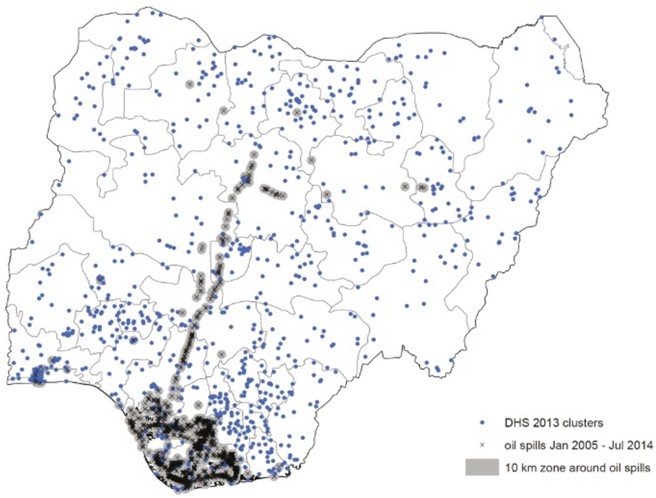

Fig. 1. Map of Nigeria showing the locations of all oil spills in our records and all clusters of the Nigeria DHS 2013. The shaded areas represent the union of all circles with a 10-km radius around all of the oil spills.

living in rural communities close to oil fields and women living in communities far away from oil fields (13). Our study differs primarily by exploiting not only spatial, but also temporal variation in the occurrence of oil spills, which allows us to identify a causal effect by comparing siblings born to the same mother. Our study further differs by analyzing effects on neonatal and infant mortality and by including onshore oil spills far from oil production sites. Other related work has studied clean-up workers and local residents exposed to major offshore oil spills (for a review, see ref. 14), parents exposed to petroleum products at their work place before the conception or birth of a child (15–17), gas production involving hydraulic fracturing in Pennsylvania and its effects on infant health (18), and development aid in Nigeria and its effect on infant mortality (19).

Results

Our treatment variable, $SPILL_{imc}$, is equal to one if infant i of mother m living in cluster c was conceived any time after an oil spill occurred less than 10 km away from the reported cluster location and zero otherwise. Our dependent variables are indicator variables for whether or not an infant died within a specific period after birth. We scale these indicator variables to align them to the conventional definitions of mortality rates, which are the number of deaths in 1,000 live births. The infant mortality indicator IMR_{imc} is equal to 1,000 if infant i died within the first 12 mo of life and zero otherwise. Similarly, the neonatal mortality indicator NMR_{imc} is equal to 1,000 if infant i died within its first month of life, and the postneonatal mortality indicator PMR_{imc} if infant i survived the first month, but died within its first year of life. Table 1 presents summary statistics. Infant and neonatal mortality rates are 60.2 and 37.1 deaths per 1,000 live births in our sample.

Table 2 presents our main results. The sample in columns 1–5 includes all infants born after 2005 and up to 12 mo before the DHS interview. Column 1 documents the relation between nearby oil spills before conception and infant mortality in the absence of any control variables, fixed effects, or time trends. Column 2 adds as controls a set of birth characteristics, including indicator variables for birth year, birth order, critical birth spacing, mother's age, multiple births, and the infant's sex (see *SI Appendix* for more information on these variables). In addition, it contains fixed effects for DHS clusters, which control for any differences across cluster locations, and cluster-specific time trends, which ensure that local economic, political, or social developments are not driving the coefficient estimate. Column 3 goes one step further by adding mother fixed effects to ensure that our results are not driven by any differences between mothers conceiving before and after the occurrence of a nearby oil spill. In columns 1–3, the effect of the oil spills on the infant mortality rate is positive, but not statistically significant at conventional levels. The point estimate in column 3 suggests that a nearby oil spill before conception leads to an increase by 31.6 deaths per 1,000 live births or, equivalently, an increase of around 50% on the sample mean.

When splitting infant mortality into neonatal and postneonatal mortality in columns 4 and 5 in Table 2, we find that oil spills cause an increase in neonatal mortality, which is statistically significant at the 5% level. The coefficient on postneonatal mortality is not statistically significant and even negative. Hence, the increase in infant mortality is entirely driven by an increase in mortality in the first month of life.

In column 6 in Table 2, we again focus on neonatal mortality, but add to the sample infants born between 1 mo and 12 mo before the DHS interview. In this larger sample, the effect of oil spills on neonatal mortality is slightly smaller, but more precisely estimated than in column 4. The point estimate suggests that nearby oil spills increase neonatal mortality by 38.3 deaths per 1,000 live births, which corresponds to an increase of around 100% on the sample mean.

The effects of nearby oil spills on neonatal mortality might vary in magnitude with the characteristics of the infant, the mother, the household, or the cluster location. Fig. 2 presents the results of regressions based on the same specification and the same sample as column 6 in Table 2, but in which we interact our treatment variable with different pairs of indicator variables. Fig. 2*A* compares the estimated effect of a nearby oil spill on neonatal mortality depending on whether the infant is male or female, whether or not the mother has secondary education, whether the household's wealth is above or below the sample median, and whether the cluster is urban or rural (see *SI Appendix* for more information on these variables).

We see strongly overlapping confidence intervals within each pair of interaction terms (e.g., for the interaction term between $SPILL_{imc}$ and a male indicator variable and the interaction term between $SPILL_{imc}$ and a female indicator variable in the first regression). *F* tests confirm that the difference between the coefficients on the two interaction terms is not statistically significant at the 10% level in any of the four regressions on which Fig. 2*A* is based. Hence, the effect of nearby oil spills on neonatal mortality does not seem to be restricted to a particular subset of infants born in areas polluted by oil spills.

Discussion

Table 2 shows that nearby oil spills before conception have a sizeable effect on the neonatal mortality rate, and Fig. 2*A* shows that this effect is fairly uniform across girls and boys, socio-economic backgrounds, and locations. Because we include mother fixed effects in these regressions, we are confident that a causal interpretation of this result is appropriate. (We discuss

Table 1. Summary statistics

Variable	Observed	Mean	SD	Min.	Max.
IMR_{imc}	4,314	60.27	238.01	0	1,000
NMR_{imc}	5,043	37.08	188.98	0	1,000
PMR_{imc}	4,314	25.27	156.95	0	1,000
$SPILL_{imc}$	5,043	0.29	0.45	0	1

See *SI Appendix* for more information on these variables and *SI Appendix*, Table S1 for summary statistics for other variables.

Table 2. Effects of oil spills on infant and neonatal mortality

Dependent variable	1) IMR_{imc}	2) IMR_{imc}	3) IMR_{imc}	4) NMR_{imc}	5) PMR_{imc}	6) NMR_{imc}
$SPILL_{imc}$	2.56	26.17	31.56	44.15*	−12.59	38.33*
	(10.41)	(19.56)	(26.73)	(21.86)	(19.01)	(14.96)
Birth characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Cluster fixed effects	No	Yes	No	No	No	No
Cluster time trends	No	Yes	Yes	Yes	Yes	Yes
Mother fixed effects	No	No	Yes	Yes	Yes	Yes
No. of infants	4,314	4,314	4,314	4,314	4,314	5,043
No. of mothers	2,547	2,547	2,547	2,547	2,547	2,744
No. of clusters	130	130	130	130	130	130
R^2	0.03	0.10	0.10	0.09	0.08	0.08

Linear fixed-effects regressions are shown. All variables (including birth characteristics) are described in *SI Appendix*. Sample in columns 1–5 (column 6) includes all infants born between January 2006 and 12 mo (1 mo) before the DHS interview to mothers in clusters less than 10 km from the closest oil spill in our records. Standard errors are clustered at the level of the DHS clusters. *, significance at the 5% level.

our identification strategy and trends before the first nearby oil spill in *Data and Methods*.)

We perform two additional tests to see whether mortality rates could be driven by other events that are correlated in time and space with the occurrence of oil spills. Such events might be linked to oil operations around the extraction sites in the Niger Delta or to violent attacks on oil infrastructure and other conflict events. Fig. 2*B* shows how the estimated effect of a nearby oil spill on neonatal mortality varies depending on whether the cluster is located in one of the oil-producing states in the Niger Delta and on whether a conflict event with a least one fatality took place within 25 km from the cluster location during the sample period. Fig. 2*B* shows that the effect tends to be stronger outside the Niger Delta. This finding makes it implausible that events related to oil production drive the relationship between oil spills and neonatal mortality. A possible reason for the lower point estimate in the Niger Delta is the longer history and higher density of previous oil spills (6, 20).

Fig. 2*B* further shows that the estimated effect tends to be larger for infants born outside conflict areas. Hence, the higher neonatal mortality rates subsequent to nearby oil spills are not the result of violence against local communities, which may coincide with pipeline vandalism or oil theft. A possible reason for the lower point estimate in conflict areas could be that conflict events may induce temporary displacement of local residents and, thereby, reduce their exposure to oil spill-related health hazards.

We conduct further analysis to understand whether and how the effect of oil spills on neonatal mortality attenuates as temporal and spatial distance to the oil spill increases. We find that the effect of oil spills within 10 km is persistent over 5 y at least, which is the period that our data allow us to analyze (*SI Appendix*, Fig. S3). When we disaggregate our treatment variable by the distance at which an oil spill occurred from the reported DHS cluster location, we find that the effect on neonatal mortality decreases slightly as the distance increases and levels off at distances above 10 km (*SI Appendix*, Fig. S4).

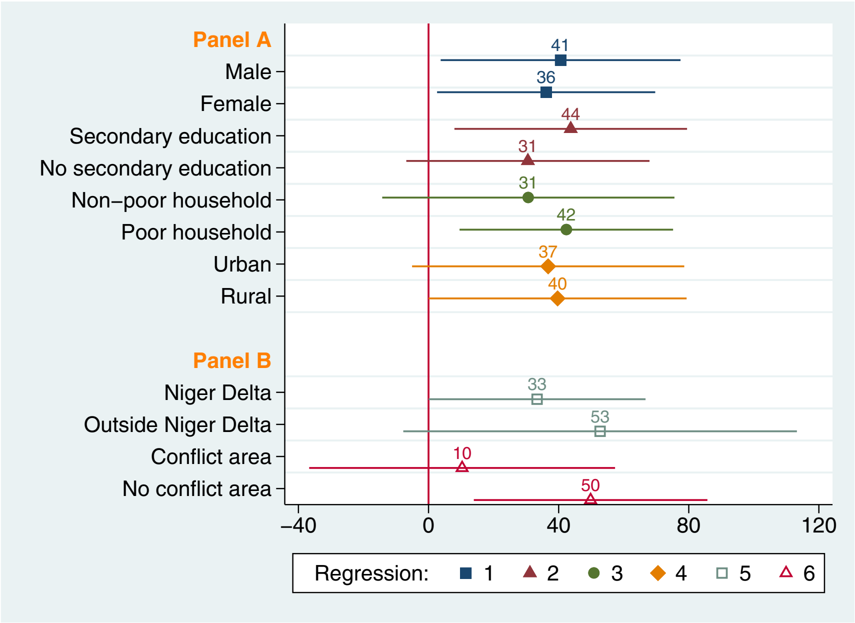

Fig. 2. (*A* and *B*) The coefficient estimates from six separate linear regressions of the neonatal mortality rate on the interaction terms $SPILL_{imc} \times Z_{imc}$ and $SPILL_{imc} \times (1 - Z_{imc})$, where Z_{imc} is a different indicator variable in each regression (e.g., an indicator for male infants in regression 1). Each regression includes mother fixed effects, cluster-specific time trends, and the same birth-specific control variables as in Table 2. The sample is the same as in Table 2, column 6. Standard errors are adjusted for clustering at the level of DHS clusters. The horizontal lines represent 95% confidence intervals.

We also examine whether mothers' exposure to oil spills during pregnancy has an effect on mortality rates (*SI Appendix*, Table S2). We cannot find any statistically significant effect on infant or neonatal mortality of oil spills that occurred within 10 km during pregnancy, except for a positive effect of oil spills that occurred during the first trimester on postneonatal mortality (*SI Appendix*, Table S2B).

Epidemiological evidence suggests that oil spills likely not only affect neonatal and infant mortality, but also increase the risk of abortion and stillbirth (13, 15–17). To study the effect of nearby oil spills on pregnancy terminations, we again use data from the Nigeria DHS. Unlike the birth history information, the information on pregnancies is taken from a "reproductive calendar" in which women are supposed to state for every month from January 2008 onward whether they used contraception, were pregnant, had a live birth, or a pregnancy termination. While levels of misreporting or omissions are generally low for the DHS birth history records (21), there are substantial inconsistencies in the reporting of terminated pregnancies in the DHS reproductive calendars (22). Nevertheless, we use pregnancies as units of observation and estimate the effect of oil spills occurring before conception within 10 km from the DHS cluster location on the pregnancy termination rate (*SI Appendix*, Table S3). We find a strong and statistically significant positive effect when controlling for mother's age and the year of conception only. This effect, however, becomes smaller and is no longer statistically significant at conventional levels when we add cluster or mother fixed effects as well as cluster-specific time trends. Possible reasons are the shorter sample period and the lower data accuracy, e.g., due to recall errors regarding pregnancy terminations.

Finally, again focusing on neonatal mortality, we conduct a back-of-the-envelope calculation to get an impression of the scale of the problem: The World Health Organization reports 5,281,386 live births in Nigeria in 2012. The Nigeria DHS 2013 suggests that 8.05% of the infants born in 2012 were born in a cluster located within 10 km from a recorded oil spill that occurred before conception. Further, our causal estimates show that an oil spill less than 10 km away before conception increases neonatal mortality by around 38.3 deaths per 1,000 live births. Taken together, these numbers suggest that oil spills before conception killed around 16,000 infants within the first month of their life in 2012. In addition, these oil spills most likely had negative effects on the health of older children and adults too.

We conclude that the frequent onshore oil spills in Nigeria are the cause of an alarming ongoing human tragedy. While our study does not lend itself naturally to proposing a specific policy intervention, we are convinced that more attention to the problem by both the research community and the public is warranted.

Data and Methods

Nigerian Oil Spill Monitor. The Nigerian Oil Spill Monitor (10) is a dedicated website (https://oilspillmonitor.ng) that is intended to raise awareness of the scale of the problem. It calls on the public to report oil spills to NOSDRA through a hotline or by email, but heavily relies on the support of oil companies to provide data. Oil companies reporting to NOSDRA can indicate whether the oil spills are caused by sabotage or theft or by factors that fall under their responsibility, such as operational or maintenance errors, pipeline corrosion, or equipment failure. We do not make use of the indicated cause of the oil spills in our analysis, because there is evidence of misreporting by oil companies, presumably to avoid payment of compensation (23). The number of recorded oil spills has steadily increased during our sample period (*SI Appendix*, Fig. S1). This steady increase in the number of recorded oil spills could be due to an increase in the true incidence of oil spills or due to an increase in the share of oil spills that get reported. While the relative importance of the two is unknown, the second reason is most likely the more important one. As a result, some infants that we assume to be untreated by a nearby oil spill may in fact have been treated by an unregistered nearby oil spill. Hence, in some cases, we assume that we compare an untreated with a treated sibling while we actually compare two treated siblings. We may thus underestimate the true effects of nearby oil spills.

Nigeria DHS 2013. DHSs are nationally representative household surveys carried out periodically in developing countries to monitor countries' development, notably in areas related to health and fertility. Information is mainly collected from women of reproductive age, i.e., between 15 y and 49 y. The Nigeria DHS 2013 (11) is based on interviews taken between February and July 2013. The mothers' complete birth histories and the information on the survival of live born infants are available at a monthly resolution. Most other information reflects the situation at the time of the interview.

The DHS samples the respondents in a two-stage procedure: At the first stage, localities, referred to as clusters, are chosen to form a nationally representative sample. At the second stage, households are drawn randomly from census registers of the selected clusters. Hence, there is no sampling bias at the level of clusters. The geo-coordinates of clusters are reported, but slightly displaced for confidentiality reasons. The displacement is done in a random direction and by a random distance of up to 2 km for urban clusters, 5 km for rural clusters, and 10 km for 1% of rural clusters. Due to this displacement, we may in some cases code infants as treated (untreated) even though the closest reported oil spill before conception was more (less) than 10 km away. The possibility of such incorrect assignments of the treatment status again implies that we may underestimate the true effects of nearby oil spills.

Empirical Strategy. Following the recent literature on the effects of prenatal exposure to various forms of pollution on infant health (e.g., refs. 18 and 24–27) and recent work based on the same infant mortality data for Nigeria (19), our analysis builds on sibling comparisons. In particular, we look at mortality rates of infants conceived by mothers in clusters that are no less than 10 km away from an oil spill in our records and compare infants conceived before the first nearby oil spill with their siblings conceived thereafter. We can thereby control for a vast number of unobserved factors that may be spuriously correlated with both infant mortality and oil spills. We moreover control for various birth characteristics and allow for location-specific time trends.

For identification, we rely on the arguably random timing of these oil spills within our sample period. Our identifying assumption is that no other systematic influences related to oil spills are driving differences in mortality rates between siblings conceived before and after nearby oil spills, conditional on birth characteristics and cluster-specific time trends. In support of this identifying assumption, we have already shown that our results are not driven by operations at oil extraction sites or violent events that could coincide with vandalism or oil theft.

In addition, we look at the development of infant and neonatal mortality rates before treatment, i.e., before and up to the first nearby oil spill. In particular, we are interested in whether there is a clear pretreatment trend in mortality rates. We focus on infants born before the first oil spill in our records within 10 km from the corresponding DHS cluster location. For these infants, we measure the time passed between the infant's birth and the first such oil spill. We then construct indicator variables for 0–1 y, 1–2 y, 2–3 y, 3–4 y, and 4–5 y that passed between the infant's birth and the first oil spill. We use these indicator variables to study pretreatment trends in two ways: First, we plot the average infant and neonatal mortality rates for infants born in these five annual intervals before the first nearby oil spill. Second, we plot the estimated coefficients from regressing IMR_{imc} and NMR_{imc} on these five indicator variables as well as mother fixed effects, cluster-specific time trends, and birth-specific control variables (as in Table 2, columns 3–6). These plots show no clear indication of any pretreatment trend (*SI Appendix*, Fig. S2). If anything, the mortality rates drop shortly before the first nearby oil spill. However, these drops are not statistically significant; and if they were taken as an indication of negative short-run pretreatment trends, then we might underestimate the true size of the effects of nearby oil spills.

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