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Abstract

Oil spills can lead to irreversible environmental degradation and pose hazards to human health. We are the first to study the causal effects of onshore oil spills on neonatal and infant mortality rates. We use spatial data from the Nigerian Oil Spill Monitor and the Demographic and Health Surveys, and rely on the comparison of siblings conceived before and after nearby oil spills. We find that nearby oil spills double the neonatal mortality rate. These effects are fairly uniform across locations and socio-economic backgrounds. We also provide some evidence for negative health effects of nearby oil spills on surviving children. (100 words)

Keywords: Oil spills, Nigeria, infant mortality, child health.

JEL classification: I10, I18, J13, Q53.

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1 Introduction

A large literature 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 (Mehlum et al., 2006; Bhattacharyya and Hodler, 2010; Tsui, 2011). In these countries, the extraction of oil and gas also typically brings a host of local side effects, including irreversible environmental degradation and hazards to human health.

Nigeria, which is Africa's most populous country and its largest oil producer, is a prime example of a country cursed by natural resources (Sala-i Martin and Subramanian, 2013). Since oil discoveries in 1956 and independence in 1960, its citizens have had to endure civil conflict, military rule, political instability, endemic corruption, and widespread poverty. Also, onshore oil operations have damaged local soil and water resources and threatened public health in adjacent communities (United Nations Environment Programme, 2011). Oil spills resulting from pipeline vandalism, theft, and poor maintenance are a major source of environmental pollution in Nigeria. The Nigerian Oil Spill Monitor, which provides data collected by the National Oil Spill Detection and Response Agency, reports 6,637 oil spills from 2005 to 2015. But the health effects of onshore oil spills are not well understood.

In this paper, we study the effects of onshore oil spills on neonatal and infant mortality, and on child health. We use geo-referenced data from the Nigerian Oil Spill Monitor and the Nigeria Demographic and Health Survey (DHS) 2013. The former provides information on date and location of oil spills. The latter provides the complete birth histories of 23,364 Nigerian mothers and information on the survival of their children, as well as height and weight measurements of their children who were below the age of five at the time of the interview. We focus on the 2,744 mothers living in the 130 different DHS clusters with a reported location less than 10 km away from the closest oil spill recorded between January 2005 and one year after the DHS interviews.

We are mainly interested in the effects of nearby oil spills that occurred prior to a child's conception or during pregnancy. Our empirical strategy relies on sibling comparisons, i.e., we compare mortality rates of infants of the same mothers, some conceived (or born) before the first nearby oil spill and some conceived (or born) thereafter. We moreover control for various birth characteristics and allow for location-specific time trends. Our identifying assumption is that, conditional on birth characteristics and location-specific time trends, differences in mortality rates between siblings conceived (or born) before and after nearby oil spills are not driven by any other systematic influences related to oil spills. In support of this assumption, we show that pre-treatment trends are absent

[1] See van der Ploeg (2011) for a review of the literature on the resource curse.

and that our results are not driven by clusters located close to oil production or in areas with violent conflict.

We find that oil spills during pregnancy have no effect on infant and neonatal mortality rates. In contrast, oil spills prior to conception lead to a strong increase in neonatal mortality. They increase the neonatal mortality rate by 38 deaths per 1,000 live births, which corresponds to an increase by 100 percent on the sample mean. Their effect on infant mortality is also relatively large, but not statistically significant. We document that the effect on neonatal mortality is highest for oil spills that occurred in close proximity, is relatively persistent over time, and does not depend on the mother's socio-economic status or the cluster location. We also find some indicative evidence that oil spills impair the health of surviving children. In particular, we find that oil spills prior to conception increase the incidence of low weight-for-height, notably in the first year of life, and the result is not robust when restricting the analysis to sibling comparisons.

The most closely related contribution in the existing literature is San Sebastian et al. (2002). They compare pregnancy outcomes across women living in rural communities in the Ecuadorian Amazon basin. They find that women living close to oil fields have a higher risk of spontaneous abortion than women living far away from oil fields.[2] Our study differs by looking at neonatal and infant mortality as well as child health, and by documenting that onshore oil spills far from oil production sites are at least as detrimental as oil spills close to oil production. From a methodological perspective, our paper differs by not just exploiting cross-sectional variation across locations, but temporal variation within locations and even across siblings born to the same mother. The use of sibling comparisons relates our paper to recent contributions studying the effects of prenatal exposure to various forms of pollution on infant health (e.g., Currie et al., 2009; Almond et al., 2009; Black et al., 2013; Currie et al., 2013).[3]

At a more general level, our paper contributes to the emerging literature at the intersection of development economics and environmental economics.[4] This literature is filling an important gap given that most studies on the economic and health effects of pollution were conducted in developed countries, while pollution levels are more extreme in some developing countries (Greenstone and Jack, 2015; Arceo et al., 2016). Like us, Jayachandran (2009) and Aragón and Rud (2016) also study the effects of pollution related to the extraction of natural resources in developing countries. Jayachandran (2009) looks at forest fires that were started by logging companies and palm oil producers, but burned out of control and affected large parts of Indonesia. She finds strong effects of air pollution due

[2]In a cross-country setting, Cotet and Tsui (2013) find that oil discoveries reduce infant mortality in the long run. By design, we cannot estimate the effect of Nigeria's oil wealth on infant mortality. Instead, we focus on the local effects of oil spills.

[3]See Almond and Currie (2011) for a review of the growing literature on the consequences of in utero health shocks.

[4]See Greenstone and Jack (2015) for a review of the literature at this intersection.

to these forest fires on infant mortality. Aragón and Rud (2016) document that pollution resulting from large-scale gold mining in Ghana lowers agricultural productivity nearby. Other contributions in this literature rely on arguably random variation in regulations (e.g., Chen et al., 2013; Greenstone and Hanna, 2014; Tanaka, 2015). In contrast, we rely on the arguably random timing of oil spills in a sample of locations that were affected by oil spills at some point during the period from January 2005 to July 2014.

Section 2 discusses the epidemiological and clinical literature on the health effects of crude oil and other petroleum products, with a focus on fetal development and infant health. Section 3 describes the data, and Section 4 our empirical strategy. Sections 5 and 6 present our findings on neonatal and infant mortality, and on child health, respectively. Section 7 briefly concludes.

2 Evidence from epidemiological and clinical research

Crude oil consists of a complex mixture of hydrocarbons of various molecular weights. When crude oil or other petroleum products leak into the environment, the different compounds may evaporate into the air, be 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 (United Nations Environment Programme, 2011). Human exposure occurs mainly through 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. Fetal and child health may be affected through exposure of parents before conception, through exposure of the mother during pregnancy, and through exposure of the child after birth. While there is little evidence to reveal which forms of exposure to oil contamination are most harmful, and for which reasons, some strands of the epidemiological and clinical literature offer insights into the likely health impacts of oil spills and some possible biological mechanisms.

Several epidemiological studies have shown adverse effects of parental exposure to hydrocarbons before or after conception on fetal development, pregnancy outcomes and child health. Currie and Schmieder (2009) find that higher air-borne releases of toluene, a hydrocarbon, by US manufacturers lead to shorter gestation, higher incidence of low birth weight, and increased infant mortality. Studies from the field of occupational medicine have documented an increased risk of spontaneous abortions among pregnant women exposed to petroleum products at their work place (Axelsson and Molin, 1988; Xu et al., 1998; Merhi, 2010). San Sebastian et al. (2002) find that women living in communities close to oil fields in the Ecuadorian Amazon basin have a higher risk of spontaneous abortion than women living far away from these oil fields. Exposure of mothers before conception or during pregnancy to organic solvents, including compounds which are also present in crude oil (e.g. toluene and benzene), has been found to be associated with an increased risk of Acute Lymphoblastic Leukemia in children (Shu et al., 1999; Infante-Rivard et al., 2005). Similarly, exposure of mothers to hydrocarbons is associated with *ras* mutations in children, which is one of the most common genetic alterations stimulating tumor growth (Shu et al., 2004). Paternal exposure to hydrocarbons, too, is associated with higher rates of spontaneous abortion (Taskinen et al., 1989; Lindbohm et al., 1991). Higher risks of fetal malformations has been found in offspring of fathers exposed to organic solvents (Logman et al., 2005; Hooiveld et al., 2006).

We are not aware of any epidemiological study focussing on the health effects of infants' postnatal exposure to environmental contamination from onshore oil spills. A number of studies however examine short-term human health effects on clean-up workers and local residents exposed to major *off*-shore oil spills (see D'Andrea and Reddy, 2014, for a review). These studies observe increases in various abnormalities in the hematologic, hepatic, respiratory, renal, and neurological functions after oil spills. Frequently reported acute symptoms include respiratory problems, diarrhea, and vomiting, which, if developed by newborns and infants, can pose serious risks. Pneumonia and diarrhea are indeed major reasons for child death in Nigeria.[5]

In addition, several epidemiological studies have found harmful effects of air pollution, notably PM and other pollutants emitted from combustion of hydrocarbons (in the context of our study, fires broken out after oil spills), on child health (e.g., Chay and Greenstone, 2003; Currie and Neidell, 2005; Ritz et al., 2006, 2007; Currie et al., 2009; Jayachandran, 2009; Greenstone and Hanna, 2014; Tanaka, 2015). They document that exposure to air pollution increases the risks of infant and child mortality, incidence of low birth weight, and premature birth.

More generally, there are good reasons to believe that unborn and newborn infants may be particularly vulnerable to oil-related pollution. First, they are in a critical developmental period. Second, they have not yet developed certain defenses against toxic chemicals, such as the blood-brain barrier. Third, even small doses of pollution may be large in proportion to their low body weight (Currie et al., 2013).

The exact biological mechanisms linking exposure to crude oil and other petroleum products to adverse effects on fetal development and infant health remain uncertain. However, a number of clinical and epidemiological studies offer some indication. First, polycyclic aromatic hydrocarbons (PAHs) present in crude oil have carcinogenic effects, and it has been demonstrated that PAHs can cross the placenta and affect the development of the fetus (Madhavan and Naidu, 1995). For example, Perera et al. (1998) found that high levels of PAH-DNA adducts in leukocytes of umbilical cord blood were associated with significantly decreased birth length, weight, and head circumference in newborns. There is also evidence that maternal exposure to benzene, a hydrocarbon, can initiate

[5] Pneumonia and diarrhea accounted for 19 percent and 14 percent, respectively, of child deaths in Nigeria in 2013 (Liu et al., 2015).

childhood leukemia while the child is still in the uterus (Carlos-Wallace et al., 2016). Even in the absence of maternal exposure during pregnancy, fetal development may be affected as harmful substances accumulate in maternal fat tissue before conception and are released during pregnancy (Reutman and Meadows, 2013). Second, the higher rates of spontaneous abortion associated with paternal exposure to hydrocarbons might result from higher rates of abnormal sperm characteristics (Celis et al., 2000). Third, hydrocarbon exposure may cause chromosomal aberrations in the unborn (Khalil, 1995), which may result in spontaneous abortion, or high morbidity and mortality in infancy and childhood (Driscoll and Gross, 2009).[6]

As regards the adverse health effects of PM inhalation, the leading explanation from clinical research is that it causes an inflammatory response that weakens the immune system (Seaton et al., 1995). Small particles of less than 10 micrometers in diameter (PM_{10}) pose the greatest risk because they penetrate deep into the lungs and can even enter the bloodstream. Seeing that exposure to PM and other air pollutants has been shown to have the largest effects if it occurs during pregnancy, and that it negatively affects pregnancy outcomes (e.g., Chay and Greenstone, 2003; Currie et al., 2009; Jayachandran, 2009), it is likely that neonatal and infant mortality due to air pollution is driven by impaired fetal development. As PM cannot cross the placenta, the impact on the fetus probably occurs indirectly by provoking inflammations in the mother (Currie et al., 2009).

Besides these direct health effects, oil spills may also have indirect health effects via damage of livelihood resources, such as diminished yields from degraded agricultural land, fishing grounds or wildlife habitat. If an oil spill impairs a community's food situation through degradation of agricultural resources and fishing grounds, resulting maternal malnutrition and sickness may also increase infant mortality risks. Rates of pre-term birth and low birth weight rise with maternal malnutrition and micro-nutrient deficiencies (Bhutta et al., 2013).[7] In addition, the disruptive effects of oil spills also likely evoke mental stress in the local residents (United Nations Environment Programme, 2011). Mental stress has been found to increase the risk of spontaneous abortion (e.g., Dean et al., 2015; Bruckner et al., 2016).

3 Data

We use information about oil spills from the Nigerian Oil Spill Monitor and geo-referenced household survey data from the Nigeria Demographic and Health Survey 2013 (ICF International and Federal Republic of Nigeria National Population Commission, 2013).

The Nigerian Oil Spill Monitor provides geo-coordinates, date of spillage, and some

[6] Congenital malformations accounted for 5 percent of neonatal deaths in Nigeria in 2013 (Liu et al., 2015).

[7] Pre-term birth complications accounted for 33 percent of neonatal deaths in Nigeria in 2013 (Liu et al., 2015).

supplementary information, for oil spills recorded by the National Oil Spill Detection and Response Agency (NOSDRA), the Nigerian environmental regulator. It 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 voluntary engagement and support of oil companies to provide data. Oil companies may be willing to provide information because it is well-known that oil spills are often caused by sabotage or theft rather than causes that fall under their responsibility, such as operational or maintenance errors, pipeline corrosion, or equipment failure.[8]

The Nigerian Oil Spill Monitor visualizes the oil spills on a map and enables downloading the data in table format.[9] There are 5,296 oil spills recorded for the time period from January 2005 to July 2014, which is one year after the collection of the survey data used in our analysis. Figure 1 illustrates the annual frequency of reported oil spills over these years. There are only few entries for 2005 and basically none for earlier years. The coverage has then steadily increased from year to year. 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.

Figure 1 around here

Demographic and Health Surveys (DHS) 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 and 49 years. The Nigeria DHS 2013 is based on interviews taken between February and July 2013. It provides the complete birth histories of 23,364 Nigerian mothers and information on survival of their live born infants. These data are both available at a monthly resolution. The Nigeria DHS 2013 further collects weight and height/length measures for most children below the age of five at the time of the interview.

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, while the sample is not representative at subnational levels such as federal states,

[8]The Nigerian Oil Spill Monitor reports that sabotage or theft is the cause for 75 percent of the oil spills and causes that fall under the responsibility of the operator for 15 percent. No cause is reported for the remaining 10 percent. The oil companies may however have strong incentives to misreport the true cause if the oil spill is their fault. The website states that "[a]lthough the data gathered by NOSDRA and displayed here is immensely useful, it does not tell the whole story as the information provided by oil companies is often incomplete."

[9]The dataset of oil spills used in this paper were downloaded by the authors in August 2014.

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 with a random distance of up to 2 km for urban clusters, 5 km for rural clusters, and 10 km for one percent of rural clusters. We can thus identify the distance between each cluster's recorded location and nearby oil spills in our records. We can also identify whether these oil spills occurred before or after an infant's conception or birth.

Our units of observation are infants born to mothers interviewed for the Nigeria DHS 2013. We include in our main sample all infants born from January 2006 onwards to mothers living in a cluster with a reported location less than 10 km away from any oil spill in our records. Our sample consists of 5,043 infants born to 2,744 different mothers living in 130 different clusters. Figure 2 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 all the oil spills in our records. The 130 DHS clusters used in our analysis are located within these shaded areas.

Figure 2 around here.

We are interested in the effects of oil spills that occurred before conception or during pregnancy. Our first treatment variable, $SPILL(CONC)_{imc}$, is equal to one if infant i of mother m living in cluster c was conceived any time after an oil spill had occurred less than 10 km away from the reported cluster location, and zero otherwise.[10] Our second treatment variable, $SPILL(PREG)_{imc}$, is equal to one if an oil spill occurred less than 10 km away during pregnancy, i.e., between infant i's conception and its birth, and zero otherwise. When looking at child health, we add a third treatment variable, $SPILL(LIFE)_{imc}$, which is equal to one if an oil spill occurred less than 10 km away between the child's birth and the DHS interview, and zero otherwise.

Our main dependent variables are indicator variables for whether or not an infant died within a specific period of time after birth. We scale these indicator variables to align them to the conventional definitions of mortality rates, which are the number of infants in 1,000 live births that died within a given period. The infant mortality rate IMR_{imc} is equal to 1,000 if infant i born to mother m in cluster c died within the first 12 months of life, and zero otherwise. The neonatal mortality rate NMR_{imc} is equal to 1,000 if the infant died within its first month of life, and zero otherwise. The postneonatal mortality rate $PNMR_{imc}$ is equal to 1,000 if the infant survived the first month, but died within the first year of life. With analogous definitions, we analyze mortality in the first week

[10]For infants conceived up to December 2007, we define as the month of conception the month of birth minus nine. For infants conceived from January 2008 onwards, we can use additional information on pregnancy duration to correct the calendar month of conception if pregnancies lasted less (or more) than nine months.

of life, $FWMR_{imc}$, and mortality after the first week but within the first month of life, $PFWMR_{imc}$. We compute the indicator variables for infant and postneonatal mortality for infants born at least 12 months before the DHS interview, and the other mortality indicators for infants born at least one month before the DHS interview.

We use two dependent variables for child health. These are indicator variables for wasting, i.e., the incidence of low weight-for-height, and stunting, i.e., the incidence of low height-for-age. Wasting is usually the result of acute significant food shortage or disease, while stunting is typically caused by long-term insufficient nutrient intake and frequent infections (UNICEF, 2007). We use the weight and height/length measures in the Nigeria DHS 2013 to compute weight-for-height and height-for-age z-scores as standard deviations from the WHO Child Growth Standards reference median. Following the WHO and DHS, we classify a child as $WASTED_{imc}$ if its weight-for-height z-score is below -2, and as $STUNTED_{imc}$ if its height-for-age z-score is below -2 (World Health Organization, 2008).[11]

In our regressions, we include various birth, pregnancy and mother characteristics from the Nigeria DHS 2013. First, we use indicator variables for the infant's year of birth. Second, we control for birth order by including indicator variables for whether the child is the mother's first live birth, her second live birth, and so forth. Third, we control for critical birth spacing by including indicator variables for whether the time elapsed between a birth and the previous birth was less than 12 months, 13-24 months, or 25-36 months. Fourth, we include the mother's age in the month of birth by a series of indicator variables for age groups of 5-year intervals, starting at 10-15 years and ending at 45-50 years. We also include indicator variables for the infant's sex and for multiple births, whereby each infant of a multiple birth enters as a separate observation.

In order to explore whether the effects we find vary in size or direction with certain mother or cluster characteristics, we use some additional variables from the Nigeria DHS 2013. First, we distinguish between mothers who completed secondary education and those who did not. Second, we distinguish mothers by their household's wealth at the time of the interview. We define the households with a DHS wealth index score below the median within our sample as poor, and the other households as non-poor.[12] We

[11] The WHO Child Growth Standards reference tables are based on data collected between 1997 and 2003 from approximately 8,500 breastfed infants and appropriately fed children from different countries (Brazil, Ghana, India, Norway, Oman, and the United States). They are intended to provide a single international standard that represents the physiological growth for all children from birth to five years of age (World Health Organization, 2006). To compute the z-scores we use the *igrowup standard* macro for Stata provided by the WHO. We further follow DHS in flagging children with z-scores below -6 or above 6 as invalid measurements and excluding them from the analysis.

[12] The DHS wealth index is based on household assets, amenities and services, including the household's drinking water source, the type of toilet facility used, the energy source used for cooking, the materials of the dwelling's floor, walls and roof, and whether the household owns certain wealth assets such as a mobile phone, a TV, a refrigerator, a motorcycle, or a car. The wealth index is then derived by principal component analysis. For a detailed description of how the DHS wealth index is constructed, see Rutstein and Johnson (2004).

also distinguish between urban and rural survey clusters, following the classification by the National Population Commission reported in the Nigeria DHS 2013. Further, we use information about whether a birth was attended by skilled health personnel, i.e., a doctor, a nurse or a midwife. This latter information is only available for infants born in the five years prior to the DHS interview.

In addition, we use spatially explicit data from the Armed Conflict Location and Event Data Project (ACLED) data base (Raleigh et al., 2010). This data base reports the actions of rebels, governments, and militias within unstable states, and specifies the exact location and date of battle events. We construct a variable that indicates whether any conflict event causing at least one fatality took place within 25 km from the reported cluster location during the sample period. In addition, we define an indicator variable that is equal to one if a cluster is located in one of the nine oil-producing states in the Niger Delta (UNDP 2006).[13]

Table 1 present summary statistics.

Table 1 around here

Among others, we see that infant and neonatal mortality rates are around 60 and 37 deaths per 1,000 live births in our sample.[14] Moreover, 29 percent of the live born infants in our sample are treated by an oil spill within 10 km before conception, and 22 percent by an oil spill during pregnancy.

4 Empirical strategy

In this section, we discuss the empirical strategy for estimating the effects of nearby oil spills before conception and during pregnancy on mortality over an infant's first year of life. The empirical strategy used for estimating the effects on wasting and stunting is very similar.

We use the following empirical specification:

$$MR_{imc} = \beta_1 SPILL(CONC)_{imc} + \beta_2 SPILL(PREG)_{imc} + \alpha_{mc} + \gamma X_{imc} + \delta_c \times t_{imc} + \epsilon_{imc} \quad (1)$$

MR_{imc} represents our different mortality rates. The mother fixed effects α_{mc} ensure that we only exploit variation in the mortality of siblings born to the same mother. Comparisons within rather than across mothers ensure that our results are not driven by any unobserved differences between mothers conceiving before and after the occurrence of a nearby oil spill or between the clusters in which these mothers are living. The vector

[13] These nine states are Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers.

[14] For the full sample of the Nigeria DHS 2013, the corresponding infant and neonatal mortality rates were 81 and 40 for the period from 2006 onwards.

X_{imc} contains our birth-specific control variables, i.e., our indicator variables for birth year, birth order, critical birth spacing, mother's age, multiple birth, and the infant's sex. We also control for cluster-specific linear time trends $\delta_c \times t$, where δ_c is a cluster-specific slope parameter and t_{imc} the infant's year of birth. We estimate specification (1) using a linear probability model, and allow standard errors to be clustered at the level of the DHS cluster.

The coefficients of interest are β_1 and β_2. Given our scaling of the mortality rates, they indicate the increase in the mortality rate per 1,000 live births caused by a nearby oil spill prior to conception or during pregnancy, respectively.

We focus on the comparison of siblings born to mothers in clusters that are no less than 10 km away from an oil spill in our records. 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 (or born) before and after nearby oil spills, conditional on birth characteristics. We take three actions in support of this assumption: First, we realize that changes in (conditional) mortality rates could be affected by local economic, political or social developments. The cluster-specific time trends in specification (1) should ensure that such local developments are not driving the results of our sibling comparisons.

Second, changes in mortality rates could be driven by other events that are correlated in time and space with oil spills. One could imagine that oil spills occur concurrently with (other) events specific to oil production. We therefore compare the effect of oil spills on mortality rates for infants born in the oil-producing states in the Niger Delta with the effect for infants born elsewhere. Alternatively, oil spills are sometimes the result of violent attacks on oil infrastructure by militant groups (U.S. Energy Information Administration, 2016). Such attacks may involve violence against civilians in the surrounding communities, which, in turn, might increase neonatal mortality rates. We compare the effect of oil spills on mortality rates for infants born close to conflict areas with the effect for infants born far from conflict areas. As shown in Section 5.4 below, we find no evidence that oil spills have more detrimental effects on mortality rates for infants born in the Niger Delta or in conflict areas. These findings suggest that our main results are not driven by other events related to oil production or conflict.

Third, we study whether there is a clear trend in mortality rates in the time before and up to the first nearby oil spill. We focus on infants born prior to the first oil spill in our records within 10 km from the corresponding DHS cluster location. For these infants, we measure how many years have passed between the infant's birth and the first such oil spill. We construct indicator variables for whether the infant's birth precedes the first nearby oil spill by up to 1 year, 1-2 years, 2-3 years, 3-4 years, or 4-5 years. Figure 3 shows how mortality rates developed prior to treatment.

Figure 3 around here

The two graphs on the left look at infant mortality rates, and the two graphs on the right at neonatal mortality rates. The top graphs plot simply the average mortality rates for infants born in the five annual intervals prior to the first nearby oil spill. These two graphs show no clear pre-treatment trends. The bottom graphs plot the coefficients from regressing the mortality rates on the five indicator variables for the time period by which the infant's birth precedes the first oil spill, as well as mother fixed effects, our birth-specific control variables X_{imc}, and cluster-specific time trends (as in specification (1)). These plots again show no clear indication of any pre-treatment trends. If anything, there is a drop in mortality rates shortly before the first nearby oil spill.[15]

Finally, we would like to discuss three data limitations that may affect our results. First, the data from the Nigerian Oil Spill Monitor are almost certainly incomplete. Figure 1 shows the steady increase in the number of recorded oil spills over time. As argued above, it is very likely that this increase is at least partly due to an increase in the share of oil spills reported and included in the Nigerian Oil Spill Monitor dataset. As a result, many 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 effect of nearby oil spills.

The second data limitation is the random displacement of the DHS cluster locations. Due to this displacement, we may in some cases code infants as treated (untreated) even though the closest reported oil spill prior to conception or during pregnancy 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 effect of nearby oil spills.

The third data limitation is that the Nigeria DHS 2013 only provides information about the mothers' place of residence in 2013. Hence, we know whether a mother's place of residence in 2013 is close to an oil spill in our records, but cannot be sure whether she lived in the same place in earlier years.[16]

[15]The difference between the coefficients for the indicator variables for infants born 0-1 years and 1-2 years before the first nearby oil spill is statistically insignificant in the regression for infant mortality ($p = 0.242$) and marginally (in)significant in the regression for neonatal mortality ($p = 0.053$). If this drop in mortality rates were taken as an indication of a negative short-run pre-treatment trend, then this trend would make it less likely that we find positive effects of nearby oil spills on mortality rates.

[16]Some DHS questionnaires ask about how long mothers have been living continuously in their current place of residence. This question provides no information about the mothers' earlier place of residence; and it is missing in the Nigeria DHS 2013.

5 Evidence on infant and neonatal mortality

5.1 Main results

Table 2 presents our estimates of the effects of oil spills prior to conception and during pregnancy on the mortality rates within the first year of life. In column (1), we control for birth characteristics X_{imc}, but we neither include any fixed effects, nor allow for different time trends across clusters. We then add fixed effects for DHS clusters in column (2) and cluster-specific time trends in column (3). In column (4), we further add mother fixed effects. In columns (5) and (6), we then split infant mortality into neonatal and post-neonatal mortality. The regressions reported in columns (4), (5) and (6) thus correspond to specification (1).

Table 2 around here

Let us first look at the effect of nearby oil spills that occurred prior to conception (i.e., $SPILL(CONC)_{imc}$). Their effect on the infant mortality rate IMR_{imc} is positive in columns (1) to (4), but never statistically significant. The point estimate in column (4) suggests that a nearby oil spill prior to conception leads to an increase by 31 deaths per 1,000 live births or, equivalently, an increase by 50 percent on the sample mean. When splitting infant mortality into neonatal and postneonatal mortality in columns (5) and (6), we find that the increase in infant mortality is driven by an increase in mortality in the first month of an infant's life. In fact, the effect of a nearby oil spill prior to conception on the neonatal mortality rate NMR_{imc} is even larger at 44 additional deaths per 1,000 live births, while the effect on the postneonatal mortality rate $PNMR_{imc}$ is a decrease by 13 deaths per 1,000 live births. These point estimates suggest that 70 percent of the additional infants who died in the first month would not have died in the absence of a nearby oil spill prior to conception, while 30 percent of them would have died later in the first year. The effect of nearby oil spills during pregnancy (i.e., $SPILL(PREG)_{imc}$) on infant mortality is negative, but statistically insignificant in all columns.

Table 3 focuses on the effect of nearby oil spills on mortality within the first month of an infant's life, which allows extending our sample to all infants born up to one month prior to the DHS interview.

Table 3 around here

Table 3 is organized in the same way as Table 2. We see that the positive effect of oil spills prior to conception on the neonatal mortality rate NMR_{imc} is statistically insignificant when not controlling for any time-invariant location, household or mother characteristics, but becomes significant and larger in magnitude when adding cluster and mother fixed effects and cluster-specific time trends. Our main specification in column (4) is equivalent to the one in column (5) of Table 2, but based on a larger sample. In this larger sample, nearby oil spills prior to conception increase the neonatal mortality rate by 38 deaths per

1,000 live births. Given the sample mean of 37 deaths per 1,000 live births, this coefficient estimate suggests that a nearby oil spill prior to conception doubles the neonatal mortality rate. Columns (5) and (6) look separately at mortality in the first week and the remaining three weeks of the first month, and show that the increase in mortality due to nearby oil spills is strongest in the first week of an infant's life.

Again we find no effect of oil spills during pregnancy. There are different interpretations of this absence of any measurable effect. First, it could be that the main biological mechanism through which oil exposure harms infant health is through parental exposure before conception. Second, it could be that only oil exposure early in the pregnancy, or only oil exposure over a long period of time during pregnancy, have tangible effects on infant health. We therefore break down oil spills during pregnancy into those that occurred in the first trimester, i.e., during the first three months of pregnancy, and those that occurred during the second or third trimester (see Table A.1 in the Appendix). We find that oil spills during the first trimester have typically larger effects on mortality rates than oil spills during the second or third trimester. However, the only statistically significant effect is the one of a nearby oil spill during the first trimester on the postneonatal mortality rate.

5.2 Temporal and spatial disaggregation

We now disaggregate the effects by the temporal and spatial distances between oil spills and births. We thereby focus on the effect of nearby oil spills prior to conception on neonatal mortality, as estimated in column (4) of Table 3.

We first focus on the persistence of this effect over time. We construct indicator variables that capture the time elapsed between the most recent oil spill before conception that occurred within less than 10 km and the infant's conception. Specifically, we construct indicator variables for 0-1 years (i.e., 1-12 months), 1-2 years (i.e., 13-24 months), and so on up to 4-5 years (i.e., 49-60 months).[17] We include the full set of these timing indicators as explanatory variables in a regression of neonatal mortality to examine whether more recent oil spills have a larger effect than those further in the past. As in our main specification, we include mother fixed effects and cluster-specific time trends, and control for nearby oil spills during pregnancy and the birth characteristics X_{imc}. Figure 4 plots the estimated coefficients on these timing indicators and the corresponding confidence intervals.

Figure 4 around here

The resulting pattern suggests that the positive effect of nearby oil spills prior to conception on the neonatal mortality rate does not fade away over time – at least not within the

[17]There are ten infants in our data for whom the most recent nearby oil spill occurred more than five years before conception. We exclude these ten observations.

period we are able to analyze. Rather, oil spills continue to have an effect for at least five years, with no decrease in the estimated magnitude of the effect.

We now focus on how the spatial proximity of oil spills affects the magnitude of their effect. To this end, we construct indicator variables for whether the spatial distance between the reported cluster location and the closest oil spill that occurred before conception is 0-1 km, 1-2 km, and so on. We replace $SPILL(CONC)_{imc}$ by these distance indicators in our main specification. Panel (a) of Figure 5 plots the estimated coefficients on these distance indicators and the corresponding confidence intervals.

Figure 5 around here

The effect of oil spills on neonatal mortality is largest for oil spills that occurred less than 2 km away from the reported cluster location. The decrease of the effect size in the spatial distance is however not very pronounced. Moreover, most confidence intervals are large given that the number of treated infants is much lower for each individual distance indicator than for the combined treatment. The limited effect of spatial distance on the effect size may indicate that some oil spills are affecting large areas in reality, but could also be due to the random displacement of cluster locations.

Panel (b) is based on an extended sample that includes all infants born during the sample period in clusters whose reported location is up to 15 km (instead of 10 km) away from the closest oil spill in our records. We see that the coefficient estimates for distances above 10 km are typically no longer positive, which we take as a validation of our choice to focus on oil spills within a 10 km zone in our main analysis.

5.3 Effect heterogeneity

The effects of nearby oil spills on infant mortality might vary in magnitude with several characteristics of the infant, the mother, or the socio-economic context. First, we want to test whether the effects are larger for boys or girls. In general, neonatal mortality is higher for boys than for girls (e.g., Naeye et al., 1971) and boys tend to be more vulnerable to in utero health shocks (e.g., Eriksson et al., 2010). We also want to study whether the effect of oil spills could be driven by out-migration of health care professionals in response to worsening local living conditions. If so, we would expect to find smaller effect sizes when just comparing siblings whose births were either all attended or all unattended by health care professionals. Further, we look at the role that the mother's education and the household's wealth play. One may expect that children born to low-educated mothers living in poor households are more vulnerable to the harmful effects of oil spills, e.g., because these mothers may find it harder to access information about the health risks related to oil spills or to afford protective measures, and also because they may be more dependent on contaminated livelihood resources. Lastly, there might be differences in the effect of oil spills on neonatal mortality between urban and rural locations, e.g., because mothers in urban locations may have better access to health facilities and information.

We examine the role of these five different birth, mother and location characteristics by running five regressions like our main regression for neonatal mortality, as reported in Table 3, column (4). In each of these five regressions, we interact our two treatment variables, $SPILL(CONC)_{imc}$ and $SPILL(PREG)_{imc}$, with indicator variables capturing one of these five characteristics. The coefficients on, and the differences between, the interaction terms with $SPILL(PREG)_{imc}$ are statistically insignificant in all cases. We therefore report only the estimated coefficients on the interaction terms with $SPILL(CONC)_{imc}$ as well as the corresponding confidence intervals in Figure 6.

Figure 6 around here

Starting from the top, the first two rows of Figure 6 show the coefficients on the interaction terms between $SPILL(CONC)_{imc}$ and the indicator variables for boys and girls, respectively. We see that the effect of nearby oil spills prior to conception is slightly larger for boys, but with largely overlapping confidence intervals. The next two rows show that the effect for births attended by professional health personnel is stronger than the effect for other births, but the point estimates suggest that these effects are both higher than the average effect reported in Table 3, column (4).[18] Hence, there is no indication that nearby oil spills prior to conception increase neonatal mortality mainly by increasing the scarcity of health personnel. We next distinguish between mothers who have completed secondary education and mothers who have not, and between poor and non-poor household. We find no clear pattern suggesting that the mothers' socio-economic background plays a key role. We also find no difference in the effects between urban and rural clusters.[19]

5.4 Possible confounders

We interpret the large and statistically significant increase of neonatal mortality after a nearby oil spill prior to conception as a causal effect of the oil spill. However, mortality rates might be driven by other events correlated in time and space with the occurrence

[18]The underlying regression for these two rows is based on a smaller sample because information on professional birth attendance is only available for the last five years prior to the DHS interview. Besides the interaction terms, this regression further includes the (uninteracted) dummy variable for the attendance of professional health personnel.

[19]F-tests confirm that the difference between the coefficients on the two interaction terms with $SPILL(CONC)_{imc}$ is not statistically significant in any of the five regressions reported in Figure 6. Complementary, we study whether nearby oil spills prior to conception affect some of these contextual characteristics. We find that nearby oil spills have no effect on professional birth attendance and do not change the composition of mothers giving births in terms of their households' wealth (see Table A.2 in the Appendix). Nearby oil spills prior to conception however increase the share of births by mothers with secondary education.

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.

In order to check whether neonatal mortality might be driven by events related to oil production, we analyze the effect of oil spills separately for DHS clusters that are located in one of the nine oil-producing states in the Niger Delta, and those located elsewhere. Of all the infants in our sample, 61 percent were born in the Niger Delta (see Table 1). We regress the neonatal mortality rate on interaction terms between our treatment variables and indicator variables for states in the Niger Delta and states elsewhere. Again, we use our standard sample and controls (as in Table 3, column (4)). Figure 7 presents the coefficient estimates on the two interaction terms with the pre-conception treatment and the corresponding confidence intervals in the first two rows.

Figure 7 around here

The coefficients are not statistically significantly different, but the point estimates suggest that nearby oil spills prior to conception have a stronger effect on the neonatal mortality rate outside the Niger Delta.[20] This finding makes it implausible that events related to oil production drive the relationship between oil spills and neonatal mortality.

We also study whether the effect of nearby oil spills on neonatal mortality is stronger in conflict areas, i.e., in cluster locations no less than 25 km away from a conflict event involving at least one fatality during our sample period. Of all the infants in our sample, 27 percent were born in such conflict areas (see Table 1). The two bottom rows of Figure 7 show that the effect of nearby oil spills on neonatal mortality is much larger for infants born outside conflict areas. This large difference is however not statistically significant. We nevertheless conclude that the higher neonatal mortality rates close to the location of oil spills that occurred prior to conception are not the result of violent conflict.

In a related exercise, we test whether our main results could be driven by events that might have taken place in a single part of the country. DHS divides Nigeria into six geopolitical zones. In five of them, there are DHS clusters less than 10 km away from an oil spill in our records. We rerun our main regression (Table 3, column (4)) five times dropping these geopolitical zones one-by-one (see Figure A.1 in the Appendix). The effect of nearby oil spills prior to conception on the neonatal mortality rate is largest (at 50 additional death per 1,000 live births), but not statistically significant when dropping the South-South zone, which covers most of the Niger Delta. The effect remains statistically significant when dropping any of the other geopolitical zones, or when dropping any of the 36 Nigerian states (results available upon request). We conclude that our main result is not driven by events in a single geopolitical zone or a single state.

[20] Results are very similar when replacing the indicator for the Niger Delta with an indicator for clusters within 25 km from an on-shore oil field, using the geo-locations of oil fields provided by the U.S. Geological Survey (Persits et al., 2002).

6 Evidence on wasting and stunting in children

We now look at the effects of oil spills on the health of the surviving children, as measured by wasting and stunting, i.e., the incidence of low weight-for-height and low height-for-age, respectively. Based on the discussion in Section 2, we see various pathways for oil spills to cause wasting or stunting: First, oil spills can impair a community's food situation and lead to malnutrition of children through degradation of agricultural resources and fishing grounds. Second, oil spills may increase the incidence of diarrhea and other infections. Third, impaired fetal development due to maternal exposure to oil pollution during pregnancy may lead to low birth weight, which may be associated with wasting or stunting in surviving children (Rahman et al., 2016).

To examine whether oil spills prior to conception, during pregnancy, or after birth lead to wasting or stunting, we use different samples of children who were born to mothers living in clusters with a reported location less than 10 km away from an oil spill. Results on wasting are presented in Table 4.

Table 4 around here.

Column (1) restricts the sample to children below the age of one and controls for our standard birth characteristics X_{imc}. Column (2) adds cluster fixed effects. We see that the effects of oil spills prior to conception is positive and statistically significant. The point estimate suggests that an oil spill prior to conception increases wasting in infants below the age of one by 25 percentage points, which corresponds to an increase by 100 percent on the sample mean (which is 0.24 for infants below the age of one). In contrast, we find no statically significant effects of oil spills during pregnancy or after birth. Columns (3) and (4) enlarge the sample to children below the age of three and five, respectively. The point estimate on oil spills prior to conception becomes smaller in magnitude, but more precisely estimated. Given that column (4) includes children born during a five-year period, we can now add cluster-specific time trends (again based on the year of birth) in column (5). The coefficient estimates in columns (4) and (5) suggest that oil spills prior to conception increase wasting in children below the age of five by 7 percentage points, which corresponds to an increase by almost 50 percent on the sample mean (which is 0.15 for children below the age of five). The effect becomes smaller in magnitude and statistically insignificant when adding mother fixed effects.

Results on stunting are presented in Table 5, which is organized in the same way as Table 4. We find no evidence for an effect of nearby oil spills on stunting.

Table 5 around here.

Taken together, Tables 4 and 5 provide some, but not overly strong evidence that nearby oil spills impair child health. The strongest result is that nearby oil spills prior to conception increase wasting among infants.[21]

7 Conclusions

Using geo-referenced data from the Nigerian Oil Spill Monitor and the Nigeria DHS 2013, and relying on sibling comparisons, we have established that nearby onshore oil spills prior to conception increase neonatal mortality in nearby locations. We have also found indicative evidence that oil spills impair the health of surviving children, manifested in an increase in wasting in infants.

To get an impression of the scale of the problem, we conduct a back-of-the-envelope calculation: The World Health Organization reports 5,281,386 live births in Nigeria in 2012. The Nigeria DHS 2013 suggests that 8.05 percent of the infants born in 2012 were born in a cluster located within 10 km from a recorded oil spill that occurred prior to conception. Further, our causal estimates show that an oil spill less than 10 km away prior to conception increases neonatal mortality by around 38 deaths per 1,000 live births. Taken together, these numbers suggest that oil spills prior to conception killed around 16,000 infants within the first month of their life in 2012. Our estimates further suggest that 70 percent of them, i.e., around 11,000 infants, would have survived their first year in the absence of oil spills.

There are good reasons to believe that the exact figure may be different than our back-of-the-envelope calculation suggests, e.g., because we may have underestimated the true effects due to the incomplete oil spill records and the random displacement of DHS clusters. Nevertheless, as long as the true figure is not substantially lower, it seems appropriate to 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.

[21] In view of the epidemiological evidence discussed in Section 2, we expect oil spills to affect not only neonatal and infant mortality and the health of the surviving children, but also pregnancy terminations. Nigeria DHS 2013 contains a calendar in which the responding mothers indicate whether they were pregnant, gave birth, or had a pregnancy termination (i.e., abortion or still birth) for each month from January 2008 to the month of the interview. We estimate the effect of oil spills prior to conception on pregnancy terminations using this calendar information, thereby taking pregnancies as units of observation (see Table A.3 in the Appendix). The point estimates of specifications with cluster or mother fixed effects suggest that an oil spill prior to conception leads to 13 to 19 additional pregnancy terminations per 1,000 conceptions. (The sample mean is 106 pregnancy terminations per 1,000 conceptions.) These effects are however not statistically significant. Recall errors by the respondents are a possible reason.

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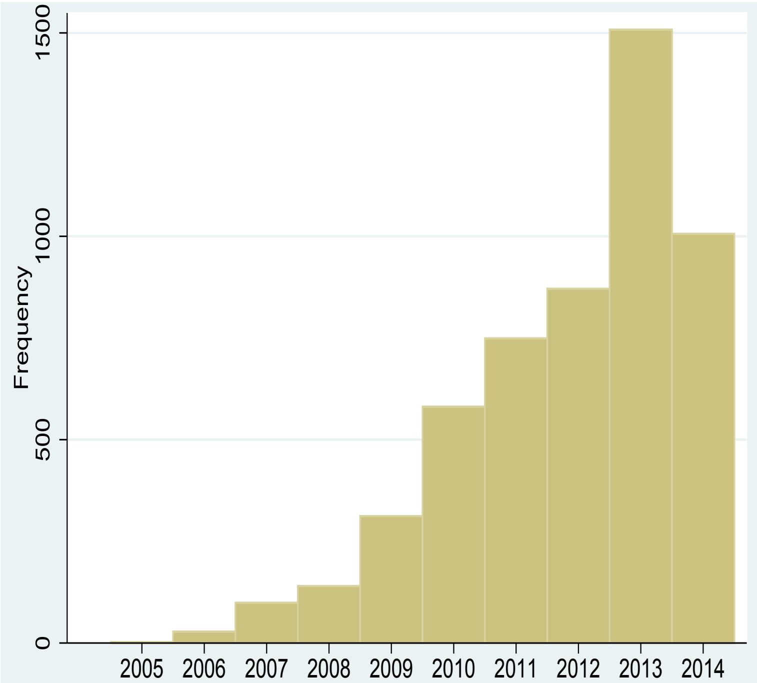
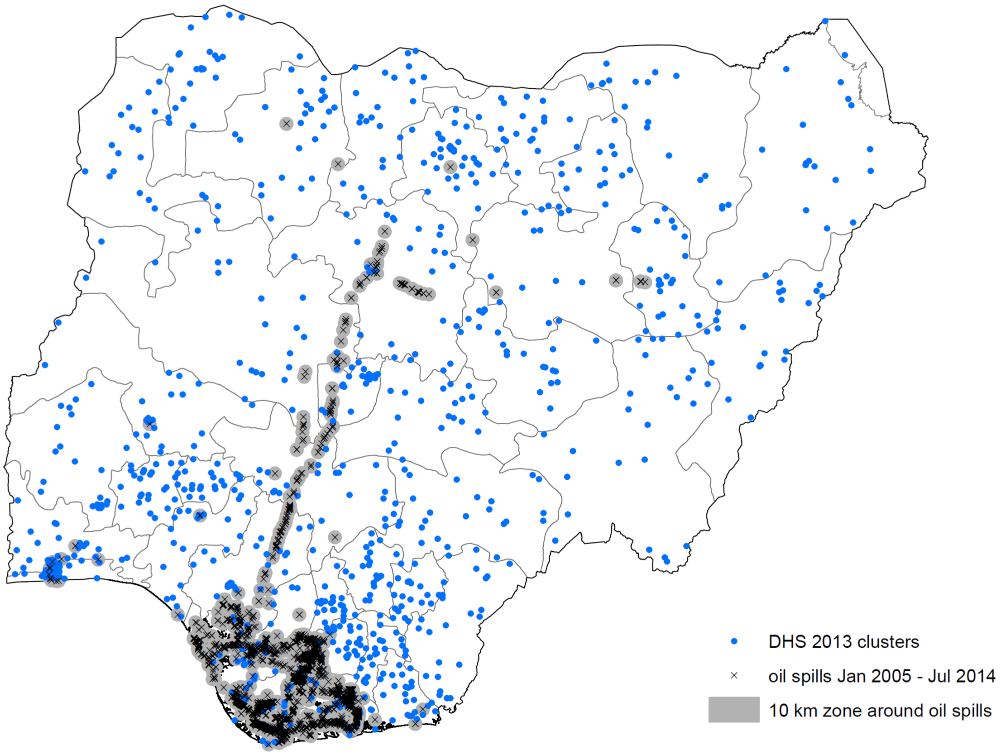
Figures and tables

Figure 1: Frequency of oil spills recorded by the Nigerian Oil Spill Monitor



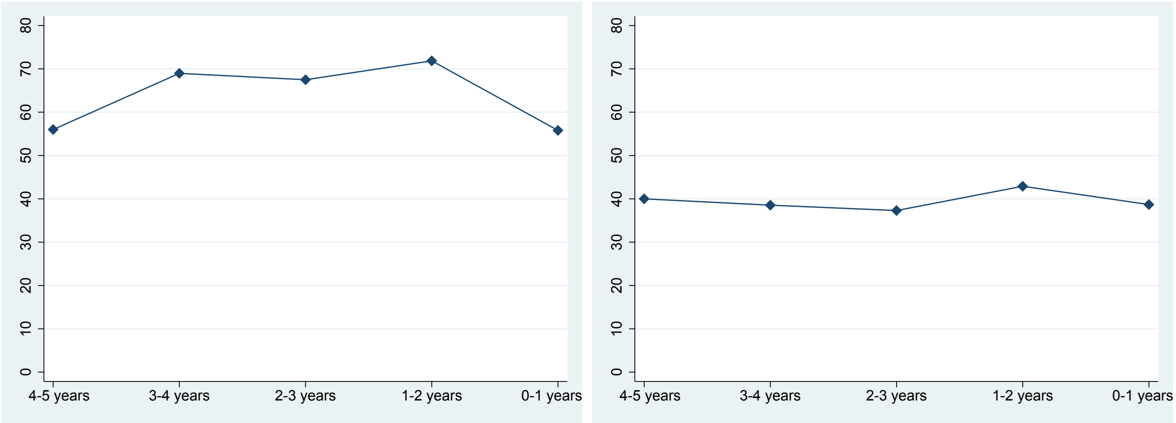
Note: Frequency for 2014 based on records up to July 2014.

Figure 2: The location of DHS clusters and oil spills in Nigeria

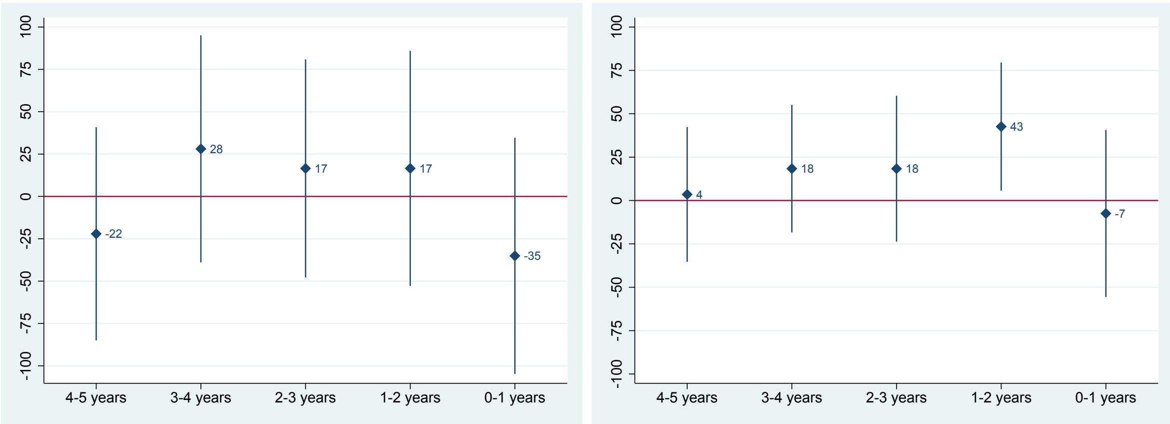


Notes: Map of Nigeria showing the locations of all oil spills in our records and all clusters of the Nigeria DHS 2013. The shaded areas represent the union of all circles with a 10 km radius around all the oil spills.

Figure 3: Pre-treatment trends



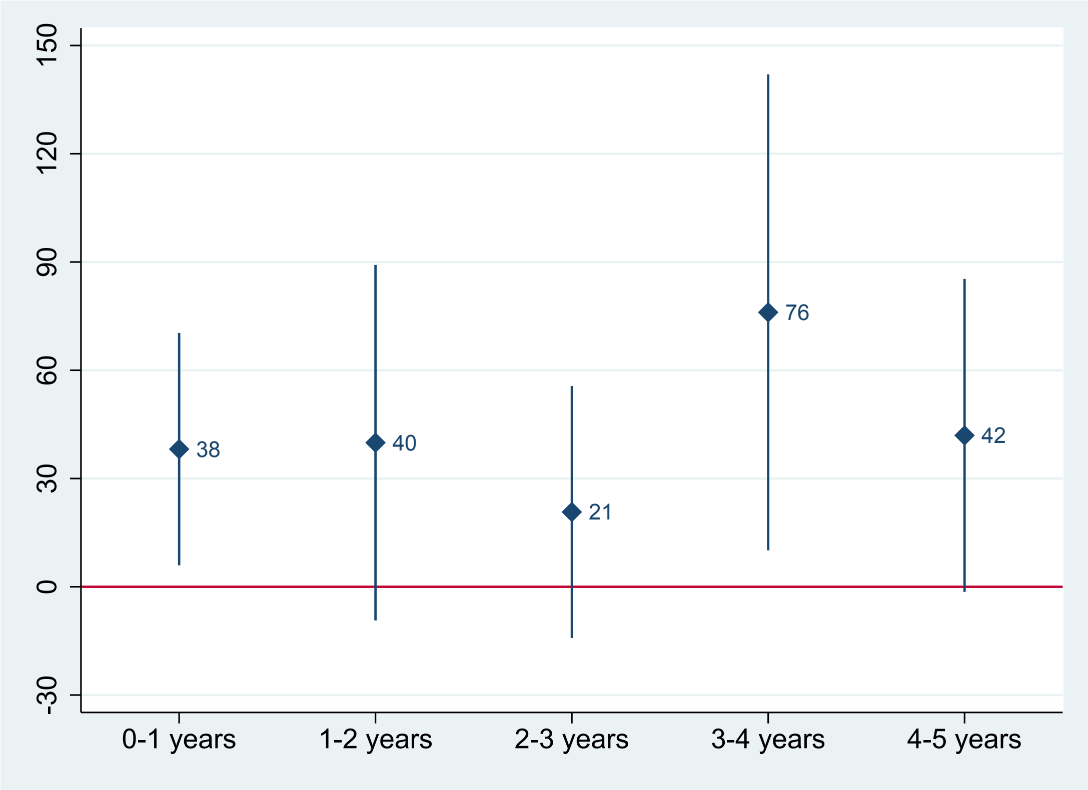
(a) Raw data



(b) Regression-based approach

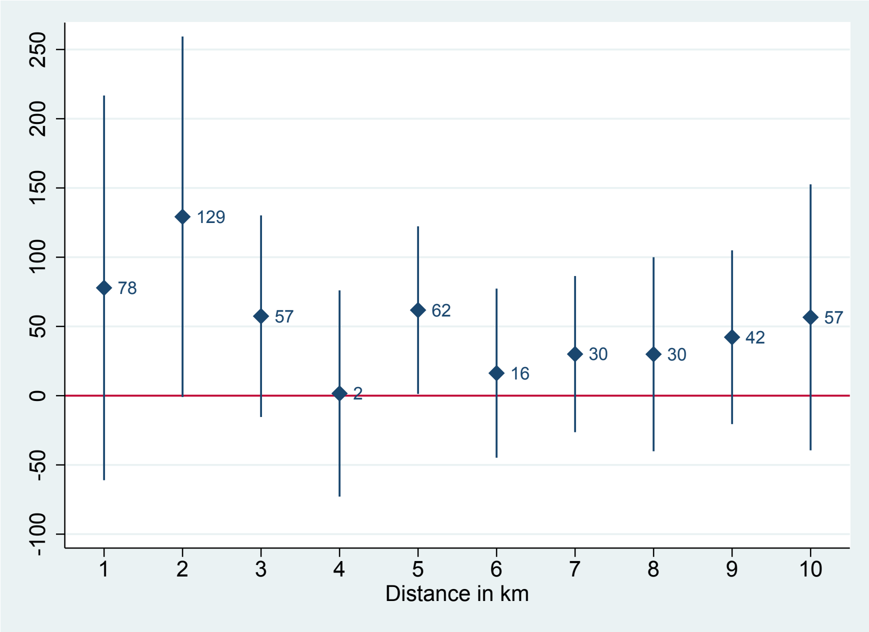
Notes: The left (right) graphs show results for infant (neonatal) mortality rates. Panel (a) plots average mortality rates for births 0-1, 1-2, ..., 4-5 years prior to the first oil spill within 10 km from the DHS cluster location. Panel (b) plots the coefficients from regressing the mortality rates on the five corresponding indicator variables while controlling for mother fixed effects, birth-specific control variables X_{imc}, and cluster-specific time trends. The control group contains all infants from our sample born more than 5 years prior to the first oil spill within 10 km from the DHS cluster location. The vertical lines represent the 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters.

Figure 4: Persistence of the effects on neonatal mortality

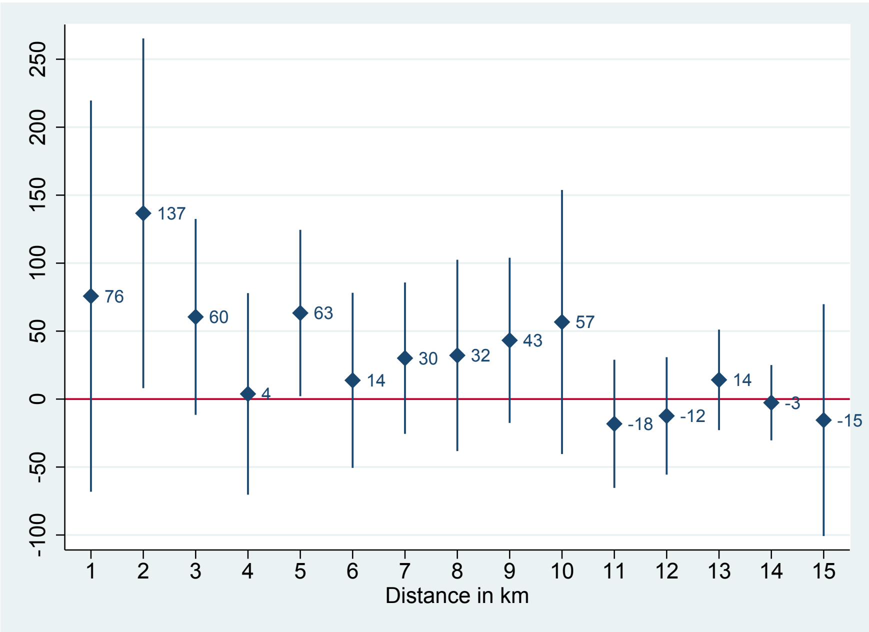


Notes: The figure plots the coefficients from a linear regression of the neonatal mortality rate on the five indicator variables for the last oil spill within 10 km from the DHS cluster location having occurred 0-1 year, 1-2 years, ..., 4-5 years before conception, while controlling for mother fixed effects, oil spills during pregnancy, birth-specific control variables X_{imc}, and cluster-specific time trends. The control group contains all infants from our sample born prior to the first oil spill within 10 km from the DHS cluster location. The vertical lines represent the 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters.

Figure 5: Spatial disaggregation of the effects on neonatal mortality



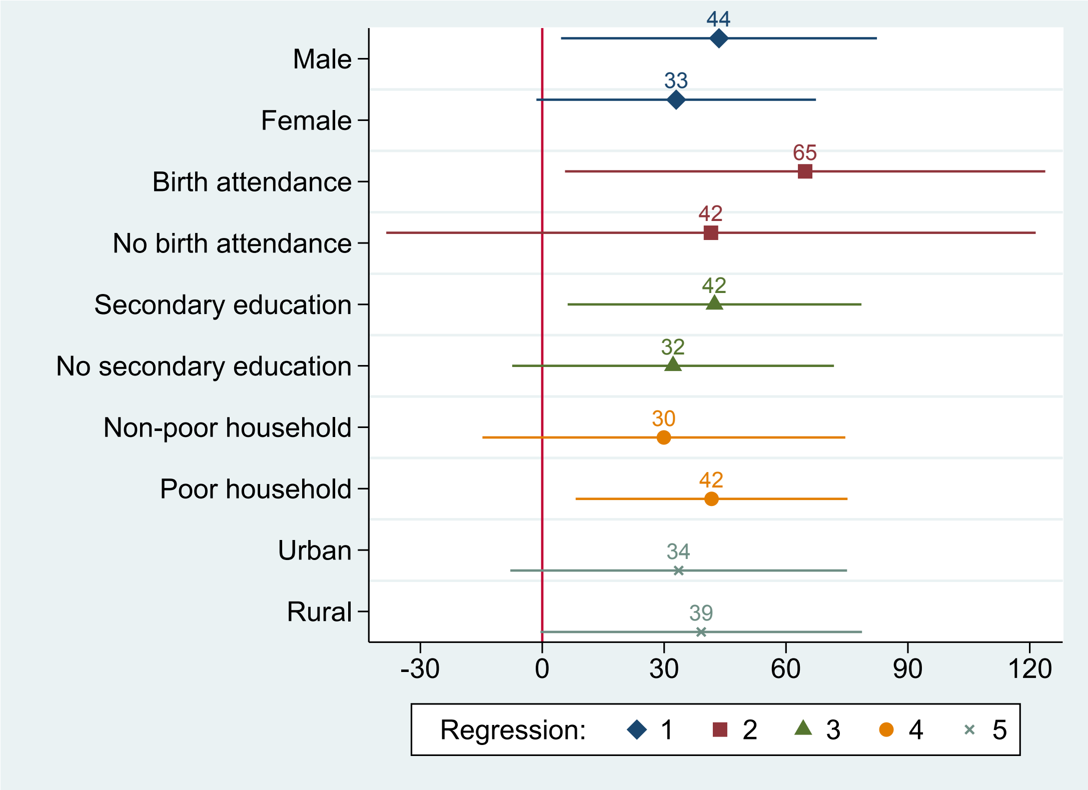
(a) Standard sample



(b) Extended sample

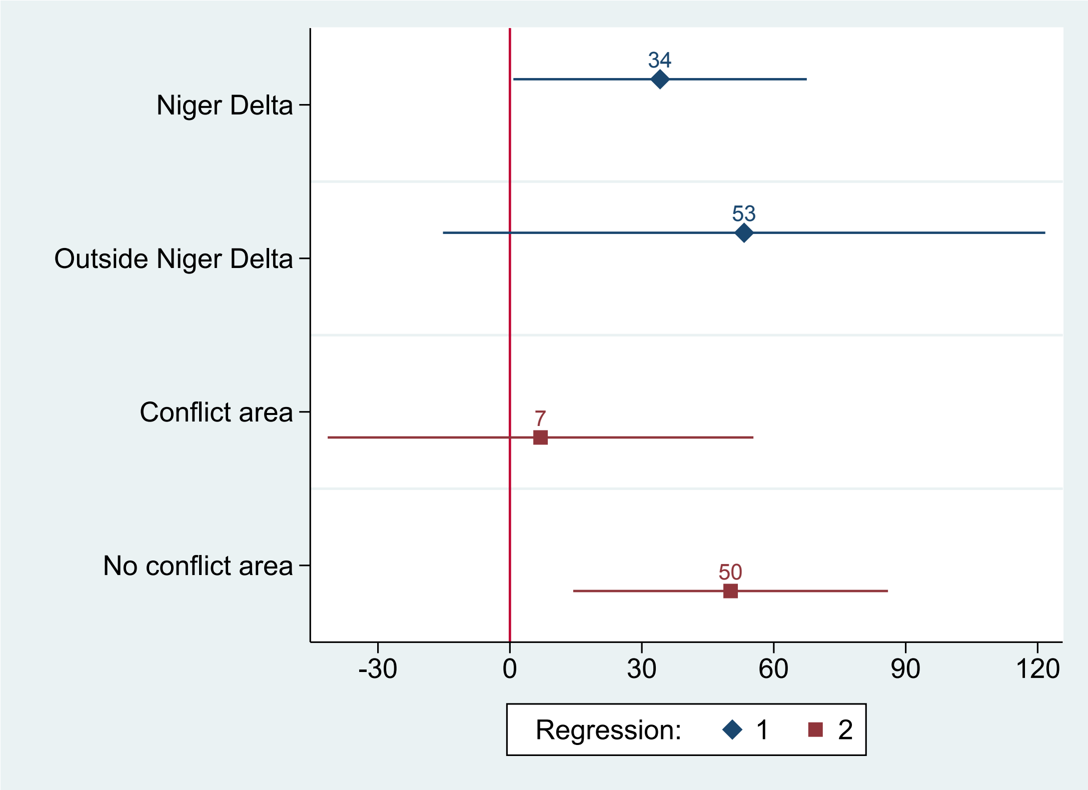
Notes: Panel (a) plots the coefficients from a linear regression of the neonatal mortality rate on the indicator variables for distances of 0-1 km, 1-2 km, etc., between the DHS cluster location and the closest oil spill before conception, while controlling for mother fixed effects, distant-specific indicator variables for oil spills during pregnancy, birth-specific control variables X_{imc}, and cluster-specific time trends. The sample is the same as in our main specification (Table 3, column (4)). The vertical lines represent 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters. Panel (b) extends the sample to all infants born in a DHS cluster within 15 km (instead of 10 km) from the closest oil spill in our records.

Figure 6: Heterogeneity of the effects on neonatal mortality



Notes: The figure plots the coefficients from five separate linear regressions of the neonatal mortality rate on the interaction terms $SPILL(CONC)_{imc} \times Z_{imc}$ and $SPILL(CONC)_{imc} \times (1 - Z_{imc})$, while controlling for mother fixed effects, $SPILL(PREG)_{imc} \times Z_{imc}$, $SPILL(PREG)_{imc} \times (1 - Z_{imc})$, birth-specific control variables X_{imc}, and cluster-specific time trends. Z_{imc} is a different indicator variable in each regression, representing one of the five characteristics for which we examine heterogeneity. The sample is the same as in our main specification (Table 3, column (4)). The horizontal lines represent 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters.

Figure 7: Potential confounders for neonatal mortality



Notes: The figure plots the coefficients from two separate linear regressions of the neonatal mortality rate on the interaction terms $SPILL(CONC)_{imc} \times Z_{imc}$ and $SPILL(CONC)_{imc} \times (1 - Z_{imc})$, while controlling for mother fixed effects, $SPILL(PREG)_{imc} \times Z_{imc}$, $SPILL(PREG)_{imc} \times (1 - Z_{imc})$, birth-specific control variables X_{imc}, and cluster-specific time trends. Z_{imc} is a different indicator variable in each regression, representing one of the two potential confounders. The sample is the same as in our main specification (Table 3, column (4)). The horizontal lines represent 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters.

Table 1: Summary statistics

Variable	Obs.	Mean	Std.Dev.	Min.	Max.
IMR_{imc}	4,314	60.27	238.01	0	1,000
NMR_{imc}	5,043	37.08	188.98	0	1,000
$PNMR_{imc}$	4,314	25.27	156.95	0	1,000
$FWMR_{imc}$	5,043	31.53	174.76	0	1,000
$PFWMR_{imc}$	5,043	5.55	74.31	0	1,000
$WASTED_{imc}$	3,088	0.15	0.35	0	1
$STUNTED_{imc}$	2,997	0.21	0.40	0	1
$SPILL(CONC)_{imc}$	5,043	0.29	0.45	0	1
$SPILL(PREG)_{imc}$	5,043	0.23	0.42	0	1
$SPILL(LIFE)_{imc}$	3,097	0.61	0.49	0	1
Birth order	5,043	3.34	2.17	1	18
Birth spacing (months)	3,855	38.12	23.96	9	226
Male	5,043	0.51	0.50	0	1
Multiple birth	5,043	0.04	0.19	0	1
Birth attendance	3,464	0.65	0.48	0	1
Mother's age at birth	5,043	28.09	6.34	12	48
Secondary education	5,043	0.62	0.49	0	1
Poor	5,043	0.61	0.49	0	1
Urban	5,043	0.54	0.50	0	1
Niger Delta	5,043	0.61	0.49	0	1
Conflict (within 25km)	5,043	0.27	0.44	0	1

Table 2: Effects of oil spills on infant mortality

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	IMR_{imc}	IMR_{imc}	IMR_{imc}	IMR_{imc}	NMR_{imc}	$PNMR_{imc}$
$SPILL(CONC)_{imc}$	5.72	16.42	24.80	31.12	43.72**	-12.60
	(11.85)	(14.06)	(19.19)	(26.42)	(21.76)	(19.05)
$SPILL(PREG)_{imc}$	-8.43	-15.85	-15.41	-19.87	-19.47	-0.40
	(10.83)	(11.31)	(12.54)	(17.42)	(14.83)	(15.57)
Birth characteristics X_{imc}	yes	yes	yes	yes	yes	yes
Cluster fixed effects	no	yes	yes	no	no	no
Cluster-specific time trends	no	no	yes	yes	yes	yes
Mother fixed effects	no	no	no	yes	yes	yes
Number of infants	4,314	4,314	4,314	4,314	4,314	4,314
Number of mothers	2,547	2,547	2,547	2,547	2,547	2,547
Number of clusters	130	130	130	130	130	130
R-squared	0.03	0.07	0.10	0.10	0.09	0.08

Notes: Linear fixed effects regressions. Sample includes all infants born between January 2006 and 12 months prior to the DHS interview to mothers in clusters less than 10 km from the closest oil spill in our records. All variables (including those in X_{imc}) are described in the main text. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

Table 3: Effects of oil spills on neonatal mortality

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	NMR_{imc}	NMR_{imc}	NMR_{imc}	NMR_{imc}	$FWMR_{imc}$	$PFWMR_{imc}$
$SPILL(CONC)_{imc}$	6.73	20.16*	30.44**	38.04**	32.79**	5.24
	(7.90)	(10.28)	(12.16)	(14.96)	(15.44)	(5.54)
$SPILL(PREG)_{imc}$	-8.16	-3.52	-3.99	-6.83	-3.37	-3.46
	(6.71)	(7.74)	(8.08)	(11.77)	(10.60)	(4.90)
Birth characteristics X_{imc}	yes	yes	yes	yes	yes	yes
Cluster fixed effects	no	yes	yes	no	no	no
Cluster-specific time trends	no	no	yes	yes	yes	yes
Mother fixed effects	no	no	no	yes	yes	yes
Number of infants	5,043	5,043	5,043	5,043	5,043	5,043
Number of mothers	2,744	2,744	2,744	2,744	2,744	2,744
Number of clusters	130	130	130	130	130	130
R-squared	0.02	0.06	0.09	0.08	0.08	0.07

Notes: Linear fixed effects regressions. Sample includes all infants born between January 2006 and 1 month prior to the DHS interview to mothers in clusters less than 10 km from the closest oil spill in our records. All variables (including those in X_{imc}) are described in the main text. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

Table 4: Effects of oil spills on wasting

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	$WASTED_{imc}$	$WASTED_{imc}$	$WASTED_{imc}$	$WASTED_{imc}$	$WASTED_{imc}$	$WASTED_{imc}$
Age group	0-1 years	0-1 years	0-3 years	0-5 years	0-5 years	0-5 years
$SPILL(CONC)_{imc}$	0.03	0.24**	0.11***	0.07***	0.07**	0.03
	(0.04)	(0.11)	(0.03)	(0.03)	(0.03)	(0.05)
$SPILL(PREG)_{imc}$	0.03	0.10	0.02	0.01	0.01	-0.00
	(0.04)	(0.08)	(0.03)	(0.02)	(0.02)	(0.04)
$SPILL(LIFE)_{imc}$	0.03	0.02	-0.01	0.00	-0.02	0.01
	(0.04)	(0.12)	(0.04)	(0.03)	(0.04)	(0.06)
Birth characteristics X_{imc}	yes	yes	yes	yes	yes	yes
Cluster fixed effects	no	yes	yes	yes	yes	no
Cluster-specific time trends	no	no	no	no	yes	yes
Mother fixed effects	no	no	no	no	no	yes
Number of children	679	679	1,931	3,088	3,088	3,088
Number of mothers	670	670	1,704	2,169	2,169	2,169
Number of clusters	126	130	130	130	130	130
R-squared	0.02	0.22	0.16	0.15	0.20	0.24

Notes: Linear fixed effects regressions. Sample is based on the Nigeria DHS 2013 and includes all children up to 1, 3 or 5 years of age (as indicated in the second row) for which weight and height measurements are available and within a valid range (see footnote 11) and who were born to mothers living in clusters less than 10 km from the closest oil spill in our records. All variables (including those in X_{imc}) are described in the main text. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

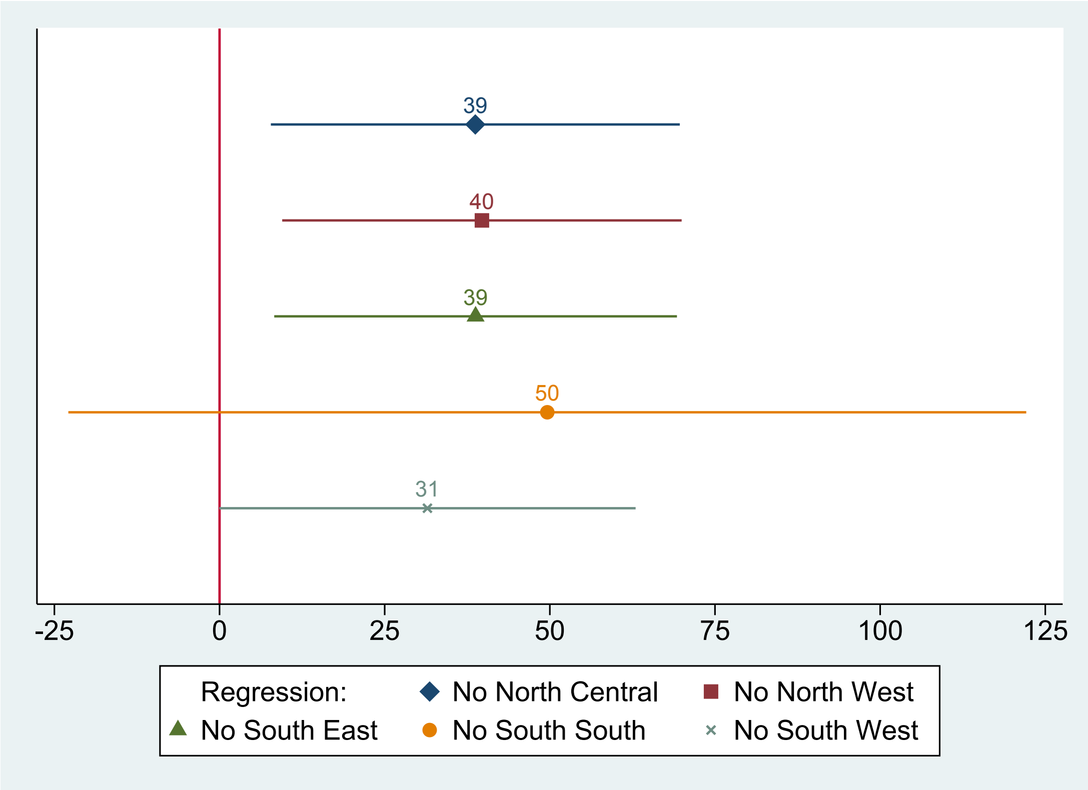
Table 5: Effects of oil spills on stunting

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	$STUNTED_{imc}$	$STUNTED_{imc}$	$STUNTED_{imc}$	$STUNTED_{imc}$	$STUNTED_{imc}$	$STUNTED_{imc}$
Age group	0-1 years	0-1 years	0-3 years	0-5 years	0-5 years	0-5 years
$SPILL(CONC)_{imc}$	0.02	-0.00	-0.08*	-0.02	-0.03	-0.03
	(0.03)	(0.08)	(0.04)	(0.03)	(0.04)	(0.06)
$SPILL(PREG)_{imc}$	-0.01	-0.08	-0.01	-0.01	-0.00	0.03
	(0.03)	(0.07)	(0.03)	(0.02)	(0.03)	(0.05)
$SPILL(LIFE)_{imc}$	0.04	0.02	0.00	0.04	-0.00	0.04
	(0.04)	(0.11)	(0.05)	(0.04)	(0.05)	(0.09)
Birth characteristics X_{imc}	yes	yes	yes	yes	yes	yes
Cluster fixed effects	no	yes	yes	yes	yes	no
Cluster-specific time trends	no	no	no	no	yes	yes
Mother fixed effects	no	no	no	no	no	yes
Number of children	636	636	1,853	2,997	2,997	2,997
Number of mothers	627	627	1,639	2,117	2,117	2,117
Number of clusters	126	130	130	130	130	130
R-squared	0.05	0.28	0.17	0.15	0.20	0.23

Notes: Linear fixed effects regressions. Sample is based on the Nigeria DHS 2013 and includes all children up to 1, 3 or 5 years of age (as indicated in the second row) for which height measurements are available and within a valid range (see footnote 11) and who were born to mothers living in clusters less than 10 km from the closest oil spill in our records. All variables (including those in X_{imc}) are described in the main text. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

Appendix: Additional figures and tables

Figure A.1: Effect of oil spills on neonatal mortality when omitting single regions



Notes: The figure plots the coefficients from five separate linear regressions of the neonatal mortality rate on $SPILL(CONC)_{imc}$, while controlling for mother fixed effects, $SPILL(PREG)_{imc}$, birth-specific control variables X_{imc}, and cluster-specific time trends. The sample is the same as in our main specification (Table 3, column (4)), but one geopolitical zone (indicated below the figure) is omitted in each regression. The horizontal lines represent 95% confidence intervals. Standard errors are adjusted for clustering at the level of DHS clusters.

Table A.1: Effect of oil spills during pregnancy on mortality rates

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	IMR_{imc}	NMR_{imc}	$PNMR_{imc}$	NMR_{imc}	$FWMR_{imc}$	$PFWMR_{imc}$
$SPILL(CONC)_{imc}$	30.00	44.99**	-14.99	38.16**	32.82**	5.34
	(27.16)	(22.28)	(19.01)	(15.07)	(15.55)	(5.58)
$SPILL(PREG1)_{imc}$	23.22	-11.56	34.78**	6.36	4.32	2.04
	(24.16)	(20.86)	(15.22)	(15.92)	(14.83)	(6.11)
$SPILL(PREG23)_{imc}$	-6.84	-13.29	6.44	-9.59	-5.90	-3.68
	(17.96)	(14.12)	(13.02)	(13.28)	(12.08)	(5.16)
Mother fixed effects	yes	yes	yes	yes	yes	yes
Birth characteristics X_{imc}	yes	yes	yes	yes	yes	yes
Cluster-specific time trends	yes	yes	yes	yes	yes	yes
Number of infants	4,314	4,314	4,314	5,043	5,043	5,043
Number of mothers	2,547	2,547	2,547	2,744	2,744	2,744
Number of clusters	130	130	130	130	130	130
R-squared	0.10	0.09	0.08	0.08	0.08	0.07

Notes: Linear fixed effects regressions. $SPILL(PREG1)_{imc}$ ($SPILL(PREG23)_{imc}$) indicates that a nearby oil spill occurred during the first (second or third) trimester of a pregnancy. All other variables (including those in X_{imc}) are described in the main text. Columns (1)–(3) rely on the same sample as columns (4)–(6) in Table 2, and columns (4)–(6) on the same sample as columns (4)–(6) in Table 3. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

Table A.2: Effect of oil spills on birth attendance and the type of mothers giving birth

	(1)	(2)	(3)
Dependent variable	Professional birth attendance	Secondary education	Household wealth
$SPILL(CONC)_{imc}$	0.03	0.05**	0.01
	(0.03)	(0.02)	(0.01)
$SPILL(PREG)_{imc}$	-0.02	-0.02	0.00
	(0.02)	(0.02)	(0.01)
Cluster fixed effects	yes	yes	yes
Birth year fixed effects	yes	yes	yes
Cluster-specific time trends	yes	yes	yes
Number of births/infants	3,464	5,043	5,043
Number of clusters	130	130	130
R-squared	0.52	0.31	0.71

Notes: Linear fixed effects regressions. All variables are described in the main text. Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.

Table A3: Effects of oil spills on pregnancy termination rates

	(1)	(2)	(3)	(4)
Dependent variable	PTR_{pmc}	PTR_{pmc}	PTR_{pmc}	PTR_{pmc}
$SPILL(CONC)_{pmc}$	32.56**	19.09	19.06	12.82
	(13.84)	(14.89)	(14.89)	(35.38)
Controls	yes	yes	yes	yes
Cluster fixed effects	no	yes	yes	no
Cluster-specific time trends	no	no	yes	yes
Mother fixed effects	no	no	no	yes
Number of pregnancies	3,680	3,680	3,680	3,680
Number of mothers	2,484	2,484	2,484	2,484
Number of clusters	130	130	130	130
R-squared	0.02	0.09	0.09	0.09

Notes: Linear fixed effects regressions. Sample is based on the Nigeria DHS 2013 and includes all pregnancies starting between January 2008 and ten month prior to the DHS interview in 2013 of mothers in DHS clusters less than 10 km from the closest oil spill in our records. The dependent variable PTR_{pmc} is equal to 1,000 if pregnancy p of mother m in cluster c ended in an abortion or still birth, and zero if it ended in a live birth. All other variables are described in the main text. The controls are an indicator variable for the year of conception and the mothers' age (in 5-year intervals). Standard errors are clustered at the level of the DHS clusters. ***, **, * indicate significance at the 1, 5 and 10%-level, respectively.