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The Effect of Dust Storms on Child Health in West Africa

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Abstract

Dust storms are a fact of life for populations residing in semi-arid environments. These storms can result in a variety of immediate and long-term impacts. Reports have included evidence of people suffocating due to airborne dust, transport networks being disrupted and leading to traffic accidents, as well as increases in asthma attacks. Despite these records, we do not know their total effect on health. In this paper, I study the effects of dust storms on child mortality using reanalysis data on Aerosol Optical Depth (AOD) and household health data from the Demographic and Health Surveys. I use dust observed over the Sahara to instrument for the dust over where the child is born. I find that a one standard-deviation increase in AOD at month of birth leads to a 0.4 percentage point decrease in the probability that a child survives to age 5. This estimate implies that about 7% of all child mortality observed in the sample is affected by dust storms.

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1 Introduction

Particulate matter is known to have human health consequences, especially for newborn children. A variety of anthropogenic pollutants have been extensively studied. Some analyses of naturally-occurring particulates have also conducted.[26] However, identifying the effects of these particulates carries a different set of challenges to identifying those associated with fires or industrial pollutants. One concern is that high levels of dust will be correlated with drought and soil conditions that may affect agriculture and other economic activity. The methods to detect dust are not perfect and can also be affected by industrial pollutants. In this paper, I utilize long-range dust transport in order to assess the direct impacts of dust storms on child mortality.

Dust storms result in a variety of impacts. Reports have included evidence of people suffocating due to airborne dust, transport networks being disrupted and leading to traffic accidents, as well as increases in asthma attacks. While some of these are very visible effects, we know that particulate matter can have impacts on child mortality, which may not be so obviously connected.

Child mortality outcomes are clearly important in and of themselves, and much progress has been made in reducing the rates of child mortality across sub-Saharan Africa. While this is promising, this region still shows some of the highest child mortality rates in the world. Economic growth continues to allow this region to improve outcomes, but there is some question as to how much the rate can be reduced given the environmental burden. An important question is how much the environment is contributing to worse health outcomes, and what can be done to address the environmental factors.

Around the world, attempts have been made to reduce the frequency and intensity of dust storms, indicating that governments and other organizations have been aware of the problem and have made some attempts to combat it. The United States invested in the Great Plains Shelterbelt, an expanse of trees across the Midwest, in the wake of the Dust Bowl in the hopes of reducing blowing dust. China has committed significant resources to the Three-North Shelter Forest Program to try to prevent expansion of the Gobi desert.

Africa attempted to establish a Great Green Wall of trees along the southern border of the Sahara desert to combat desertification, though now the resources have largely been re-appropriated for general development purposes in the region, as the program was seen as ineffective.

While there have been attempts to reduce dust storms, climate change is threatening to increase the frequency in certain parts of the world. The United States is expected to see an increase in dust storms,[30] and it is projected that Southern African sand dunes could become a major dust source in the future.[7] Dust sources are also controlled to an uncertain extent by human changes to land use, making predictions of future dust emissions difficult.[32] There has recently been an expansion of effort to improve short-term dust storm forecasts in various parts of the world, which could be incorporated into early warning systems, as recently implemented in South Korea.[23] All of these efforts point to a growing realization that understanding the effects of dust storms are important, even if our methods for both adaptation and mitigation may be limited.

2 Related Literature

This paper relates to a large body of literature in public health and economics on air pollution and health outcomes. This work is largely summarized by the Global Burden of Disease,[9] which seeks to recover the response function of various diseases and mortality to ambient $PM_{2.5}$.

Dust storm effects on health have also been examined in various parts of the world, including North America,[14] Europe,[2] and Asia.[13] Scientists studying dust movements around the world have also considered the effects these storms have, both on human health and on climate.[28] [29] [20] [24] This work has highlighted how little we know about the effects of dust on health in Africa, as well as how little we understand the human response to repeated bouts of dust storms.

There has recently been interest in the economics literature on the effects of dust storms, as well as a continued interest in the atmospheric sciences. The dust bowl in the United States has shown to have long-lasting economic impacts, as well as impacts on where populations chose to locate.[22 25] The dust bowl is of particular interest, as it resulted from a combination of natural and human forces.[27] It has been shown to have not only direct and immediate impacts, but also long-run consequences for human capital.[5]

Other literature has shown that dust storms may have important consequences for child mortality, both in the developing and developed world,[1] with some evidence that institutional interventions such as warning systems for dust storms can reduce impacts.[6] Child mortality rates have consistently been shown to increase during periods of particularly high dust concentrations. If some of these deaths could be avoided by simple interventions such as early warning systems, this may be a productive area of study for actionable policy. It is also important to know the effects to evaluate whether development assistance could target investments to protect against dust storm-related child mortality.

The economics literature has also contributed novel identification strategies for attributing health damages to air pollutants health,[31 18 12] as well as determining the total costs of having poor health.[8 16] These papers have supplemented the work in public health that seeks to estimate health response functions to particulates. Economists have the potential to contribute both in terms of identification issues, as well as quantifying adaptation and the costs and benefits of various policy options.

This study also relates to the literature on the effects of the climate on health. While dust storms are not as destructive as tropical cyclones, they are a major feature of the climate system in West Africa as well as other arid regions of the world. Antilla-Hughes and Hsiang[3] show that cyclones have significant impacts on child mortality, with most of the effects attributable to income effects, rather than direct physical impacts. Other studies have also noted a connection between dust storms and meningitis outbreaks, which could be one of the mechanisms through which dust storms affect health.[19 4]

Questions also remain about the mechanisms by which dust storms impact health outcomes, whether it is through the health of the fetus due to exposure of pregnant mothers to dust, or whether it is impacting economic outcomes that are either directly or indirectly affected by dust storms. While this study can shed some light on these questions, they remain largely unresolved.

3 Empirical Strategy

The main concern in identifying the impact of dust storms is that local dust levels could be affected by many factors. Another problem arises from the methods used to detect dust. While AOD is dominated by dust over West Africa, other aerosols will affect it. One obvious concern is that economic activity could produce air pollution that increases AOD. This could introduce downward bias in the OLS estimates if greater economic activity leads to lower child mortality. Another concern could be that the most severe storms often occur during times of drought or other environmental shocks that may impact health, either directly through biological effects of temperature, or indirectly through agricultural productivity or other income effects. There is also the problem that AOD is not measuring dust concentration at the surface, but total column aerosol. This will likely introduce measurement error, possibly non-classical in form.

In order to address these concerns, I focus on the effects of long-range transport of desert dust from the largest dust source in the world, the Bodélé depression. Dust can be transported large distances across the world, with countries in the Caribbean receiving nontrivial amounts of dust from the Sahara. There is inherently a trade off between identification and the intensity of dust that we can measure. Dust transported to the Caribbean, for example, from the Sahara will be credibly exogenous to local conditions. Dust over the Sahel region could still be related statistically and meteorologically to weather over the Sahel,[11] so I test for these effects where possible.

While using dust over major source regions in the Sahara as an instrument for dust over West Africa largely addresses the concern of the effects of local conditions, it does not necessarily identify only the biological effects of dust. Dust can have other effects on health through any effects that it may also have on income or agricultural productivity. In this study, I take the results to be the total effect, with the exploration of the various channels left to further work.

4 Data

4.1 Dust storm data

There are many ways to measure dust in the atmosphere. Dust storms are defined to be when visibility is less than 1000 meters and dust particles are entrained in the air. While weather stations typically measure visibility and may even report weather codes for "blowing dust," in the regions where dust storms are important features of weather patterns, weather station data can be unreliable, particularly for measures other than temperature and precipitation readings. It is also geographically sparse in less-developed regions of the world. Such a setting calls for the application of satellite-based observations or reanalyses, which provide more reliable spatio-temporal coverage. Here, I utilize a new reanalysis product, the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2),[10] which "is the first long-term global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other physical processes in the climate system." This product integrates a climate model with aerosol models, but is also constrained by satellite observations. In particular the Aerosol Optical Depth (AOD) is calibrated to observations from various satellite instruments.

While AOD can increase due to various types of aerosol, including sulfates and sea salt, over the world's "dust belt" across the Middle East and northern Africa, it is largely dominated by dust. Even if it measured only dust, however, it is still not the ideal measurement of dust that will affect human societies, as it is affected by total atmospheric column dust, not just dust at or near the surface. MERRA-2 also provides 3-dimensional dust simulations, which are expected to be less reliable, as this estimate is more model-dependent and not directly constrained by observation. In this study, I focus primarily on measurement of dust by AOD.

MERRA-2 AOD is provided from 1980-present every day for a $0.5^\circ \times 0.625^\circ$ grid.

Annual average optical depth over a location varies from 0.1 in regions of very little aerosol up to 2 in highly dusty regions. The highest values for much of the year occur over and downwind of the Sahara Desert. Large values are also seen over the other large deserts of the world, including the Arabian Desert, the Gobi Desert, much of Australia, and to a lesser extent the Southwestern United States, the Patagonian Desert, and the Kalahari Desert. I focus on West Africa due to the extremes in dust concentration, as well as the potential vulnerability of these regions as some of the poorest countries in the world are located here.

The inputs to the MERRA-2 reanalysis also changed over time as new instruments became available and others went out of use. The largest change is the introduction of new instruments in 2000. For this reason, I estimate effects separately pre- and post-2000. The results in table 15 do not show any significant differences between the two periods.

4.2 Health outcome data

The data from the DHS includes extensive information about each household surveyed, with various household members answering questions primarily about individual health as well as basic demographic and socio-economic questions. The surveys are conducted throughout the developing world, and for each country, multiple rounds of the survey have been done, typically at five year intervals. The primary data I use comes from the birth recode data which includes questions about children born in the household. For each child born, the data contains the month of birth, whether the child is still alive, and if the child is no longer alive, the length of time the child survived. It is possible to match data from the birth recodes to the individual recode data, which contains information on the household characteristics including household wealth categories and urban/rural classification. Each cluster in the survey is also linked to geographic coordinates, which I use to match the household data to the data on dust.

4.3 Combining Datasets

One of the challenges to answering questions about dust and health is how to combine data on dust to the data on health outcomes. Various dust products have different temporal and spatial resolutions. The dust products also have varied reliability at finer scales. One main priority in this project is to detect the movement of dust across the Saharan desert and over West Africa, a phenomenon that occurs on the time scale of days. Therefore, temporal resolution is highly important. While I would like to have very fine-scale dust data, there will be a trade-off between validity and increased resolution. The most valid satellites for detecting dust often have relatively low spatial resolution. For my purposes, that is a reasonable tradeoff to make, but should be kept in mind when interpreting some of the results.

The DHS data also includes an offset of up to 10 km, so a high level of geographic accuracy may not be rewarded, and averaging readings over space may be necessary regardless of the spatial resolution of the data. To minimize the noise in the dust data, I average the MERRA-2 AOD over all observations within 1° of the DHS cluster coordinates on the day of observation.

5 Results

5.1 First-stage Results

Because the measured dust D may be correlated with factors affecting also child survival outcomes, I use the modeled long-range dust over region $r(i)$ in season s and month m, $\widehat{D}_{r(i),sm}$ in a 2SLS regression. I estimate $\widehat{D}_{r(i),sm}$ using the following equation:

$$D_{r(i),sm} = \sum_{j=-2}^{1} \beta_{r,js} D_{B,sd-15j} + \theta_{r,s} + \gamma_{r,y} + \rho_{r,m} + \epsilon_{r,sm} \tag{1}$$

where $D_{B,sd-15j}$ is the 15-day average of dust observed over the Bodélé depression in season s in the jth period after the start of month m. Estimating the parameters $\beta_{r,js}$

and $\theta_{r,s}$ using OLS gives $\widehat{\beta}_{r,js}$, $\widehat{\gamma}_{r,t}$, $\widehat{\rho}_{r,m}$ and $\widehat{\theta}_{r,s}$, which can be used to construct a predicted value of D, namely, $\widehat{D}_{r(i),sm}$.

This equation is run for each cluster location separately, meaning all of the parameters are cluster-specific. Since a large number of parameters are therefore being estimated, I run robustness checks to rule out that nearly all variation in dust is being captured, not just the long-range component of interest. I run a placebo test by predicting West African dust using future values of Bodélé dust, as well as predicting dust over the Gobi desert using Bodélé dust. If this model were over-fit, I would be re-introducing the OLS bias.

Once I have predicted dust for each location, I use it as an instrument for the actual observed dust level. One way to assess the validity of the long-range dust prediction model is to consider the F-statistic. Since the regression is run for each cluster separately, there is a distribution of F-statistics. The distribution is shown in Figure 3. Roughly one-fifth of the F-statistics are greater than 10, indicating that some of the instruments may be weak. The results for only the sample with large F-statistics show an effect about two-thirds the size of the full-sample estimate. To check that other climate variables are not directly affected by the same processes as transported dust, I run the same model with the temperature in each cluster as the outcome. This is the expected direction, as weak instruments will also re-introduce some of the OLS bias.

5.2 Second-stage Results

5.2.1 Main Results

To determine the impact of dust on child mortality, I run regressions of the form

$$Y_{it} = f(\hat{D}_{r(i),t}) + \rho C_{r(i),t} + \gamma X_i + g_r(t(i)) + \alpha_{r(i),t} + \epsilon_{it} \tag{2}$$

where Y_{it} is an indicator for whether the child survives to age 5, $\widehat{D}_{r(i),t}$ is the predicted AOD in child i's region in his or her month of birth, $C_{r(i),t}$ includes flexible temperature and precipitation controls in the month of birth, X_i controls for household characteristics, $g_r(t(i))$ is a region-specific time trend, and $\alpha_{r(i),t}$ are time and region fixed effects. I am interested in recovering f, the effect of varying dust exposure on child survival, holding all else constant. Standard errors are two-way clustered by DHS cluster, roughly a village, and month, allowing for arbitrary correlation in error terms across time within a cluster and within a month across all locations. This is relatively conservative, as the correlations within a month are likely to be across smaller geographic areas than the entire area of study.

The primary results are shown in Table 1, which compares the OLS results taking the observed values of AOD to the results with the AOD instrumented by the Saharan dust. There appear to be significant effects of dust on child mortality in both regressions. The results using instrumented AOD are larger, likely indicating the importance of measurement error and capture of other pollutants associated with the AOD. The AOD values are normalized by the average within-cluster standard deviation. Column 3 in Table 1 implies that a one-standard deviation increase in AOD in the month of birth leads to a 0.4 percentage point decrease in the probability of survival to age 5. This estimate implies that about 7% of all child mortality observed in the sample is affected by dust storms.

5.2.2 Heterogeneous Effects

Given that there are large effects of airborne dust on child mortality outcomes, it is interesting to explore how these effects differ across different populations in West Africa. The first question of interest is how these effects differ across countries. Countries will vary along many characteristics, including level of exposure, level of wealth, and institutional capacity.

The largest effects are in Sierra Leone and Niger, as shown in Figure 6. These two countries are two of the poorest in the region. The largest effects also occur during the dry season, as seen from the breakdown in the effect by month in Figure 7. This could be due to nonlinearities in the response, although I do not find other evidence for nonlinearities using a binned response function. Another explanation may be that this is a time of tightened liquidity constraints, such that medical attention is less likely to be sought after due to a lack of funds. The negative effects of dust are strongest in the month of birth and the last trimester of pregnancy. This most likely indicates that the effects are primarily biological, since if the effects propagated through an income channel, there should be a more uniform response around the time of birth or larger effects of dust early in the pregnancy.

Since dust storms are a known feature of the climate in this part of the world, it may be expected that people will make defensive investments that allow them to adapt, and reduce the effects on child mortality. One check for this is to see if places that have higher average levels of dust in the air exhibit a differential response to dust. The interaction between dust at the time of birth and mean dust over the period is actually negative, as shown in Table 2. This indicates that places with larger baseline dust levels show stronger effects on child mortality. This could be due to a compounding of effects, where higher levels of dust lead to lower economic development in an area, causing dust to be a larger problem. There is also no evidence that the effects have been decreasing over time, which might be expected as incomes rise or as people implement adaptation strategies. In fact, there is some evidence that the effects have been worsening over time. Another means of adaptation could be living in a more urban area. However, the results in Table 7 show that after controlling for income, the effects appear to be larger in urban than rural areas.

One defensive investment that households could make that I observe in the data is the wall material of the family's dwelling. This data is collected in order to contribute to the proxy of household wealth, but controlling for other indicators of wealth and interacting with the effect of dust can shed some light on whether such an investment can make a difference. The results of the interaction between having a sturdy wall material and dust levels at time of birth are shown in Table 2. Even though having a solid wall material at the time of survey is not a perfect indicator for the wall material at the time of the birth of the child, we see that having solid walls significantly reduces the effect of dust on child survival, approximately cutting it in half.

5.2.3 Other Health Effects

To get a fuller understanding of the consequences of these effects, I also consider other outcomes of interest. In particular, I have thus far considered child mortality (by age 5), which should capture the full effect over early childhood development, but these could be noisier than the actual effects if the main effects are in the first month or year of life. To check for this, I also estimate the effect of dust on infant (1 year) mortality and neonatal (1 month) mortality, and the results are presented in Tables 11 and 12, respectively. The effects on mortality are about half the child mortality effects, suggesting that deaths are increasing both near the time of birth and in the years after. However, the infant and neonatal results are very close, suggesting that most of the infant mortality occurs within the first month.

I also look at the effect of dust on the sex ratio at birth. A one standard-deviation increase in dust at month of birth leads to a .05 percentage point increase in the child being female, which is not large and not precisely estimated. If the were effects on stillbirths, I would expect in increase in female births, as male fetuses tend to be more vulnerable to environmental stressors.[17] However, I find no evidence to support this effect.

While particulates can affect mortality in small children, effects on the rest of the population will likely not be as severe, but still potentially important. The DHS data includes questions about recent health problems, in particular whether children in the household have recently experienced coughing, fever, and shortness of breath. For this data, there is less variation over time, as the survey only asks about outcomes in the two weeks prior to the survey, but where I have multiple surveys over time in the same location, I can identify the effects of variation in dust. The results of regressions of the same form as in equation 2, with the outcome as a dummy for having the condition, and the AOD is the value observed in the month of the survey. The results are reported in Table 3. The occurrence of coughs and shortness of breath both increase, with a 1 standard deviation increase in AOD leading to a 1 percentage point increase in the probability of having a cough and a 3 percentage point increase in having experienced shortness of breath. These effects could have broader implications for development, as parents may be more likely to work less when their children are sick.[21]

6 Conclusion

Dust storms are found to significantly contribute to child mortality, as well as other health indicators across West Africa. Households in this region appear to have some scope to adapt through costly investment. More wealthy areas appear to be less affected, while more dusty places do not exhibit any diminished response. There is also no evidence that the effects are decreasing over time, even as child mortality rates are quickly falling across this region. These impacts could lead to reductions in development status across this region, which has remained one of the poorest in the world.

These effects could also be considered by organizations working to improve development outcomes. There may be health interventions that could be targeted toward minimizing these health effects in this region. One possibility would be the introduction of an early warning system, as these storms can be predicted in advance. There could also be added benefits to soil conservation practices over and above the usually cited ones for added agricultural productivity over the long term.

Future work could evaluate how important these effects are for economic development. If children provide income support to the family over the parents' lifetimes, the fertility rate in this region may be higher due to excess mortality, which may prevent these countries from receiving a demographic dividend.[15] While it cannot be expected that the development problems in this area will be solved by reducing child mortality rates associated with dust storms, it is an important aspect to understand.

More work also needs to be done to determine how much of the observed effects are due to direct biological effects versus indirect effects that may occur due to an income or capital stock effect. These channels are important to disentangle, as it affects which policies are most relevant. If the effects are largely biological, then interventions should be targeted to affect behaviors of households around the time of birth to protect pregnant mothers and infants from dust. If the effects are instead driven by changes in income or liquidity, expanding access to credit or insurance may be more important for mitigating the effects. Also of interest is how the dust storm effects interact with the diseases that the children are facing. Given the size of the effects, it is possible that exposure to dust is increasing susceptibility to various diseases, and these effects may be useful to understand.

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Tables and Figures

VARIABLES	(1) surv	(2) surv	(3) surv	(4) surv
bin1 AOD		0.00237		0.00226
		(0.00173)		(0.00182)
bin3 AOD		-0.00242		-0.00159
		(0.00174)		(0.00184)
bin4 AOD		-0.00505***		-0.00272
		(0.00194)		(0.00217)
bin5 AOD		-0.00892***		-0.00607***
		(0.00192)		(0.00224)
AOD	-0.335***		-0.230***	
	(0.0576)		(0.0694)	
Observations	534,982	534,982	518,846	518,846
R-squared	0.066	0.066	0.066	0.066
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(1) surv	(2) surv	(3) surv	(4) surv
bin1 AOD		0.00485**		0.00470**
		(0.00188)		(0.00193)
bin3 AOD		-3.75e-05		0.000689
		(0.00166)		(0.00166)
bin4 AOD		-0.00429**		-0.00227
		(0.00193)		(0.00220)
bin5 AOD		-0.00970***		-0.00658**
		(0.00209)		(0.00274)
AOD	-0.541***		-0.437***	
	(0.0888)		(0.138)	
Observations	533,972	533,972	517,836	517,836
R-squared	0.066	0.066	0.066	0.066
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 1: Impacts of dust on child survival, using OLS and using predicted AOD. Bins are determined as quintiles for each cluster.

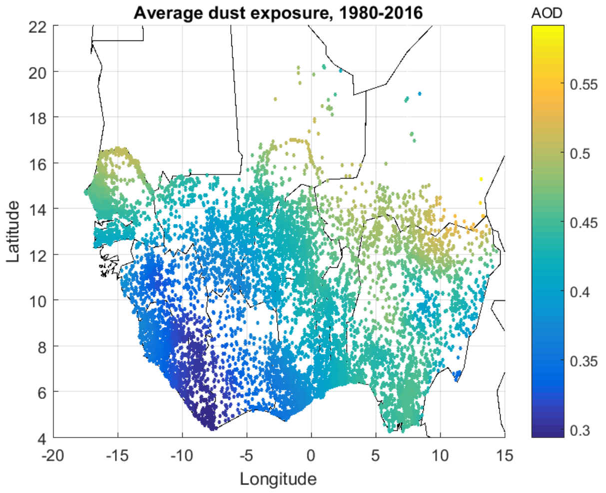

Figure 1: Mean AOD over West Africa during the sample period.

VARIABLES	(1) surv	(2) surv	(3) surv
Predicted AOD	0.493	-0.485***	-0.44764***
	(0.448)	(0.171)	(0.12497)
AOD x avg AOD	-2.196**		
	(1.057)		
sturdy wall x AOD		0.207***	
		(0.068)	
year x pred AOD			-0.01609**
			(0.00636)
Observations	934,636	398,854	934,636
R-squared	0.067	0.067	0.06652
cluster FE	X	X	X
year FE	X	X	X
MOY FE	X	X	X
country-year trend	X	X	X
climate controls		X	X

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2: Impacts of dust on child survival, using predicted AOD, allowing for various adaptation strategies.

VARIABLES	(1) cough	(2) fever	(3) breath
AOD	0.262	-0.0208	1.044**
	(0.168)	(0.186)	(0.470)
female	-0.00955***	-0.0127***	-0.0117
	(0.00284)	(0.00297)	(0.0111)
Observations	61,497	75,438	8,960
R-squared	0.161	0.124	0.349
cluster FE	X	X	X
year FE	X	X	X
MOY FE	X	X	X
country-year trend	X	X	X
Climate controls	X	X	X

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

VARIABLES	(1) cough	(2) fever	(3) breath
pred AOD	0.546**	0.444*	1.396*
	(0.241)	(0.264)	(0.775)
female	-0.00955***	-0.0127***	-0.0118
	(0.00284)	(0.00297)	(0.0111)
Observations	61,497	75,438	8,960
R-squared	0.161	0.124	0.348
cluster FE	X	X	X
year FE	X	X	X
MOY FE	X	X	X
country-year trend	X	X	X
Climate controls	X	X	X

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: Impacts of dust on cough, fever, and shortness of breath, using AOD and predicted AOD.

VARIABLES	(1) surv	(2) surv
AOD	-0.344***	
	(0.0598)	
F> 10 x AOD	0.121	
	(0.183)	
Predicted AOD		-0.489***
		(0.154)
F> 10 x AOD		0.170
		(0.343)
Observations	534,982	517,836
R-squared	0.066	0.066
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
Climate controls		X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Impacts of dust on survival, by high or low F-statistic.

VARIABLES	(1) birth weight (g)	(2) birth weight (g)
AOD	222.188	-1,090.168
	(777.614)	(1,573.809)
Observations	221,958	221,958
R-squared	0.447	0.447
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
climate controls	X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Impacts of dust on birth weight, using AOD and predicted AOD.

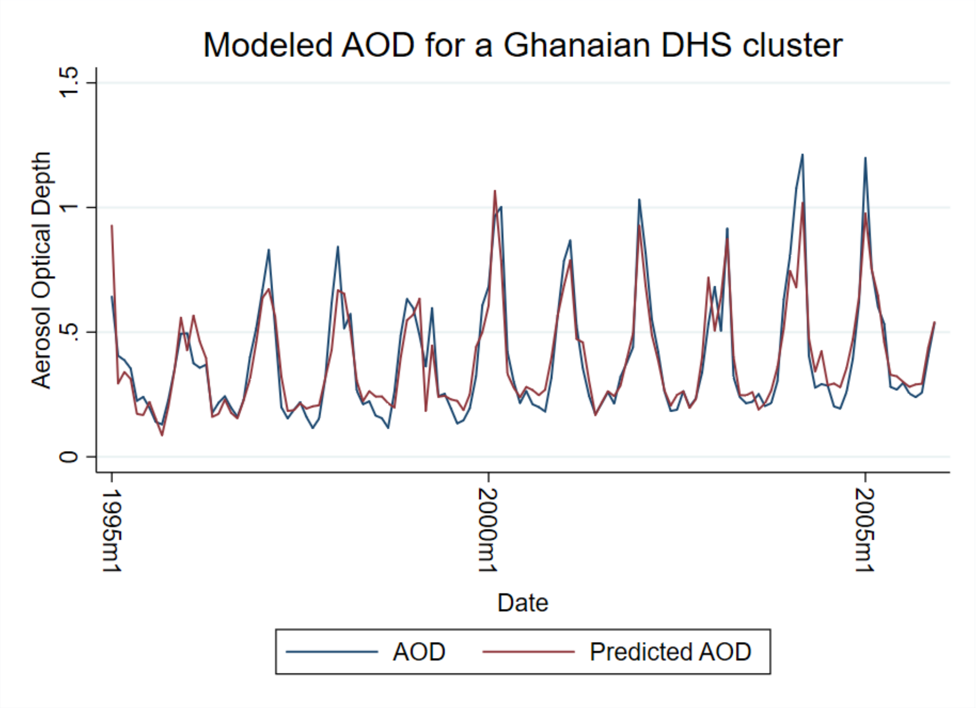

Figure 2: Predicted vs actual AOD for a single cluster

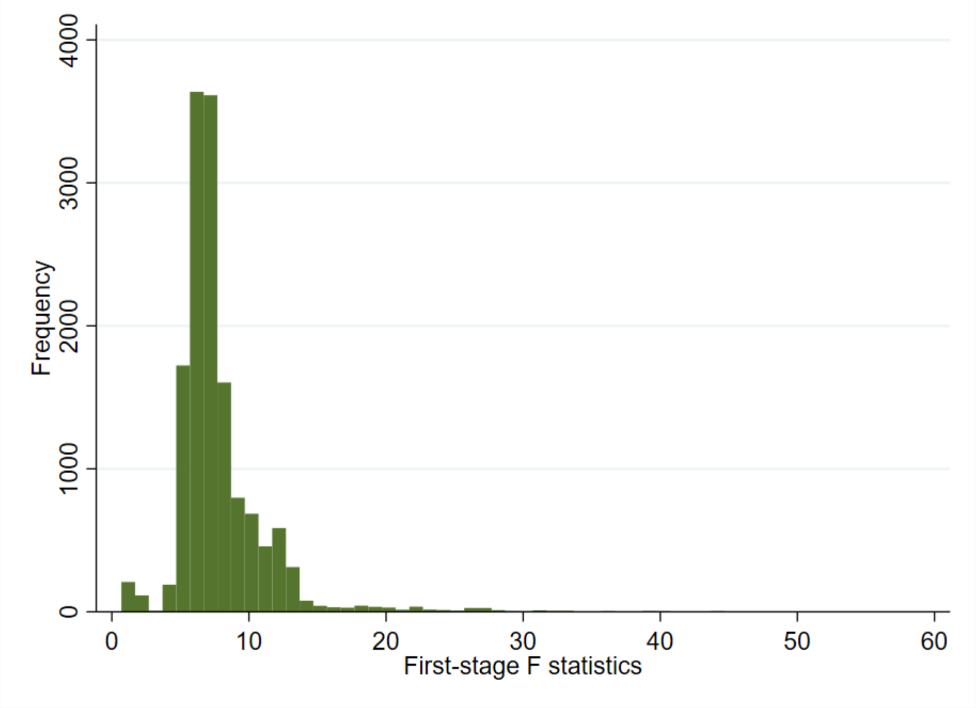

Figure 3: F-statistics for first stage regressions

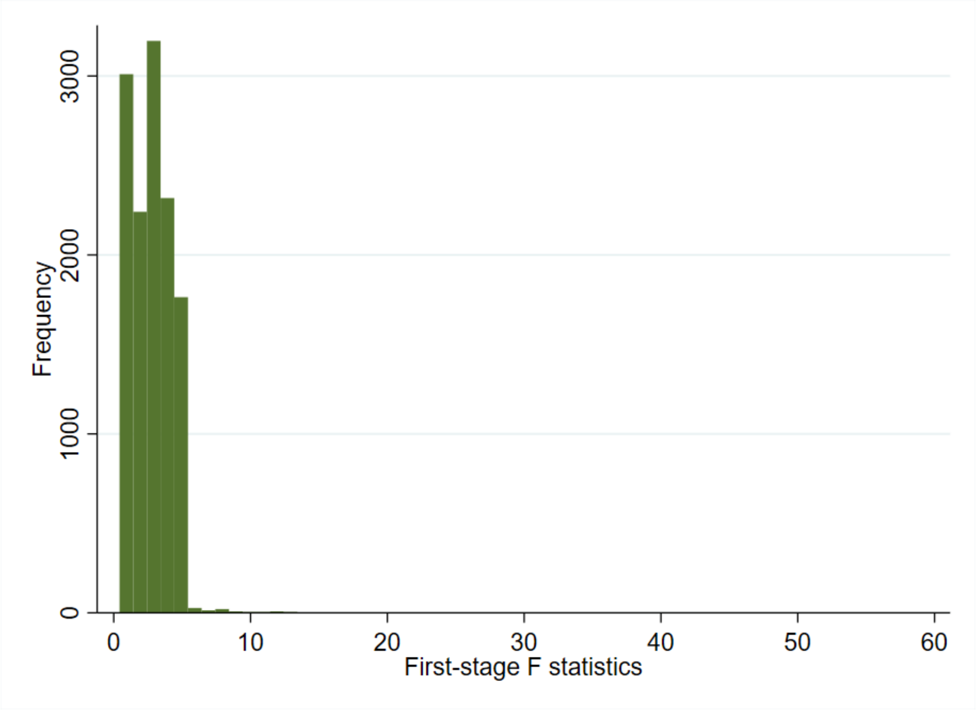

Figure 4: F-statistics for first stage regressions, with temperature as the outcome

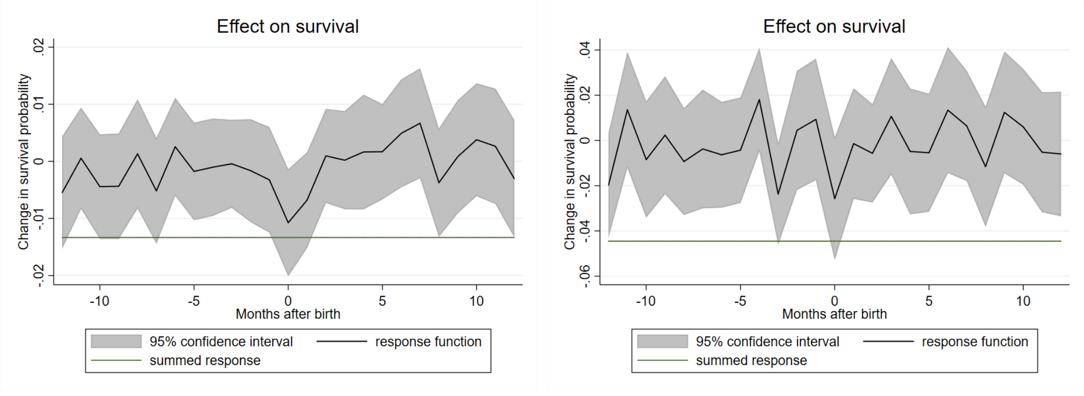

Figure 5: Effect over 1 year of leads and lags

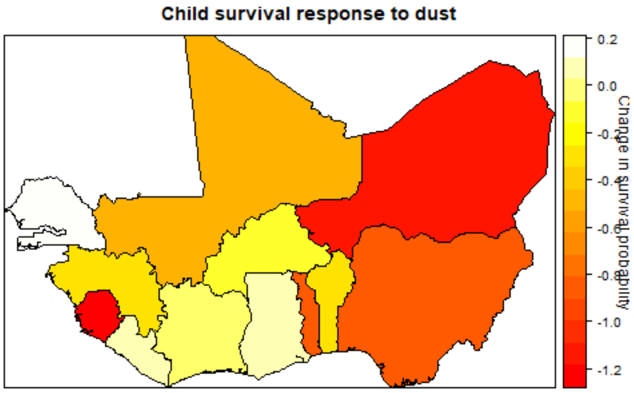

Figure 6: Effect by country, as measured by the change in survival probability for a 1-standard deviation increase in AOD.

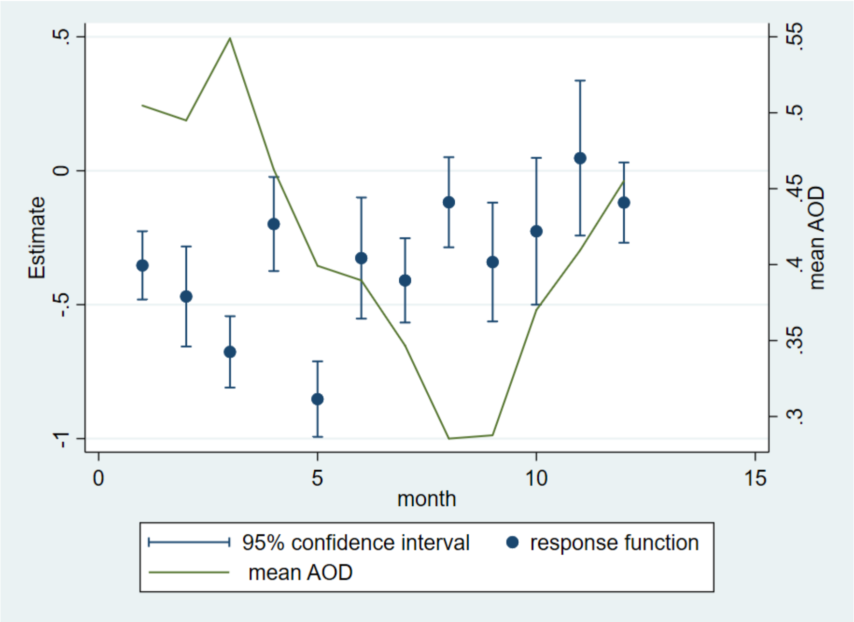

Figure 7: Effect by month of year compared to average AOD in each month.

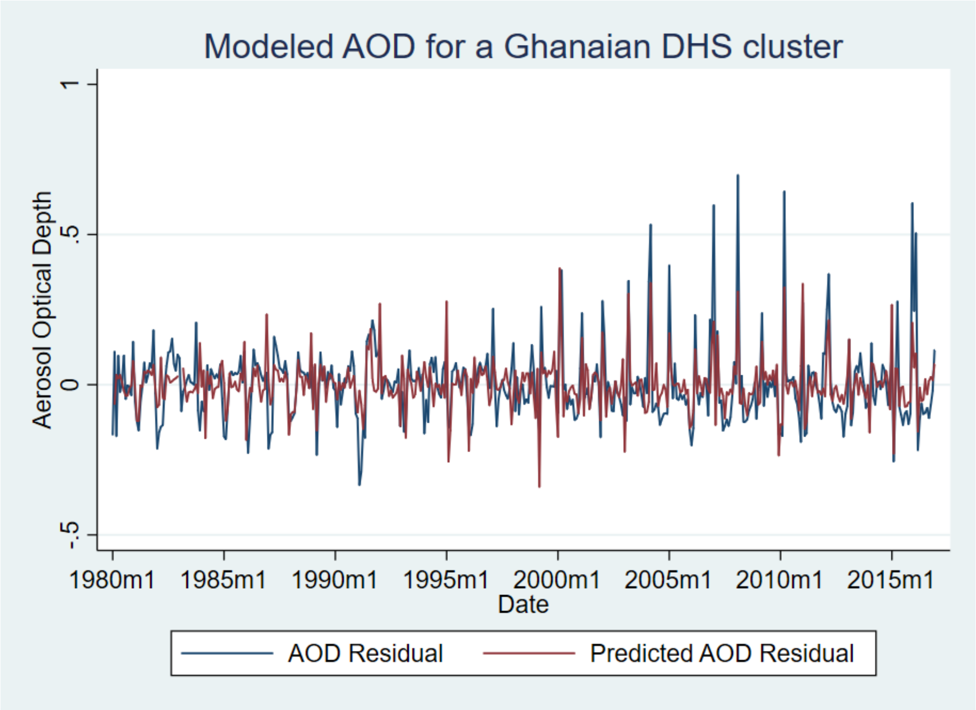

Figure 8: Predicted vs actual AOD for a single cluster, residualized by month and year fixed effects.

VARIABLES	(1) female	(2) female
AOD	-0.024	-0.057
	(0.071)	(0.143)
Observations	939,225	934,636
R-squared	0.013	0.013
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
climate controls	X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Impacts of dust on child sex ratio at birth, using AOD and predicted AOD.

VARIABLES	(1) surv	(2) surv
Urban x AOD	-0.183	
	(0.146)	
Rural x AOD	-0.139	
	(0.100)	
Poorest x AOD	0.0163	
	(0.115)	
Middle x AOD	-0.0604	
	(0.127)	
Richer x AOD	-0.285**	
	(0.143)	
Richest x AOD	-0.157	
	(0.168)	
Urban x pred AOD		-0.606***
		(0.225)
Rural x pred AOD		-0.371**
		(0.177)
Poorest x pred AOD		-0.0777
		(0.159)
Middle x pred AOD		0.0499
		(0.171)
Richer x pred AOD		-0.168
		(0.201)
Richest x pred AOD		0.0643
		(0.232)
Observations	518,978	517,967
R-squared	0.066	0.066
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
Climate controls	X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Impacts of dust on child survival by urban status and wealth quintile, using AOD and predicted AOD. The second quintile, “poorer” is the omitted category.

VARIABLES	(1) surv	(2) surv
AOD	-0.245**	-0.372**
	(0.0965)	(0.177)
Observations	360,589	359,766
R-squared	0.068	0.068
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Impacts of dust on child survival, using predicted AOD, controlling for the Palmer Drought Severity Index.

VARIABLES	(1) profdeliv	(2) hospital	(3) surv
Predicted AOD	0.668*	0.564*	-0.388
	(0.365)	(0.337)	(0.300)
Observations	91,877	91,877	91,877
R-squared	0.482	0.447	0.097
cluster FE	X	X	X
year FE	X	X	X
MOY FE	X	X	X
country-year trend	X	X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Impacts of dust on having help during child delivery, being born in a hospital, and child survival after controlling for having help during delivery.

VARIABLES	(1) Infant survival	(2) Infant survival	(3) Infant survival	(4) Infant survival
bin1 AOD		0.00170		0.00200
		(0.00140)		(0.00151)
bin3 AOD		-0.00159		-0.000848
		(0.00148)		(0.00154)
bin4 AOD		-0.00283*		-0.000647
		(0.00158)		(0.00174)
bin5 AOD		-0.00703***		-0.00441**
		(0.00152)		(0.00181)
AOD	-0.239***		-0.150***	
	(0.0453)		(0.0559)	
Observations	534,982	534,982	518,846	518,846
R-squared	0.047	0.047	0.048	0.048
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Impacts of dust on infant survival using OLS.

VARIABLES	(1) Infant survival	(2) Infant survival	(3) Infant survival	(4) Infant survival
bin1 AOD		0.00480***		0.00484***
		(0.00151)		(0.00162)
bin3 AOD		0.000382		0.00120
		(0.00138)		(0.00136)
bin4 AOD		-0.00366**		-0.00158
		(0.00155)		(0.00181)
bin5 AOD		-0.00641***		-0.00311
		(0.00164)		(0.00219)
AOD	-0.389***		-0.258**	
	(0.0730)		(0.125)	
Observations	533,972	533,972	517,836	517,836
R-squared	0.047	0.047	0.048	0.048
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Impacts of dust on infant survival using predicted AOD.

VARIABLES	(1) Neonatal survival	(2) Neonatal survival	(3) Neonatal survival	(4) Neonatal survival
bin1 AOD		0.00219**		0.00237**
		(0.000980)		(0.00107)
bin3 AOD		-0.00225**		-0.00200*
		(0.00114)		(0.00113)
bin4 AOD		-0.00289**		-0.00192
		(0.00118)		(0.00129)
bin5 AOD		-0.00568***		-0.00464***
		(0.00117)		(0.00134)
AOD	-0.204***		-0.158***	
	(0.0352)		(0.0424)	
Observations	534,982	534,982	518,846	518,846
R-squared	0.026	0.026	0.027	0.027
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 12: Impacts of dust on neonatal survival using OLS.

VARIABLES	(1) Neonatal survival	(2) Neonatal survival	(3) Neonatal survival	(4) Neonatal survival
bin1 AOD		0.00363***		0.00357***
		(0.00108)		(0.00115)
bin3 AOD		-0.000611		-0.000329
		(0.00106)		(0.00107)
bin4 AOD		-0.00340***		-0.00257*
		(0.00121)		(0.00143)
bin5 AOD		-0.00492***		-0.00302*
		(0.00125)		(0.00168)
AOD	-0.301***		-0.220**	
	(0.0553)		(0.0930)	
Observations	533,972	533,972	517,836	517,836
R-squared	0.026	0.026	0.027	0.027
cluster FE	X	X	X	X
year FE	X	X	X	X
MOY FE	X	X	X	X
country-year trend	X	X	X	X
Climate controls			X	X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Impacts of dust on neonatal survival using predicted AOD.

VARIABLES	(1) surv	(2) surv
AOD x post-2000	0.119	0.0156
	(0.119)	(0.113)
AOD	-0.427***	-0.242**
	(0.115)	(0.114)
Observations	534,982	518,846
R-squared	0.066	0.066
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
Climate controls		X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: Impacts of dust on child survival using predicted AOD.

VARIABLES	(1) surv	(2) surv
pred AOD x post-2000	-0.0661	-0.149
	(0.142)	(0.143)
Predicted AOD	-0.528***	-0.381**
	(0.137)	(0.171)
Observations	533,972	517,836
R-squared	0.066	0.066
cluster FE	X	X
year FE	X	X
MOY FE	X	X
country-year trend	X	X
Climate controls		X

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15: Impacts of dust on child survival using predicted AOD.