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The Epidemic Effect: Epidemics, Institutions and Human Capital Development*

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Abstract

Epidemics can negatively affect economic development unless they are mitigated by global governance institutions. We examine the effects of sudden exposure to epidemics on human capital outcomes using evidence from the African meningitis belt. Meningitis shocks reduce child health outcomes, particularly when the World Health Organization (WHO) does not declare an epidemic year. These effects are reversed when the WHO declares an epidemic year. Children born in meningitis shock areas in a year when an epidemic is declared are 10 percentage points (pp) less stunted and 8.2 pp less underweight than their peers born in non-epidemic years. We find evidence for the crowd-out of routine vaccination during epidemic years. We analyze data from World Bank projects and find evidence that an influx of health aid in response to WHO declarations may partly explain these reversals.

JEL classification: I12, I15, I18, H84, O12, O19

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1 Introduction

The virulence and human cost of recent epidemics have reignited policy debates on optimal strategies to mitigate the economic burden of infectious diseases. One of the most rigorously debated policies is providing aid funding or other forms of stimulus to areas affected by epidemics. How effective are these aid funding strategies in mitigating the negative effects of epidemics? The declaration of national epidemics for countries by global health governance organizations, which is based on certain thresholds of infectious disease cases, may trigger an influx of disaster aid and financing efforts that can improve human capital outcomes and reverse the negative effects of epidemics. Our work provides key insights into this epidemic effect.

In this study, we investigate the following: (i) how do epidemics of infectious disease affect human capital development? and (ii) what roles, if any, do global governance institutions play in mitigating these impacts? Exploiting exposure to meningitis shocks and epidemic years in the African meningitis belt, we assemble data on meningitis cases, epidemics, the flow of the World Bank's aid expenditure, and child health outcomes to investigate the effects of epidemics on human capital outcomes. The meningitis belt comprises approximately 23 African countries, extending from Senegal to Ethiopia, and over 700 million individuals frequently exposed to meningitis epidemics as shown in Figure 1a. The epidemic[1] form of meningitis is caused by the bacterium *Neisseria meningitidis* and is characterized by an infection of the meninges, which is the thin lining covering the brain and spinal cord. Direct transmission is through contact with respiratory droplets or throat secretions from infected individuals (LaForce et al., 2009; García-Pando et al., 2014). Infection is associated with

[1]Epidemics are defined in the sub-Saharan Africa context as greater than 100 cases per 100,000 population nationally within a year by the WHO (LaForce et al., 2009).

fevers, pain, and reduced cognitive function; in the worst cases, it can also lead to permanent disability and long-term neurological damage and death. Young children and adolescents are particularly at risk of infection, and epidemics can be very costly for households. Households in the belt spend up to 34% of per capita GDP on direct and indirect costs related to meningitis epidemics (Colombini et al., 2009).

We exploit quasi-random variation in district-level exposure to meningitis shocks and country-year variation in the announcement of an epidemic year to examine these effects within a panel regression framework. Our meningitis shock variable is constructed from a new dataset of mean weekly meningitis cases per 100,000 population for districts across eight countries in the belt between 1986 and 2008. The shock variable is an indicator that equals one if meningitis cases within a given year exceed the district's standardized long-term mean, following the definition of epidemics outlined by the World Health Organization (WHO, 2020)[2].

We examine the effects of meningitis shocks on child health outcomes, such as stunting or underweight status. The results on child health are economically important, given the vast literature linking child stunting and underweight status, both of which are primary markers of malnutrition, with poor cognitive and earnings outcomes in adulthood (Jayachandran and Pande, 2017; Bisset et al., 2013).[3] In other words, individuals who are shorter and underweight as children have worse health outcomes, lower cognitive ability and lower earnings as

[2]The WHO defines an epidemic as "the occurrence in a community or region of cases of an illness clearly in excess of normal expectancy. The number of cases indicating the presence of an epidemic varies according to the agent, size, and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence." (WHO, 2020).

[3]A child is considered stunted or underweight if she has a height-for-age or weight-for-age (measured by the height-for-age and weight-for-age z-scores) that is two standard deviations or more below the worldwide reference population median for her gender and age in months. Jayachandran and Pande (2017) provides a review of the literature showing a positive relationship between child height and adult height, with taller adults having 'greater cognitive skills, fewer functional impairments and higher earnings'. A recent literature has also linked underweight status in early childhood to poorer cognitive outcomes later in life (Bisset et al., 2013).

adults than their peers. The results show that meningitis shocks or high, unexpected levels of meningitis are associated with significant reductions in child health outcomes, reflected in increased incidence of stunting and underweight status, particularly during non-epidemic years. The effect of meningitis shocks on child health is nonlinear. Meningitis shocks increase child health outcomes during years declared by the WHO as epidemic years and reduce health outcomes during non-epidemic years. Children born in meningitis shock areas during a year declared as an epidemic year are 8.2 percentage points (pp) less underweight and 10 pp less stunted than their non-epidemic year born peers. Overall, being born in a meningitis shock district during a declared epidemic year reduces the incidence of being underweight by 4.1 pp, compared to an increase in the incidence of being underweight by 4.1 pp for children born in meningitis shock districts during non-epidemic years. Similarly, being born in a meningitis shock district during a declared epidemic year reduces the current incidence of being stunted by 5.6 pp, compared to an increase in the incidence of being stunted by 4.4 pp for children born in meningitis shock districts during non-epidemic years.

We find evidence for the crowd-out of routine vaccinations during declared epidemic years. On average, meningitis shocks are associated with an increase in total vaccinations, including routine childhood vaccines for tuberculosis (BCG), polio, diphtheria, pertussis and tetanus (DPT) and measles. We find heterogeneous effects, depending on whether the WHO declares an epidemic year. During a declared epidemic year, children born in meningitis shock districts experienced a 20% relative reduction in their total vaccinations received, and their peers born in shock districts during non-epidemic years experienced a 13% increase in total vaccinations received relative to the sample mean. While weight and height improve for children born in meningitis shock areas during declared epidemic years, routine vaccinations decline, as domestic and international organizations focus on meningitis vaccination in these areas. We conduct several robustness checks on our results, and provide evidence that selective migration does not appear to be driving our results.

We show that a primary mechanism explaining the heterogeneity in the results and the reversal of the negative effect of meningitis shocks on economic outcomes during declared epidemic years is the influx of health aid when the WHO announces an epidemic year, which may offset the negative income shock owing to increased costs resulting from meningitis shocks. We document an increase in World Bank health aid projects funded in meningitis shock districts during declared epidemic years. The funding epidemic effect is redistributive, with funds flowing away from non-health to health sector projects. The results suggest that global governance organizations, such as the WHO, play an important role in mitigating the adverse effects of epidemics, partly by coordinating decision-making and funding behavior of international agencies around the disbursement of health aid to affected regions.

We add to several distinct literatures. First, our work is related to the economics literature on the economic burden of infectious diseases and early life shocks (Acemoglu and Johnson, 2007; Adhvaryu et al., 2019; Almond, 2006; Bleakley, 2007; Bloom and Mahal, 1997; Dupas and Robinson, 2013; Adda, 2016; Rangel and Vogl, 2019; McDonald and Roberts, 2006; Maccini and Yang, 2009; Christensen et al., 2021). These studies have demonstrated that exposure to health shocks like infectious diseases in early life can affect various future life outcomes, including school enrollment, performance and attainment (Bleakley, 2007; Archibong and Annan, 2017; Fortson, 2011), gender inequality (Archibong and Annan, 2019), and labor market outcomes (Almond, 2006; Gould, Lavy, and Paserman, 2011; Bhalotra and Venkataramani, 2015). Recent literature has explicitly focused on epidemics and examined the effects of individual and coordinated government responses to epidemics on societal well-being (Fitzpatrick et al., 2021; Maffioli, 2021; Christensen et al., 2021; Xu, 2021). The studies have highlighted the importance of local accountability in health systems in managing epidemics like the 2014 Ebola epidemic (Christensen et al., 2021), and representation in government bureaucracies as a mitigating factor in reducing mortality during the 1918 pandemic (Xu, 2021). We expand the literature by providing quantitative esti-

mates of the economic impacts of epidemics and the role of global governance institutions in mitigating the adverse effects of epidemics through policy coordination.

Our work also contributes to the economics literature on the role of aid in development (Alesina and Dollar, 2000; Burnside and Dollar, 2000; Easterly, 2006; Nunn and Qian, 2014; Bräutigam and Knack, 2004; Deserrano, Nansamba, and Qian, 2020; Aldashev, Marini, and Verdier, 2019). Although some studies have found mixed results on the benefits of foreign aid for development (Burnside and Dollar, 2000; Moyo, 2009), a more recent literature has noted that health aid may have positive impacts on human capital outcomes, particularly in asset-constrained regions (Odokonyero et al., 2015; Kotsadam et al., 2018; Gyimah-Brempong, 2015; Miguel and Kremer, 2004; Bandiera et al., 2019; Ndikumana and Pickbourn, 2017; Mishra and Newhouse, 2009). These studies have highlighted heightened incentives of domestic governments to comply with donor agencies regarding aid in the public health sector (Dietrich, 2011). Our study provides quantitative evidence on the positive effects of health aid in reversing the negative effects of epidemics, wherein aid increases in response to epidemic announcements.

The rest of the paper is organized as follows. Section 2 provides a brief background on infectious disease epidemiology and associated costs, with a focus on meningitis epidemics. Section 3 describes the data. Section 4 outlines our empirical strategy and presents results on the effects of meningitis epidemics on human capital development outcomes. Section 5 provides quantitative estimates on the role of World Bank aid as a potential mechanism that explains the results. Section 6 concludes.

2 Epidemiology and Costs of Epidemics: Evidence from the Meningitis Belt

The WHO defines an epidemic as "the occurrence in a community or region of cases of an illness clearly in excess of normal expectancy. The number of cases indicating the presence of an epidemic varies according to the agent, size, and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence." (WHO, 2020). This definition allows us to distinguish locally defined disease shocks or "local epidemics" from officially designated national epidemics by the WHO.

This study examines meningitis epidemics in the African meningitis belt (Figure 1a).[4] Meningococcal meningitis is endemic in sub-Saharan Africa. The WHO estimates that approximately 30,000 cases of the disease are reported annually, with figures rising sharply in regions during epidemic years.[5] While cases of meningitis may vary significantly within a country, national epidemics are declared by the WHO only when the national average incidence of meningitis exceeds 100 cases per 100,000 population in a country (de Onis, 2006).

The disease can lead to high mortality rates of up to 50% if untreated.[6] Vaccines have been introduced to combat the spread of the disease since the first recorded cases in 1909 in sub-Saharan Africa. However, the efficacy of vaccines has been constrained because of the bacterium's mutation and virulence tendencies (LaForce et al., 2009).[7] The periodicity of

[4]The WHO lists 26 countries in total as being at risk for meningitis epidemics, including Burundi, Rwanda and Tanzania (WHO, 2018).

[5]Source: http://www.who.int/mediacentre/factsheets/fs141/en/

[6]http://www.who.int/mediacentre/factsheets/fs141/en/

[7]The most recent vaccine MenAfriVac has been available in meningitis belt countries since 2010 and has been found to be effective against serogroup A, the strain of the bacterium most frequently associated with epidemics in the belt (Karachaliou et al., 2015). There has been a reduction in serogroup A cases in many countries since the introduction of the vaccine with the vaccine hailed as a success. Concerns have been raised about waning herd immunity over the next decade especially if the vaccine does not become part of routine childhood vaccinations; and an increase in serogroup C cases has been observed in other regions more

epidemics in the belt differs by country, with epidemic waves in the meningitis belt occurring every 8 to 12 years on average by some estimates (Yaka et al., 2008). Young children and adolescents are especially at risk of infection (Archibong and Annan, 2017).

The epidemiology of the disease is complex.[8] Direct transmission is through contact with respiratory droplets or throat secretions from infected individuals (LaForce et al., 2009; García-Pando et al., 2014). The bacteria can be carried in the throat of healthy human beings, and, for reasons not completely understood, suppress the body's immune system, thereby facilitating the spread of infection through the bloodstream to the brain following a 3-7 day incubation period (Basta et al., 2018; WHO, 2018).[9]

2.1 Costs and Policy Responses to Epidemics

Meningitis epidemics are a notable negative income shock to households in the belt. Documented data on countries' health expenditure in the meningitis belt show that households spend a significant portion of their incomes on direct and indirect costs resulting from meningitis epidemics (Colombini et al., 2009). In Burkina Faso, a country in the meningitis belt, households spent approximately $90 per meningitis case- 34% of per capita GDP- in direct medical and indirect costs from meningitis infections during the 2006-2007 epidemic (Colombini et al., 2009). In households affected by sequelae, costs increased to $154 per case. Costs were associated with direct medical expenses, which included spending on prescriptions and medicines[10], and indirect costs from loss of caregiver income (up to 9 days of lost work), loss of infected person income (up to 21 days of lost work), and missed school (12 days of missed

recently, prompting concerns about more epidemics from other serogroups of the bacterium (Karachaliou et al., 2015). Currently, no vaccine prevents all serogroups of *Neisseria meningitidis* (Yezli et al., 2016).

[8]Meningitis epidemics are similar to the COVID-19 pandemic as they spread through contact with infected individuals' respiratory droplets or throat secretions. A significant difference is that a virus causes COVID-19, whereas a bacterium causes meningitis epidemics.

[9]The WHO estimates that between 10% and 20% of the population carries *Neisseria meningitidis* in their throat at any given time, with carriage rate spiking in epidemic years (WHO, 2018).

[10]Vaccines and treatment are technically free during epidemics. However, information asymmetry among healthcare workers and a shortage of medicine often raise the price of medications (Colombini et al., 2009).

school) (Colombini et al., 2009).

In its 1998 report on meningococcal meningitis, the WHO recommended several government responses to meningitis epidemics (WHO, 1998). These include developing crisis committees with groups, such as the Ministry of Health and the WHO, to manage epidemic responses, such as information dissemination to the general public, mass national vaccination campaigns for the disease, and disbursement of funds for health projects and antimicrobial drugs for treatment[11] (WHO, 1998). The costs of full antibacterial therapy treatment for bacterial meningitis ranged from just under $10 to over $250 (WHO, 1998). The demand for the disbursement of funds for health projects and medicines during epidemics is crucial for countries in the meningitis belt given that, not only are meningitis epidemics very costly for households, governments in the meningitis belt spend relatively little on per capita health spending (Abubakar et al., 2022). The World Bank estimates that, as of 2017, government spending was 23% of the total health spending for countries in the meningitis belt; this figure was lower than the average within Africa (35%) and the worldwide average (60%).

Additionally, out of pocket spending as a share of health expenditure for countries in the meningitis belt was among the highest in the world at 47%, compared with 37% within Africa and 18% globally. A key feature of health spending in meningitis belt and African countries is the high share of health spending from external, donor sources. External spending on health accounts for 23% of the health spending in meningitis belt countries, which is significantly more than the global average (0.2%) and roughly equal to the Africa average (20%). Considering the high share of health spending from donor sources and the recommended policy response of disbursement of funds for health projects during epidemics, international aid has historically featured as a significant part of mitigating the adverse effects of epidemics in the region (Benton and Dionne, 2015).

[11] Unlike the COVID-19 pandemic, during meningitis epidemics, there were no recommendations for physical distancing or lockdown.

3 Description of Data: Child Health and World Bank Aid

We combine data from multiple sources for eight countries in the meningitis belt where data on meningitis cases and child health outcomes were available: Benin, Burkina Faso, Cameroon, Ghana, Mali, Nigeria, Niger and Togo (Figure 1b). Further details on the data are provided in the proceeding sections and summarized in Table 1.

3.1 Meningitis Cases

We assemble district-level records of mean weekly meningitis cases per 100,000 population from the WHO between 1986 and 2008 for eight sub-Saharan African meningitis belt countries with available data (Figure 1b).[12] The WHO data span several countries. The WHO collaborates with various health ministries to collect survey data from local facilities and minimize the probability that any error in measuring health information would be systematically correlated with other outcomes within and across country partners (de Onis, 2006).

As mentioned in Section 2, the who declares epidemic years of meningitis when the national average incidence of meningitis exceeds 100 cases per 100,000 population. Table 1 shows that the average weekly cases per year were approximately 4 meningitis cases per 100,000 for the district/years in the entire study sample, with significant variability both across and within countries and years (Figure A1). Following the WHO's definition of epidemics as "cases of an illness clearly in excess of normal expectancy," we define a "local" epidemic, meningitis shock, variable, as a measure of the "outside-of-normal expectancy" meningitis events at the district level. The meningitis shock variable is an indicator that takes on a value equal to 1 if meningitis cases in a given year exceed the district's standardized

[12] The WHO data are available primarily at the district level. District-level weekly cases of meningitis case per 100,000 population are available from 1995 to 1999 for 28 districts in Benin, 1996 to 1999 for 30 districts in Burkina Faso, 1997 to 1998 for 10 districts in Cameroon, 1996 to 1998 for 138 districts in Ghana, 1989 to 1998 for 80 districts in Mali, 1986 to 2008 for 34 districts in Niger, 1995 to 1997 for 116 districts in Nigeria and 1990 to 1997 for 59 districts in Togo (Figure A1). These comprise a dataset of district-level meningitis cases in 495 districts across 8 countries.

long-term mean. In other words, the meningitis shock variable equals 1 if the z-score relative to the district's long-term mean of weekly meningitis cases per 100,000 population is greater than 0. 30% of districts in the sample are classified as meningitis shock districts following this definition as shown in Table 1. We provide further details on the specification of the meningitis shock variable in Section 4.

3.2 Child Health

We use geocoded data from the birth recode (BR) of the Demographic and Health Surveys (DHS) for various years for the eight study countries to examine the effects of epidemics on child health outcomes. The DHS data are nationally representative cross-sectional household surveys that provide information on the demographic characteristics of individuals within households. For the BR sample, women aged 15-49 years are individually interviewed to gather information on every child ever born to the woman. For each woman interviewed, the BR has one record for every birth.[13]

The DHS data contains information on child anthropometric outcomes, including the weight for age z-score (WFA z) and height for age z-score (HFA z), vaccinations, and mortality status (i.e., whether a child is alive or dead and age at death if dead) for births within the past five years at the time of each survey. Combined with the district-level meningitis record, this information provides a dataset of nationally representative individual-level data of births from 1992 to 2014, covering 14 DHS surveys across the eight study countries.[14]

The WFA z and HFA z reflect factors that may affect a child's health in utero, at birth, and after birth. High values are generally associated with favorable health conditions

[13]The BR of the DHS, including important geocoded information on the location of households or household clusters, is available for 1996, 2001 and 2012 for Benin; 1999, 2003 and 2010 DHS for Burkina Faso; 2004 and 2011 DHS for Cameroon; 1998, 2003, 2008 and 2014 DHS for Ghana; 1996, 2001, 2006 and 2012 DHS for Mali; 1992 and 1998 DHS for Niger; 2003, 2008 and 2013 for Nigeria; and 1998 and 2013 for Togo.

[14]The final dataset contains data on combined meningitis cases and DHS outcomes for children born between 1986 and 1999.

(Jayachandran and Pande, 2017). A child is considered underweight with a WFA z of less than -2.0; a child is considered stunted with an HFA z of less than -2.0. In the sample, 38% of children are underweight, and 36% are stunted. Finally, we examine child vaccination rates for routine vaccines. We collect available information on BCG (tuberculosis), polio, DPT (diphtheria, pertussis and tetanus), and measles vaccinations and the total of all vaccinations.[15] A key feature of these routine vaccines is that they are offered free of charge in many low-income countries, such as the countries considered in our sample. Thus, the direct costs are often null. However, households may face other indirect costs, such as insufficient supply or transportation costs involved in procuring the vaccines (Bobo et al., 2022). 61% and 42% percent of children in the sample received BCG and measles vaccinations, respectively. The average total number of vaccines received by children in the sample was 3.83 out of a maximum of 8 vaccines (Table 1). Notably, the recommended schedule for routine vaccinations of children as per the WHO standards is the BCG and first dose of polio at birth (Table A1). The recommendation for DPT is near birth (first dose at 6 weeks). This recommendation contrasts with the recommendation for measles, which may be taken much later after birth (at nine months) (WHO, 2019).

3.3 World Bank Aid Data

We use geocoded data on World Bank-funded projects in the International Bank for Reconstruction and Development (IBRD) and International Development Association (IDA) lending lines by sectors from AidData (AidData, 2017) to examine the relationship between WHO epidemic announcements and disaster aid. This dataset is the only publicly available micro-level dataset on aid projects for our study region. The World Bank is a major donor in the Africa region, and was the top donor in Nigeria- the most populous country in the continent- between 2000 and 2014, funding 31% of recorded aid projects in the country. The second- and third-ranked donors in Nigeria were the Bill and Melinda Gates Foundation

[15] There is no information on meningitis vaccination rates in the DHS.

(20% of aid projects) and the European Commission (10%) over the same period (AidData, 2017).[16] The World Bank aid data contain the location and sectors of World Bank-funded projects between 1995 and 2014, as shown in Figure 1c. Projects are classified by the World Bank as belonging to up to five sectors: health, central government administration, general public administration, other social services, railways, and roads and highways. The amount of "aid" or loans and grants (in 2011 USD) committed and disbursed for each project is also reported. To match the duration of our meningitis case data, we limit our sample to the subset of projects approved between 1995 and 2008. Summary statistics in Table 1 show that while, on average, approximately $56 million was committed to projects approved during our study years, only 12% were health projects. We define a project as belonging to the health sector if any one of its five sector categories corresponds to health. The average duration of these projects was approximately six years.

4 Epidemics and Human Capital Development

4.1 Meningitis Shocks and Human Capital Development

We can examine the effects of meningitis shocks on child health outcomes by estimating the following equation:

$$y_{idctr} = \alpha \text{Menin. Shock}_{dct} + \mathbf{X}'_{idctr}\theta + \mu_d + \eta_t + \eta_r + \phi_d r + \epsilon_{idctr} \tag{1}$$

where y_{idctr} is the outcome of interest (weight, height and vaccination outcomes in Section 3) for child i born in district d in country c at time t, whose health outcomes are registered in survey-year round r. Our main measure of meningitis shocks is "Menin. Shock"

[16] We explore the effects of epidemic declarations on official development assistance (ODA) aid from the Organisation for Economic Co-Operation (OECD) at the country level for 20 countries in the meningitis belt from 1995 to 2008 in Appendix A.4.

or "Meningitis Shock", which is an indicator that equals 1 if a district's meningitis caseload z-score, or deviation from the district's long-run average of mean weekly meningitis cases per 100,000 population, is greater than 0. In practice, we explore two constructions for "Menin. Shock": the indicator reflecting strictly positive deviations from the district level long-run mean, and another using the continuous z-score measure. We present the results from the indicator specification in the main text. We also discuss results from robustness checks for marginal changes in the shock measure cutoff, and using the continuous z-score measure.

This specification includes a set of unrestricted within-country district dummies, denoted by μ_d, which capture unobserved differences that are fixed across districts. We also include year of birth fixed effects to account for potential life cycle changes across cohorts. Equation 1 includes district-specific trends, $\phi_d r$ that allow our "Meningitis Shock" and non-shock districts to follow different trends that may relate to factors like differences in internal migration patterns that could affect disease transmission.[17] The child health regressions also include controls for the mother's age at birth and level of education, $\mathbf{X}'_{idctr}$. Errors are clustered at the district level to allow for arbitrary correlations.[18] In alternate specifications, we estimate Equation 1 using country-by-year fixed effects to control for aggregate changes that are common across countries over time, e.g. aggregate prices, and national policies. The results are robust to alternate specifications, and we present the results from our main model with district-specific trends in the text. We provide further evidence for inference robustness in Section 4.2.

4.1.1 Design and Validity Checks

The intuition behind defining meningitis shock as in Equation 1, as stated previously, follows the WHO definition of an epidemic, such that an individual district may be experiencing

[17] This specification is widely used in the health economics literature, following (Maccini and Yang, 2009).

[18] We estimate all models with standard errors clustered at the district level and Conley standard errors with a cutoff window of 100 km to account for spatial autocorrelation (Conley, 1999).

epidemic levels of meningitis cases relative to its expectation, but the national average does not rise to the level that the WHO declares a country-wide epidemic. A notable feature of our shock measure is that there is significant variation in meningitis cases within country-districts, with no apparent trends in meningitis cases. Districts switch quasi-randomly between being meningitis shock or non-shock districts from year to year, and there are no districts that are only shock or only non-shock districts over the years of study.

Our OLS framework in Equation 1 requires an important identifying assumption:

$$E(\text{Meningitis Shock}_{dt} \times \epsilon_{dtr} | \mu_d, \eta_{(t,r)}, \phi_d r) = 0$$

In words, this says within a country, conditional on the time trends, year and district fixed effects (and other observed district characteristics), the meningitis shock term must be orthogonal to the random error term, ϵ_{dtr}. We conduct the following placebo tests to evaluate the plausibility of this assumption.

I. Balance Tests: Do relevant demographic and geographic factors vary evenly between meningitis shock and non-shock districts? That is, are individuals that are located in meningitis shock districts an appropriate counterfactual for those located in non-shock districts? To test this, we first estimate simple regressions of the relationship between meningitis shocks and the individual demographic characteristics, $\mathbf{X}'_{idctr}$, of mothers in the districts. In other words, we estimate Equation 1 using $\mathbf{X}'_{idctr}$ as our outcome to see if mothers' characteristics differ significantly in meningitis shock and non-shock districts. The results in Table A2 of Appendix A.1 show no significant differences between the educational attainment and age at birth of mothers in meningitis shock and non-shock districts. To assess if time-varying geographic characteristics like precipitation, temperature and dust concentration[19] differ sig-

[19]These variables have been linked to meningitis incidence in previous studies (Yaka et al., 2008).

nificantly in meningitis shock and non-shock districts, we estimate Equation 1 using these geographic characteristics as the outcome. The results in Table A3 of Appendix A.1 show no notable differences in the time-varying geographic characteristics between shock and non-shock districts.

Additionally, we estimate simple regressions of the likelihood of being a meningitis shock district, measured as our meningitis shock variable averaged over the years of available data for each district in each country, on several geographic, weather, and institutional characteristics for each district. We show balance across a number of geographic, weather and institutional characteristics of the meningitis shock measure in Table A4 in Appendix A.1, and the results in Table A4 show no observable differences in outcomes across districts that experienced more meningitis shocks between 1986 and 2008 and those that did not. We show that the results are robust to a number of falsification and inference tests, providing further suggestive evidence of the effects of the meningitis shock measure in Section 4.3.

4.1.2 Mechanisms: The Role of WHO Epidemic Year Announcements

As discussed in Section 2, meningitis epidemics are very costly for households in the African meningitis belt. While meningitis cases may vary widely within a country, the WHO declares a national epidemic only when the number of meningitis cases passes a certain threshold namely, 100 cases per 100,000 population within a country in a particular year. Once the threshold is passed, the primary policy responses recommended by the WHO, as discussed in Section 2.1, include mass national vaccination campaigns for the disease and disbursing funds for health projects and antimicrobial drugs for treatment. Countries in the meningitis belt, and African countries in general, also rely relatively heavily on external donor sources for health spending as mentioned in Section 2.1. Hence, one hypothesis is that a main channel that may modulate the effects of meningitis shocks on child health outcomes is through the WHO announcement of a national epidemic, which could trigger policy responses in the form

of mass vaccination campaigns and disbursement of funds to affected regions. To test this hypothesis, that the effects of meningitis shocks on child health outcomes may be mediated by WHO announcements of national epidemic years, we estimate Equation 2 below:

$$y_{idctr} = \alpha \text{Menin. Shock}_{dct} + \beta \text{Epidemic Year}_{ct} + \gamma \underbrace{\text{Menin. Shock}_{dct} \times \text{Epidemic Year}_{ct}} + \mathbf{X}'_{idctr}\theta + \mu_d + \eta_t + \eta_r + \phi_d r + \epsilon_{idctr} \tag{2}$$

where "Epidemic Year" is an indicator that equals 1 if the WHO declares an epidemic year in country c and year t, following the aforementioned threshold rule. Our key parameter of interest γ provides a statistical test of the difference in child health outcomes in meningitis shock and non-shock districts in WHO announced epidemic years versus non-epidemic years. This provides an estimate of the "epidemic effect," that is, how global policy responses may mediate the effects of meningitis epidemics on human capital development outcomes. To fully explore this "epidemic effect," we focus on presenting the results from Equation 2 in this study, with the results outlined in Section 4.2.

4.2 OLS Estimates

Figure 2 shows the density distributions for two primary child health outcomes: the weight for age z-scores (WFA z) and height for age z-scores (HFA z) by the meningitis shock indicator measure. It indicates slight stochastic dominance in non-shock districts, where child WFA z and HFA z are higher in non-shock districts than in meningitis shock districts. The patterns in the raw data are replicated in Figure 3, which depicts the average share of stunted and underweight children, along with the average total vaccination received by children and infant mortality in meningitis shock and non-shock districts for children born between 1986 and 1999. The figure also shows the declared epidemic years across all countries in the

study sample.[20] In 8 out of 12 years or 67% of the years in the sample, for which complete data is available, meningitis shock districts have a higher share of stunted children than non-shock districts. The pattern for the share of underweight children is similar; the share of underweight children is higher in meningitis shock districts than in non-shock districts in 58% of the sampled years. In most years of available data, patterns in the raw data show that children born in meningitis shock districts are more likely to be stunted and underweight than those born in non-shock districts. Conversely, the average number of vaccinations received by children was higher in meningitis shock districts thank in non-shock districts in 83% of the sampled years. The pattern in the raw data for infant mortality is the least pronounced of the child health outcomes, with a higher share of children born who die within a year in meningitis shock districts than in non-shock districts in 54% of the sampled years.[21]

Table 2 presents the OLS estimates of the effects of meningitis shocks on these child health outcomes, following the specification in Equation 1. The results are robust to a number of different specifications, including controlling for the yearly level of economic activity in a district using night light density as shown in columns (2), (4) and (8) of Table 2.[22] The estimates in columns (1) to (6) of Panel A on child height and weight outcomes, are qualitatively similar to the depictions in Figure 2 and Figure 3. Meningitis shocks, on average, are negatively associated with child height and weight, and conversely, positively associated with child stunting and underweight status; the estimates are economically large, though imprecisely measured. There is no effect of meningitis shocks on infant mortality in column

[20]Epidemic year announcements differ at the country level as shown in Figure A1 in the Appendix. For example, Niger, which accounts for 35% of the sample, had 4 declared epidemic years between 1987 and 1999, from 1993-1996. Nigeria, the most populous African country, had just one declared epidemic year in 1996 over 3 years of available data from 1995-1997.

[21]These patterns are summarized in Figure A2 in Appendix A.1 which shows that child stunting and underweight levels and total vaccinations are higher on average in meningitis shock districts than in non-shock districts.

[22]Further discussion of the night light density measure is provided in Appendix A.3, and all outcomes are robust to the night light density measure as shown in Table A5 and Table A6 in the Appendix. The results with night light density should be interpreted with caution, since economic activity is plausibly an outcome of meningitis shocks as we discuss in Section 4.4 and Appendix A.3.

(7) of Panel A, following the specification in Equation 1. Columns (1) to (8) of Panel B of Table 2 report estimates for child immunization outcomes, classified by immunization recommended at or near birth (BCG, polio, DPT) versus immunizations recommended much later following birth (measles) as discussed in Section 3. For routine vaccinations, the results show significant positive effects of meningitis shocks on BCG, DPT and the number of polio vaccination doses (i.e. at or near birth), with positive but insignificant signs for measles or non-at/near birth vaccinations. On average, a child born in a meningitis shock district is more likely to be completely vaccinated than their peers born in a non-shock district, as shown in column (7) of Panel B of Table 2. The size of the effect is a relative increase of 0.21 vaccinations for children born in meningitis shock districts, equivalent to a 5.7% increase relative to the sample mean.

We investigate how the WHO announcements of national epidemic years mediate the effects of meningitis shocks on child health outcomes by estimating Equation 2 and examining heterogeneity in the effects of meningitis shocks on child health by WHO epidemic year declarations. The results are shown in Table 3. Children born in meningitis shock districts during a declared epidemic year are taller (column (5) of Panel A) and weigh more (columns (1) and (2) of Panel A) than their peers born in meningitis shock districts during non-epidemic years. Children born in meningitis shock districts during a declared epidemic year are 8.2 percentage points (pp) less underweight (column (3)) and 10 pp less stunted (column (6)) than their meningitis shock, non-epidemic year-born peers. Overall, being born in a meningitis shock district during a declared epidemic year reduces the current incidence of being underweight by 4.1 pp, versus an increase in the incidence of being underweight by 4.1 pp for children born in meningitis shock districts in years non-epidemic declared years. The total effect is equivalent to a 4.1 pp and 5.6 pp reduction in the current incidence of being underweight and stunted respectively for children born in meningitis shock districts in declared epidemic years. The epidemic year coefficient itself is positive and significant for

the child stunting and underweight outcomes, reflecting the aggregate negative shock effects of epidemics.

Panel B of Table 3 reports the estimates for child immunization outcomes. For routine vaccinations, the results show significant negative effects of meningitis shocks in declared epidemic years on BCG, DPT, and the number of polio doses (i.e., at or near birth) vaccinations, with the signs negative but not significant for measles or non-at/near birth vaccinations. A child born in a meningitis shock district during a declared epidemic year is less likely to be completely vaccinated than her peers born in a meningitis shock district during a non-epidemic year, as shown in columns (7) and (8) of Panel B. The size of the effect is a relative reduction of 0.72 vaccinations (column (7)), or a total reduction of approximately 0.24 vaccines for children born in meningitis shock districts during declared epidemic years, equivalent to a 20% and 6.5% reduction, respectively, relative to the sample mean. The results were reversed for children born in meningitis shock districts during non-epidemic years, who experienced an increase in total vaccinations of up to 0.48 vaccines, or a 13% increase in total vaccinations received relative to their epidemic year-born peers. Our results show that the meningitis shock and epidemic effects are particularly robust for vaccines that should be administered at or close to the time of birth (Deserrano, Nansamba, and Qian, 2020; Boone, 1996; Bräutigam and Knack, 2004).

4.3 Inference Robustness

We conduct several inference tests to assess if the results are robust to (i) the continuous z-score measure of meningitis shocks and (ii) marginal changes in the meningitis shock indicator cutoff for $z \in (0, 1]$. The results are robust to using the continuous measure and marginal changes in the meningitis shock indicator cutoff, and the estimates are largely stable as shown in Table A7, Table A8, Table A9 and Table A10 of Appendix A.1 and summarized in Figure 4. As discussed in section 3, just 30% of districts are classified as meningitis shock

districts under our main indicator shock measure. As we increase the meningitis shock indicator cutoff, the share of shock districts in the sample declines, falling to only 15% of districts at the $z > 1$ indicator cutoff. The estimates are robust to marginal changes in the meningitis shock indicator cutoff up to the $z > 1$ cutoff, at which point, the coefficients become less precisely estimated with the loss in statistical power, although the magnitudes of the estimates remain largely stable. The results are also robust to using the continuous z-score measure instead of the indicator specification of meningitis shocks as shown in Table A7 and Figure 4. We also estimate the main results with alternative specifications, replacing time trends with country-by-year fixed effects, adding country-year fixed effects and estimating separate district and year fixed effects in Equation 1 and Equation 2. The results are robust to alternative specifications as shown in Tables A11- A16 of Appendix A.1.

We also conduct several placebo tests, including an indicator for the epidemic years 2 and 3 years following the child's year of birth to test the sensitivity of our results to arbitrary changes in the epidemic year designation. We use the 2 and 3-year leads, and not the 1 year lead, given the positive correlation between the epidemic year indicator in concurrent year t and the following year t+1 (arising from the fact that some countries may experience consecutive epidemics). The results show that both the meningitis shock and meningitis shock x epidemic year interactions are not significant, using the 2 and 3-year leads as shown in Table 4. In Table A17 of Appendix A.1, we change the epidemic year cutoff, to examine the sensitivity of the results to changes in the definition of the epidemic year. The meningitis shock x epidemic year interaction, using low numbers (< 20 per 100,000 pop.) of meningitis cases nationally to define the epidemic year, is insignificant with an example shown in Table A17. The results in Table 4 and Table A17 show no significant effects of erroneous epidemic year designations on our child health outcomes.

Inference for our main analyses is based on the robust cluster (i.e., district) estimator,

which allows for arbitrary correlations at the district-level, our main level of analysis for the meningitis shock assignment. Following the recent literature on inference robustness (Abadie et al., 2017; Bertrand, Duflo, and Mullainathan, 2004), we test the sensitivity of the results to alternative inference procedures, that account for the panel structure of the data, over districts and time. In particular, we report additional standard errors using (i) two-way clustering (i.e., district and time) which accounts for the possibility that errors may be either spatially or serially correlated, and (ii) Conley standard errors with a cutoff window of 100 km to account for spatial autocorrelation. Overall, the baseline results on inference show robustness to different procedures, with the results summarized in Table A18 of Appendix A.1.

4.4 Channels

What explains the varying results on the average effects of meningitis shocks on child health outcomes and the heterogeneity in these effects by WHO epidemic year announcements in Section 4.2? Meningitis shocks are significant negative income shocks for households, as documented in previous literature. We provide suggestive evidence of reduced economic activity in meningitis shock districts in Table A22 of Appendix A.3. Following the literature using night light density as a proxy for economic activity (Henderson, Storeygard, and Weil, 2011; Michalopoulos and Papaioannou, 2013), we use data on night light density from the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Since a notable fraction of the district level observations take on the value of zero, following previous literature, we use the log of night light density, adding a small number (ln (0.01+ Light Density)) as our measure of night light density (Michalopoulos and Papaioannou, 2013).[23] The results from

[23] We outline the methods used in detail in Appendix A.3.

the night light density analysis suggest economically significant effects of meningitis shocks on night light density. On average, meningitis shocks reduce economic activity by around 6%. Meningitis shocks increase economic activity by around 17.1% in epidemic years, and reduce economic activity by 14.2% in non-epidemic years. Lowered household budgets may leave less income for food and other necessities necessary for proper nutrition, resulting in malnutrition, which is subsequently reflected in the form of stunted growth and underweight status of children in meningitis shock districts.

While there are more stunted and underweight children in meningitis shock districts, these children receive more vaccinations than their peers in non-shock districts. One explanation for this phenomenon comes from the public health literature on the drivers of routine child vaccinations, particularly in lower and lower middle income countries (LIC), similar to the countries in our sample (Bobo et al., 2022). As mentioned in Section 3.2, a key feature of these routine vaccines, is that they are often offered free of charge in LIC countries, so the direct costs are usually null. However, households may face other indirect costs, such as insufficient supply or transportation costs involved in procuring vaccines (Bobo et al., 2022). The parental demand for these vaccines often acts as a significant barrier to child vaccination, either because of higher transport costs to procure the vaccines or general hesitancy of parents in these settings to take up these vaccines for their children, due, for example, to past negative experiences with health institutions (Archibong and Annan, 2021). However, when districts are experiencing a local epidemic, or meningitis shock, poor households may be more motivated to consider free immunization for their children as the least cost medication available to them, which may explain the higher levels of routine vaccinations in meningitis shock districts.

While there is a paucity of detailed data on household income in the study region, we can test this hypothesis around the differing income effects of meningitis shocks on child

health outcomes using asset ownership data from the DHS. Using data on assets from the DHS, we construct a wealth index based on principal components analysis scores. We define liquidity or asset constrained households as those located in the lower parts of the asset distribution.[24] Lower wealth households, with wealth in lower than the third quintile of the wealth distribution, feature largely in the dataset, constituting approximately 43% of the sample on average. The results in Table 5 provide suggestive evidence that both the negative effects of meningitis shocks on child height and weight and the positive effects of shocks on vaccination are concentrated among poorer or more asset-constrained, lower wealth households, in line with the aforementioned hypotheses.

Meningitis shocks further worsen child height and weight outcomes for children from lower wealth households, thereby heightening the likelihood of being underweight and stunted by 4.9 pp and 3.8 pp, respectively, and increasing the likelihood of infant mortality by 3.8 pp among children in lower wealth households relative to their lower wealth peers in non-shock districts, as shown in Panel A of Table 5. The vaccination results in Panel B of Table 5 also show that while poorer households in non-shock districts are much less likely to vaccinate their children, consistent with previous studies on the links between income and vaccination (Bobo et al., 2022), poorer households in meningitis shock districts are more likely to vaccinate their children, which is in line with our "seeking out free/least cost medication during a local epidemic" hypothesis. Children in lower wealth households born during meningitis shocks received 0.21 more total routine childhood vaccines or 5.4% more total vaccines relative to the sample mean compared with their lower wealth peers born in non-shock districts.

To what extent does migration rationalize our results? We investigate the possibility

[24]Specifically, we conduct a wealth quintile index from 10 assets, with details provided in the Appendix, and defined asset-constrained or lower wealth households as households situated in lower than the third quintile of wealth. The analysis assumes stationarity in the wealth status of women's households and the results should be interpreted with caution here.

that unhealthy individuals (e.g., with low WFA z or low HFA z) might have moved from areas affected by meningitis to unaffected areas, and consequently, unaffected areas experience low economic outcomes relative to the affected areas. The dual, though prima facie less plausible, statement is that more "healthy" individuals might have moved from areas unaffected by meningitis to the affected areas and as result, unaffected areas experience low economic outcomes. Thus, instead of assuming limited (selective) internal migration between districts for identification, we relax this assumption and examine it as an alternative explanation for our results in Appendix A.2. Although there is no detailed data on internal migration in our context, available evidence suggests that migration is limited in the study region, with just 9% of the population reporting changing their place of residence between 1988 and 1992 (Bocquier and Traoré, 1998). In Appendix A.2.2, we conduct trimming exercises, to test that selective migration is not a driver of the results. For these exercises, described in detail in Appendix A.2.2, we begin with the supposition that migration is indeed selective, and then ask "what level of such selective migration would be needed to make our results insignificant?". We reclassify the districts as either meningitis affected (if the observed meningitis cases are above the sample average) or unaffected (if the observed meningitis cases are below the sample average) year to year. We then trim the outcomes using different migration rates in increments of 5%. That is, we recursively drop the top 5%, 10%, 15%, ... of the data with the highest outcomes- reflecting the most healthy individuals- only in the meningitis affected districts. In each step, we re-estimate our baseline model, and continue the process until the effects for our main interaction term,"Meningitis shock x Epidemic year", become insignificant. Our trimming exercise results in Figure A3 suggest that migration would have to, differentially, rise by at least 55% to explain the results, which is very unlikely given the available aforementioned empirical evidence. The results are consistent with other papers showing a lack of selective migration in developing country settings (Bazzi et al., 2016).

What explains the reversal in the effects of meningitis shocks on child health outcomes

during WHO declared national epidemic years, or the epidemic effect? Although there are multiple possible mechanisms that may explain these reversals, one key channel comes from the policy recommendations of the WHO described in Section 2.1, which highlights responses, such as mass national vaccination campaigns for the disease and disbursement of funds for health projects and antimicrobial drugs for treatment during declared epidemic years. The inflow of health aid to affected regions during declared epidemic years may significantly offset the negative income effects of the meningitis shock on child weight and height outcomes in a setting where 23% of health funding comes from external, donor sources, among a largely poor, asset constrained population. Conversely, targeted mass national vaccination campaigns for meningitis during declared epidemic years may crowd-out routine vaccinations either through reduced demand from parents or caregivers as households forgo routine vaccination in favor of the provided meningitis vaccination or through the supply side, as donor aid focused on epidemic response redirects skilled health workers from routine immunization to epidemic treatment- a pattern that has been found in numerous settings in the public health literature (Mansour et al., 2021; Deserrano, Nansamba, and Qian, 2020; Boone, 1996; Bräutigam and Knack, 2004; Dinleyici et al., 2021). To the extent that both parents and donor funded healthcare providers view vaccination as costly, then both sides may choose to forego routine vaccinations in favor of meningitis vaccination during meningitis epidemics.To test this influx of health aid hypothesis, we use aid data from World Bank projects described in Section 3.3 and provide further discussion in Section 5.

5 Role of Health Aid: Evidence from World Bank Projects

We use aid data from World Bank projects to investigate the inflow of disaster health aid in response to the epidemic hypothesis. As mentioned in Section 3.3, this dataset is the only publicly available micro-level dataset on aid projects for our study region over the years of available data. The World Bank is a major donor in the Africa region, funding 31%

of recorded aid projects in the continent's most populous country, Nigeria, between 2000 and 2014. We estimate Equation 1 and Equation 2 for individual projects and examine the effects of meningitis shocks and epidemics on inflows of World Bank aid. We also modify Equation 2 to specifically test the hypothesis that the World Bank may respond to shocks during epidemic years with targeted health aid, by examining the triple interaction with an additional indicator that equals 1 if the project funded is a health project.

5.1 How World Bank Projects are Approved and Funded

A complete understanding of the results requires some additional information on how World Bank projects are funded. Limited research exists on the World Bank's internal management practices (Ika, Diallo, and Thuillier, 2012); thus we conducted qualitative interviews with World Bank officials and employees to gain insights into how World Bank aid projects are approved and funded. Our research revealed that projects take a relatively long time to be approved, with estimates of an average of 7-12 months to approve a single project. Projects must pass "concept approval, final design approval, then final package to the Board" before possibly being approved and funded. The shortest amount of time to approve projects in an "emergency" setting is reported to be around 3 to 4 months.[25]

What this means is that locations for World Bank health projects are often chosen ex-ante relative to the declaration of an epidemic year[26] (Öhler et al., 2017; Duggan et al., 2020). This approach affects the targeting and distribution of health aid as the relatively small number of health aid projects funded in the sample (12%) are run by officials who are often trying to meet particular funding targets in each year. Bank fund managers attempting to meet specific funding targets for countries may also choose to redirect funds from non-health projects to the existing health projects in areas with the most need during emergencies

[25] A snapshot of the World Bank project approval process is provided in Figure A4.

[26] Öhler et al. (2017) provide suggestive evidence that projects are targeted geographically by population share, with more populous regions receiving more projects, rather than by poverty status.

like epidemics. Hence, our results may underestimate the full effect of health aid on human capital development outcomes during declared epidemic years.

5.2 World Bank Aid Results

Table 6 reports the estimates showing the effects of meningitis shocks on the total amount of funds (in millions 2011 USD) committed and disbursed to World Bank aid projects. In column (1) and column (4) of Table 6, there is no significant effect of meningitis shocks on World Bank aid committed and disbursed respectively. In column (2) and column (5) of the same table, there is no effect on aid committed and disbursed to meningitis shock districts during declared epidemic years. In fact, the sign on the epidemic year term is negative and significant, indicating a reduction of aid to non-shock areas during epidemic years. However, when we examine disbursement of aid to health projects in particular, however, the results change. Column (3) and column (6) of Table 6 show the results for the amount committed and disbursed to World Bank health aid projects in meningitis shock districts during declared epidemic years. The triple interaction is positive and significant for both total committed and total disbursed funds to health projects in meningitis shock districts during epidemic years in columns (3) and (6).

Meningitis shock districts received approximately $52 million more funds in total commitments to health projects during declared epidemic years over their peers. By contrast, these shock districts received fewer funds for non-health projects during declared epidemic years (-$58 million) as shown in column (2). These patterns are replicated for the total amount of funds disbursed by the World Bank to shock districts during epidemic years, though the magnitudes are lower for the amount of funds disbursed to health projects in meningitis shock districts during declared epidemic years ($18 million in column (6) of Table 6). There appears to be a redistribution of funds away from non-health projects and towards health projects in meningitis shock districts during declared epidemic years. There

also appears to be a redistribution of funds committed to health projects during epidemic years away from non-shock districts towards shock districts as shown in column (3) and column (6). We provide further evidence of an influx of foreign health aid response to WHO epidemic announcements in Section A.4 in the Appendix.

Although publicly available data on the details of the projects approved during the study period are limited, the dataset includes project titles that provide suggestive evidence on the kinds of health and non-health projects funded in declared epidemic versus non-epidemic years.[27] A notable aspect is the difference between the funded health project titles in the epidemic and non-epidemic years. During the epidemic year, the top health project titles are "health sector and development program" and "economic recovery and adjustment credit (ERAC) project", whereas during non-epidemic years, the top project titles are "community action program", "social fund" and "health, fertility and nutrition project", providing suggestive evidence of the responsiveness of World Bank health funding to epidemic year announcements. The results demonstrate that donor agencies, like the World Bank, may respond to declared epidemics by increasing disbursement of health aid, while also jointly decreasing funding to non-health projects.

6 Conclusion

Recent scientific literature has provided evidence that future global warming may significantly increase the incidence and alter the geographical distribution of aggregate shocks, such as infectious disease epidemics. This may have potentially devastating consequences for global welfare, absent effective redistributive institutions aimed at improving human capital outcomes.

An important contribution of our study is to provide quantitative estimates of the effects of epidemics on human capital development outcomes. We use evidence from the

[27] A snapshot of the top 5 titles in each period is provided in Figure A5.

African meningitis belt, where meningitis is endemic, and examine the effects of meningitis shocks or local epidemics on human capital development outcomes. We highlight the role of WHO epidemic year announcements in coordinating policy responses to these shocks and show heterogeneity in the effects of meningitis shocks depending on whether the WHO declares an epidemic year. We show that meningitis shocks reduce child health outcomes on average, increasing the incidence of stunting and underweight status for children born in shock districts. The effects on reduction in child weight and height are particularly stark for children born in meningitis shock districts during non-epidemic years. Conversely, children born in meningitis shock districts during a WHO-declared epidemic year are less underweight and less stunted than their non-epidemic year-born peers.

We also document increases in routine childhood vaccinations in meningitis shock districts on average, where poorer households may seek out free/least-cost routine immunization for their children during periods of meningitis shocks or local epidemics. In contrast, children born in meningitis shock districts during declared epidemic years receive lower numbers of routine child vaccinations than their non-epidemic year-born peers. Further, we provide suggestive evidence for crowd-out of routine childhood vaccinations in these shock districts during declared epidemic years, as governance institutions focus on meningitis vaccination and treatment in these regions, with resulting implications for the demand and supply of routine vaccinations. We demonstrate that a primary mechanism explaining the reversal in the negative effects of meningitis shocks on child health outcomes during epidemic years, is an influx of disaster, health aid as a coordinated policy response when the WHO announces a national epidemic. The results show an increase in World Bank health aid projects funded in meningitis shock districts during declared epidemic years. The epidemic funding effect is redistributive, with funds flowing away from non-health projects towards health sector projects.

Our analyses demonstrate that global governance institutions, like the WHO, play an important role in mitigating the adverse effects of epidemics, partly by coordinating the decision-making and funding behavior of international agencies regarding the disbursement of health aid to affected regions. The disbursement of health aid to affected regions during epidemics can be an effective policy to mitigate, and reverse the negative effects of epidemics, particularly among low-income communities. Additionally, disaster aid policies in response to epidemics need to account for routine vaccine crowd-out and think carefully about the implications and potential long-run effects of the redistribution of donor aid away from non-health projects towards health projects during epidemics. Given that health projects often constitute a relatively smaller share of donor budgets compared to non-health projects, the net effect may be to decrease overall aid spending to affected regions during epidemic years, with potential implications for long-run development. Future research should examine this aid redistribution effect, and the implications of the crowd-out of routine vaccination, particularly in environments of significant vaccine hesitancy in the aftermath of epidemics (Archibong and Annan, 2021).

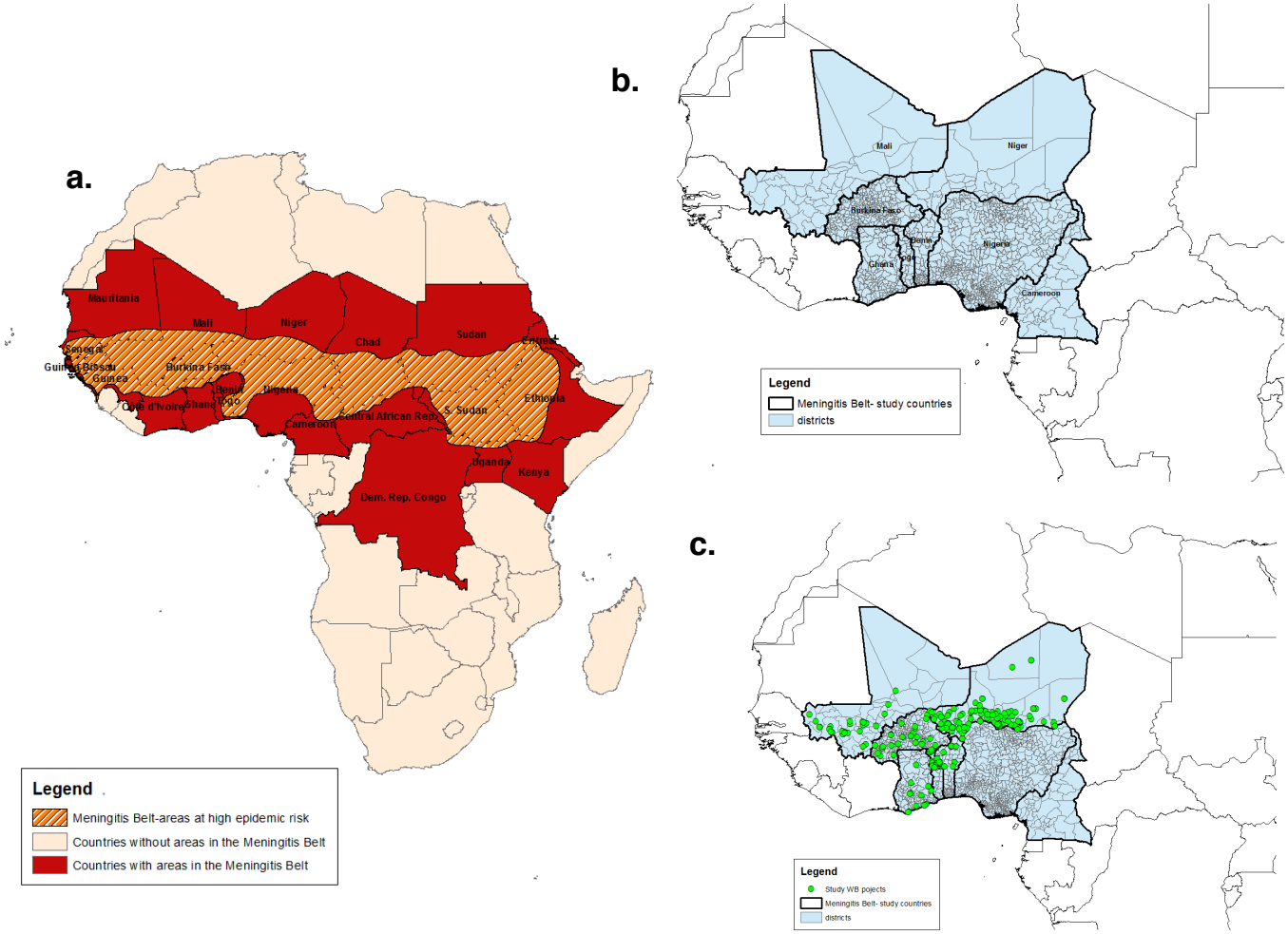

Figure 1: Countries in the African Meningitis Belt (a), with districts in study region (b) and locations of World Bank aid projects for countries and districts in study region over study years (c)

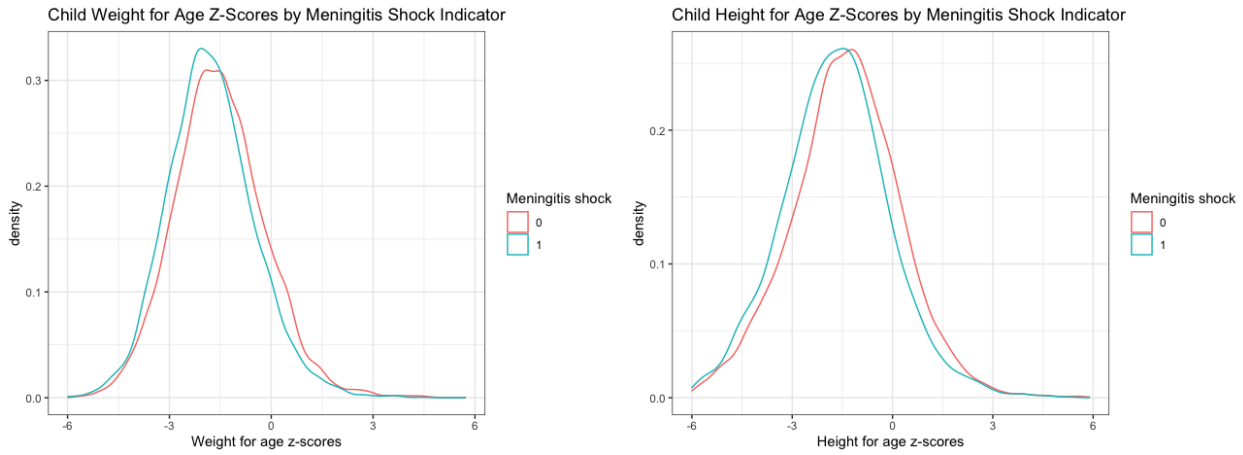

Figure 2: Stochastic dominance: Child weight for age and height for age z-scores are lower in meningitis shock districts on average

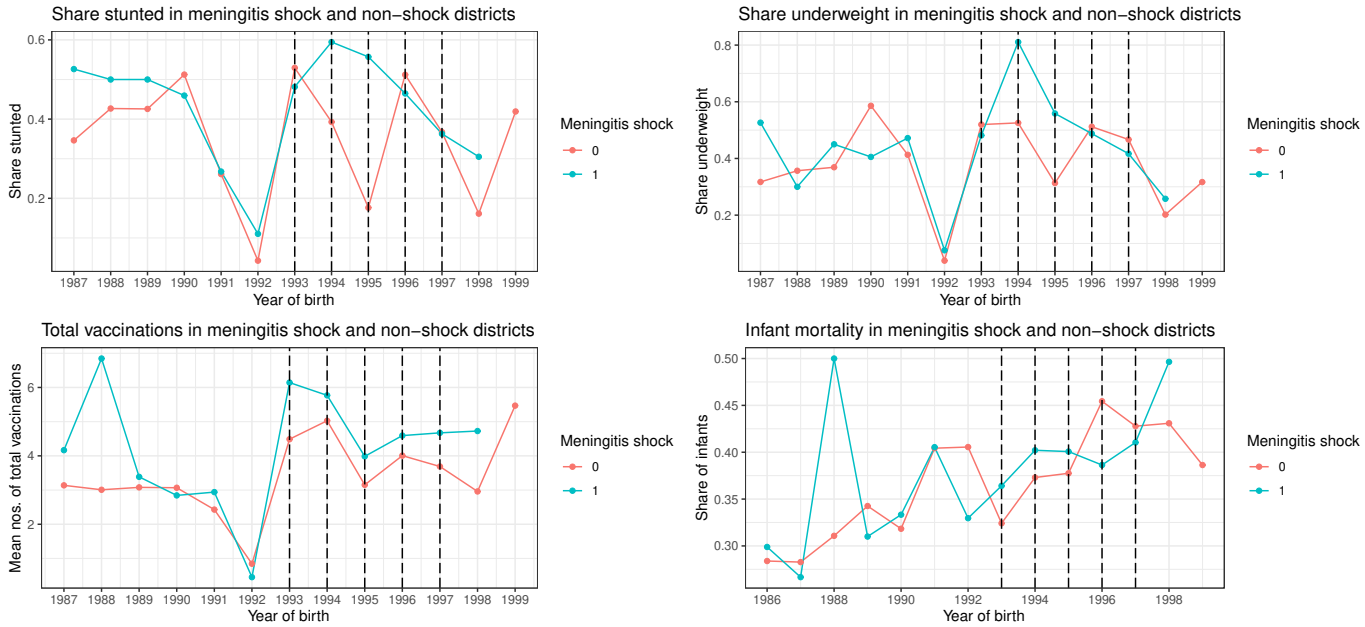

Figure 3: Average child current health outcomes in meningitis shock and non-shock districts, with epidemic years across study African countries between 1986 and 1999 outlined. Share stunted and underweight and total vaccination is higher in most years in meningitis shock districts

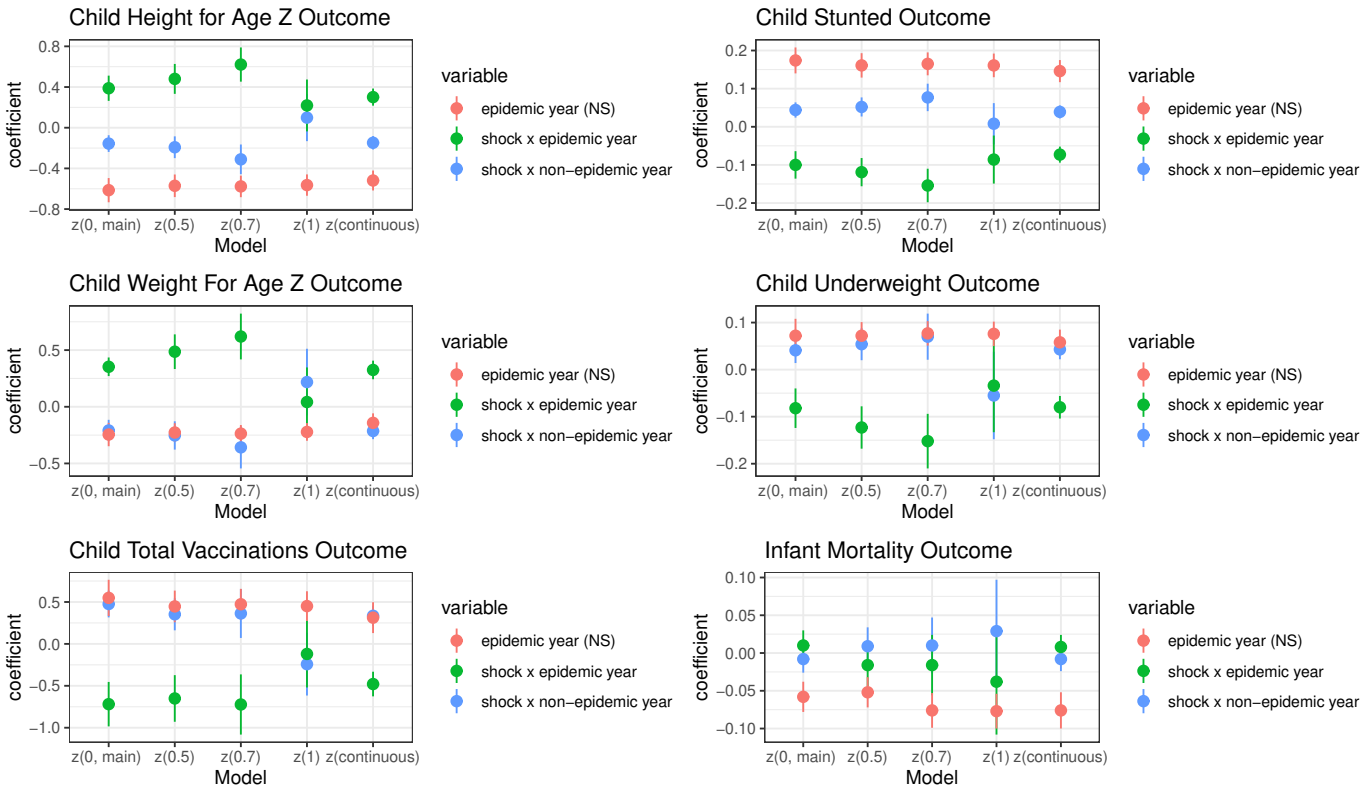

Figure 4: Effects of meningitis shocks on child health outcomes in epidemic versus non-epidemic years for shock and non-shock (NS) districts. Coefficients and standard errors from various model specifications, changing the definition of the meningitis shock measure from the main model (z(0, main)), to defining the shock indicator measure relative to various cutoffs, x, (z(x)), and using the continuous z-score measure of meningitis shocks (z(continuous))

Table 1: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
			District Level Meningitis Data		
Meningitis Shock (Indicator)	2,137	0.30	0.46	0.00	1.00
Meningitis Shock (Continuous)	2,137	0.00	0.91	−2.00	4.54
Weekly Meningitis Cases (/100,000)	2,282	4.29	11.92	0.00	200.07
Epidemic Year	2,398	0.33	0.47	0.00	1.00
			DHS Child Level Data		
Infant Mortality	16,486	0.38	0.49	0.00	1.00
WFA z	17,401	−1.54	1.33	−5.99	5.72
HFA z	17,401	−1.47	1.63	−6.00	5.89
Underweight	17,401	0.38	0.48	0.00	1.00
Stunted	17,401	0.36	0.48	0.00	1.00
BCG	22,401	0.61	0.49	0.00	1.00
Nos. Polio	22,422	1.45	1.31	0.00	3.00
Nos. DPT	22,323	1.38	1.34	0.00	3.00
Measles	21,979	0.42	0.49	0.00	1.00
Nos. Total Vaccines	21,806	3.83	3.33	0.00	8.00
			World Bank Project Level Data		
Health Project	556	0.12	0.33	0	1
Total Committed, USD	556	55,657,922	28,851,034	5,302,687	238,620,908
Total Disbursed, USD	547	47,585,463	26,440,235	1,987,862	310,653,294
Project Duration	547	6.117	1.412	1.000	11.000
IEG Outcome	301	3.98	1.24	1.00	6.00

Table 2: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality

	Panel A: Child Health and Infant Mortality Outcomes							
	Child Weight				**Child Height**		**Infant Mortality**	
	WFA z		Underweight		HFA z	Stunted	Mortality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Meningitis shock	−0.063	−0.043	0.011	0.011	−0.075	0.026	−0.015	−0.025*
	(0.059)	(0.073)	(0.020)	(0.025)	(0.071)	(0.018)	(0.012)	(0.014)
Mean of outcome	−1.583	−1.583	0.388	0.388	−1.476	0.362	0.374	0.374
Observations	15,032	11,483	15,032	11,483	15,032	15,032	14,842	9,495
Clusters	135	135	135	135	135	135	223	222
	Panel B: Child Vaccination Outcomes							
	BCG		Nos. Polio		DPT	Measles	Total Vaccines	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Meningitis shock	0.026**	0.033***	0.066*	0.054	0.071*	0.027	0.208**	0.194*
	(0.011)	(0.012)	(0.038)	(0.043)	(0.043)	(0.018)	(0.099)	(0.114)
Mean of outcome	0.591	0.591	1.375	1.375	1.328	0.406	3.674	3.674
Observations	19,581	13,425	19,606	13,438	19,548	19,258	19,151	13,019
Clusters	136	136	136	136	136	136	136	136
Night light density	No	Yes	No	Yes	No	No	No	Yes
Mother's controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Night light density is rom the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity in the absence of detailed microlevel income estimates for the study countries. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 3: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes							
	Child Weight				**Child Height**		**Infant Mortality**	
	WFA z		Underweight		HFA z	Stunted	Mortality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Meningitis shock	−0.209**	−0.257*	0.041	0.064	−0.156*	0.044**	−0.008	−0.008
	(0.094)	(0.147)	(0.027)	(0.042)	(0.082)	(0.020)	(0.018)	(0.026)
Epidemic year	−0.245**	−0.261**	0.072**	0.078**	−0.614***	0.174***	−0.058***	−0.081***
	(0.103)	(0.105)	(0.036)	(0.037)	(0.119)	(0.034)	(0.020)	(0.023)
Meningitis shock x Epidemic year	0.353**	0.406**	−0.082*	−0.107**	0.388***	−0.100***	0.010	−0.004
	(0.139)	(0.178)	(0.042)	(0.051)	(0.124)	(0.036)	(0.020)	(0.028)
Mean of outcome	−1.583	−1.583	0.388	0.388	−1.476	0.362	0.374	0.374
Observations	15,032	11,483	15,032	11,483	15,032	15,032	14,842	9,495
Clusters	135	135	135	135	135	135	223	222
	Panel B: Child Vaccination Outcomes							
	BCG		Nos. Polio		DPT	Measles	Total Vaccines	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Meningitis shock	0.065***	0.115***	0.183***	0.245***	0.174***	0.035	0.476***	0.666**
	(0.016)	(0.021)	(0.062)	(0.093)	(0.064)	(0.033)	(0.160)	(0.270)
Epidemic year	0.053**	0.062**	0.194**	0.205***	0.175*	0.131***	0.549**	0.581***
	(0.022)	(0.022)	(0.076)	(0.076)	(0.091)	(0.042)	(0.216)	(0.216)
Meningitis shock x Epidemic year	−0.092***	−0.142***	−0.293***	−0.355***	−0.259**	−0.067	−0.719***	−0.905**
	(0.026)	(0.028)	(0.095)	(0.123)	(0.108)	(0.052)	(0.265)	(0.361)
Mean of outcome	0.591	0.591	1.375	1.375	1.328	0.406	3.674	3.674
Observations	19,581	13,425	19,606	13,438	19,548	19,258	19,151	13,019
Clusters	136	136	136	136	136	136	136	136
Night light density	No	Yes	No	Yes	No	No	No	Yes
Mother's controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Night light density is rom the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity in the absence of detailed microlevel income estimates for the study countries. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 4: Placebo tests for Epidemic year: Effect of meningitis shock on child health (weight-for-age WFA z and height-for-age HFA z)

	Child Weight WFA z			**Child Height** HFA z		
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	−0.209**	−0.051	−0.041	−0.156*	0.008	−0.063
	(0.094)	(0.067)	(0.064)	(0.091)	(0.083)	(0.078)
Epidemic year	−0.245**			−0.614***		
	(0.103)			(0.119)		
Epidemic year, t+2		−0.248			0.510***	
		(0.154)			(0.159)	
Epidemic year, t+3			−0.730***			−0.764***
			(0.207)			(0.210)
Meningitis shock x Epidemic year	0.353**			0.388***		
	(0.139)			(0.124)		
Meningitis shock x Epidemic year t+2		−0.179			−0.157	
		(0.130)			(0.179)	
Meningitis shock x Epidemic year t+3			−0.107			−0.078
			(0.165)			(0.181)
Mean of outcome	−1.583	−1.583	−1.583	−1.476	−1.476	−1.476
Observations	15,032	15,032	15,032	15,032	15,032	15,032
Clusters	135	135	135	135	135	135
Mother's controls	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries and are WFA z scores in columns (1) to (3), and HFA z scores in columns (4) to (6). Epidemic year t+2 is an indicator for an epidemic year 2 years after the child's year of birth; t+3 is 3 years after the child's year of birth. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Meningitis shock is z-score indicator based on district-level mean and equal to 1 if the z-score is greater than 0. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 5: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality by wealth status

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.015	−0.015	0.009	0.007	−0.034**
	(0.072)	(0.025)	(0.091)	(0.023)	(0.017)
Lower wealth	−0.180***	0.071***	−0.234***	0.064***	−0.027**
	(0.046)	(0.016)	(0.057)	(0.014)	(0.012)
Meningitis shock x Lower wealth	−0.151**	0.049**	−0.161*	0.038	0.038*
	(0.062)	(0.023)	(0.084)	(0.025)	(0.020)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.005	0.025	0.032	0.024	0.099
	(0.014)	(0.044)	(0.051)	(0.021)	(0.115)
Lower wealth	−0.195***	−0.452***	−0.490***	−0.125***	−1.284***
	(0.024)	(0.055)	(0.057)	(0.015)	(0.015)
Meningitis shock x Lower wealth	0.059***	0.079*	0.077	0.007	0.210*
	(0.018)	(0.043)	(0.049)	(0.021)	(0.117)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Lower wealth is an indicator that equals one if the household is in less than the third quintile for wealth in the sample based on the wealth index calculated from the DHS using principal component analysis of asset ownership, as described in text. The wealth index is a 1 to 5 categorical variable where 1 is the poorest quintile and 5 is the richest quintile. So Lower wealth is an indicator that equals one if the household wealth index is less than 3. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 6: Effect of meningitis shock on amount committed and disbursed to World Bank aid projects by epidemic year and health project status

	Total Committed (mn USD)			**Total Disbursed (mn USD)**		
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	1.575	0.866	0.043	1.422	0.704	0.227
	(2.256)	(0.814)	(1.037)	(2.574)	(1.618)	(1.366)
Epidemic year		−31.767***	19.179***		−30.001***	−8.259***
		(10.337)	(1.242)		(6.240)	(1.497)
Health			6.524***			12.362***
			(0.545)			(0.368)
Meningitis shock x Epidemic year		−4.477	−57.557***		−3.886	−22.853***
		(8.588)	(1.037)		(4.983)	(1.366)
Meningitis shock x Health			2.968			0.459
			(3.776)			(2.314)
Epidemic year x Health			−108.421***			−55.057***
			(0.999)			(1.046)
Meningitis shock x Epidemic year x Health			51.656***			18.246***
			(5.206)			(3.209)
Mean of outcome	40.953	40.953	40.953	36.846	36.846	36.846
Observations	213	213	213	204	204	204
Clusters	64	64	64	64	64	64
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables is millions USD (in 2011 dollars) committed and disbursed for World Bank aid projects in columns (1) to (3) and columns (4) to (6) respectively, as described in text from study countries. Meningitis shock is z-score indicator based on district level mean as described in text. Epidemic year is an indicator that equals 1 if the year in the study country is declared an epidemic year by the WHO. Health is an indicator that equals 1 if the project is a health project. Linear time trends are district specific time trends. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

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A.1 Summary Statistics and Robustness

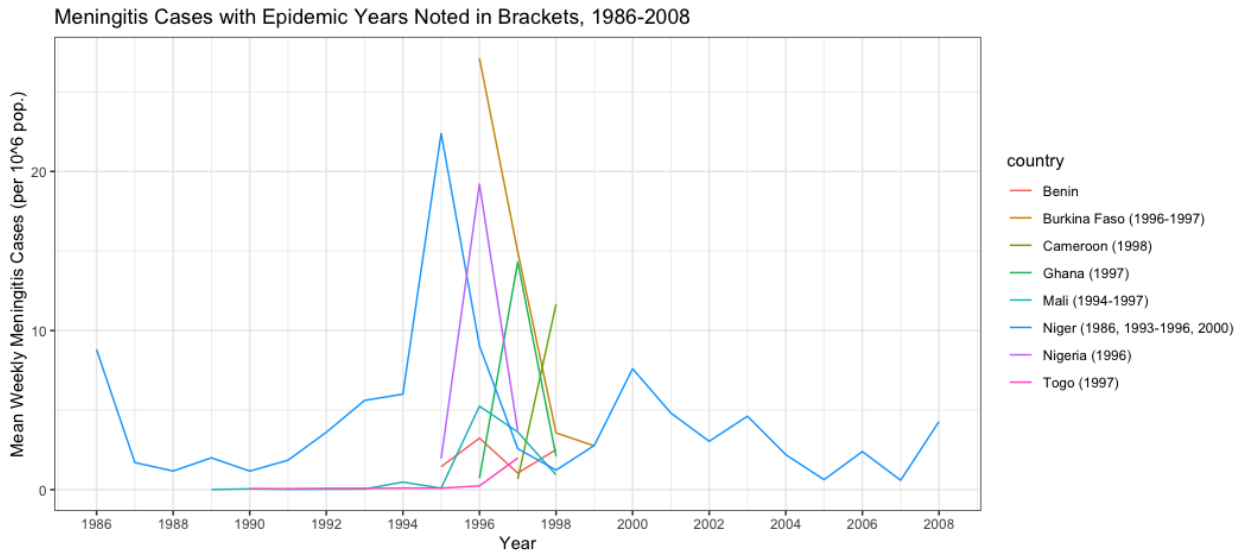


Figure A1: Mean weekly meningitis cases per district over study region, with epidemic years specified in brackets

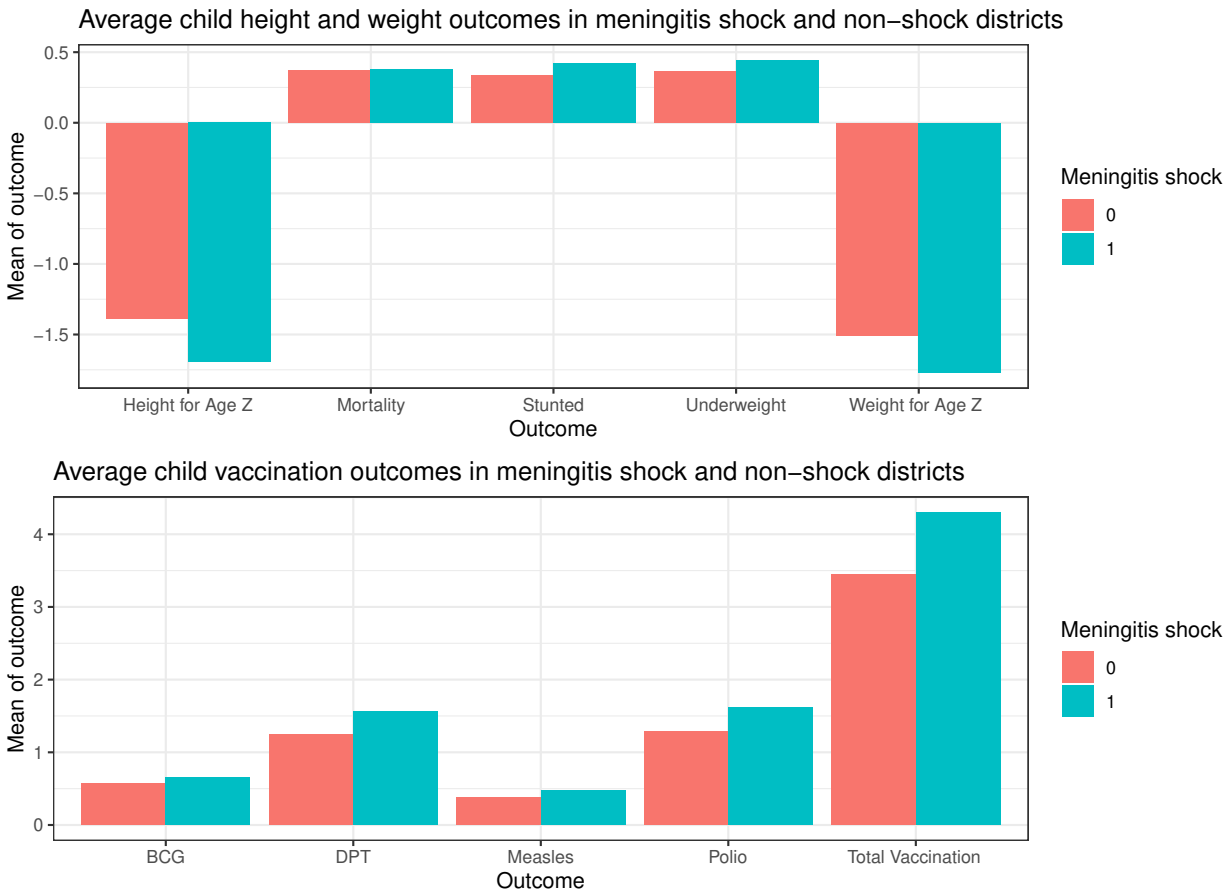


Figure A2: Average child current health outcomes in meningitis shock and non-shock districts. Share stunted and underweight and total vaccination is higher, on average, in meningitis shock districts.

Table A1: WHO recommended vaccination schedule

	Vaccine	Diseases	Age
1	BCG	tuberculosis	at birth
2	Polio (OPV)	polio	at birth, 6, 10, 14 weeks
3	DPT	diphtheria, pertussis, tetanus	6, 10, 14 weeks
4	Measles	measles	9 months

Table A2: Balance tables: Meningitis shocks and mother's characteristics

	Education		Age at First Birth	
	(1)	(2)	(3)	(4)
Meningitis shock	0.007	0.007	0.072	0.049
	(0.005)	(0.005)	(0.055)	(0.055)
Mean of outcome	0.181	0.181	26.181	26.181
Observations	68,352	68,352	68,353	68,353
Clusters	228	228	228	228
District FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	No	Yes	No
Country x year FE	No	Yes	No	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Outcomes are mother's educational attainment (columns (1)-(2)) and mother's age at first birth (columns (3)-(4)) from 8 African countries as described in text. Education is a categorical variable where 0 is no education, 1 is primary education completed, 2 is secondary education completed and 3 is higher or post-secondary education completed. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Country x year fixed effects (FE) are country x survey year FE. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A3: Balance on geographic characteristics, with time-varying geographic variables

	Temperature		Precipitation		Dust Concentration	
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis Shock	−0.017	0.044	−0.010	−0.003	−0.010	0.008
	(0.057)	(0.045)	(0.013)	(0.009)	(0.006)	(0.006)
Mean of outcome	300.553	300.553	−11.058	−11.058	−16.652	−16.652
Observations	1,358	1,358	1,358	1,358	1,358	1,358
Clusters	238	238	238	238	238	238
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	No	Yes	No	Yes	No
Country x year FE	No	Yes	No	Yes	No	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. All observations are at the district level. Outcomes are weather variables. Temperature is in Kel is Meningitis shock. Temperature is in Kelvin from the NASA MERRA-2 dataset. Precipitation and dust concentration values are in logs for ease of interpretation with small values. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Linear time trends (D) are district specific time trends. Year FE are year fixed effects. Country x year fixed effects (FE) are country x year FE. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A4: Balance on geographic and institutional characteristics

	Panel A: Geographic Characteristics						
	Malaria	Land Suitability	Elevation	Access to Rivers	Distance to Sea Coast	Distance to Capital	Precipitation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Meningitis shock average	−1.680	−0.007	18.696	−0.077	−22.516	−19.465	0.274
	(3.214)	(0.081)	(51.375)	(0.339)	(57.331)	(131.928)	(0.279)
Mean of outcome	22.204	0.325	374.821	0.467	128.404	404.695	−10.583
Observations	242	239	242	242	242	242	238
R^2	0.576	0.503	0.554	0.094	0.322	0.250	0.495
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Geographic and Institutional Characteristics						
	Share Muslim	Pastoral	Centralization Index	Centralization Dummy	Diamond	Petrol	Temperature
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Meningitis shock average	−0.218	−0.025	−1.182	−0.419	0.009	0.002	−0.452
	(0.149)	(0.052)	(0.867)	(0.437)	(0.100)	(0.007)	(0.470)
Mean of outcome	0.688	0.026	1.288	0.721	0.012	0.004	299.988
Observations	236	764	768	768	242	242	238
R^2	0.536	0.191	0.078	0.055	0.092	0.025	0.545
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors clustered by district in parentheses. Observations at the district level in all specifications except panel B for the centralization and pastoral outcomes, where observations are districts intersected with Murdock ethnicity regions. 'Meningitis shock average' is the likelihood that a district is a meningitis shock district over the period of study. Land Suitability is land suitability for agriculture from FAO data. Elevation is mean elevation in km from the Global Climate database. Distance to capital and seacoast in km. Malaria stability is from the malaria ecology index from Kiszewski et al. (2004). Precipitation is in logs and Temperature is in Kelvin from the NASA MERRA-2 dataset. Share Muslim is based on DHS data. Access to Rivers is an indicator for whether a district has a river running through it. Centralization Index is the level of precolonial centralization from Murdock ethnicity data (Murdock, 1967) and Centralization Dummy is an indicator that equals 1 if the index is greater than 0 (following Archibong (2019)). Pastoralism dummy equals 1 if pastoralism was the primary contributor to livelihood in precolonial ethnic region from Murdock data. Petrol and Diamond are indicators equal to 1 if the district has recorded deposits of petroleum and diamonds respectively from the PRIO dataset. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A5: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.043	0.011	−0.069	0.030	−0.025*
	(0.073)	(0.025)	(0.088)	(0.022)	(0.014)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	11,483	11,483	11,483	11,483	9,495
Clusters	135	135	135	135	222
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.033***	0.054	0.065	0.022	0.194*
	(0.012)	(0.043)	(0.050)	(0.024)	(0.114)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	13,425	13,438	13,380	13,118	13,019
Clusters	136	136	136	136	136
Night light density	Yes	Yes	Yes	Yes	Yes
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Night light density is rom the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity in the absence of detailed microlevel income estimates for the study countries. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Meningitis shock is z-score indicator based on district-level mean as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A6: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.257*	0.064	−0.194	0.068**	−0.008
	(0.147)	(0.042)	(0.124)	(0.028)	(0.026)
Epidemic year	−0.261**	0.078**	−0.625***	0.181***	−0.081***
	(0.105)	(0.037)	(0.120)	(0.034)	(0.023)
Meningitis shock x Epidemic year	0.406**	−0.107**	0.429***	−0.127***	−0.004
	(0.178)	(0.051)	(0.148)	(0.040)	(0.028)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	11,483	11,483	11,483	11,483	9,495
Clusters	135	135	135	135	222
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.115***	0.245***	0.242**	0.024	0.666**
	(0.021)	(0.093)	(0.101)	(0.070)	(0.270)
Epidemic year	0.062**	0.205***	0.185**	0.127***	0.581***
	(0.022)	(0.076)	(0.091)	(0.041)	(0.216)
Meningitis shock x Epidemic year	−0.142***	−0.355***	−0.325**	−0.053	−0.905**
	(0.028)	(0.123)	(0.139)	(0.084)	(0.361)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	13,425	13,438	13,380	13,118	13,019
Clusters	136	136	136	136	136
Night light density	Yes	Yes	Yes	Yes	Yes
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Night light density is rom the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity in the absence of detailed microlevel income estimates for the study countries. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Meningitis shock is z-score indicator based on district-level mean as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A7: Robustness to continuous measure: Effect of meningitis shock (continuous z-score) on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (C)	-0.214^{***}	0.043^{**}	-0.148^{**}	0.039^{**}	-0.008
	(0.072)	(0.021)	(0.066)	(0.017)	(0.016)
Epidemic year	-0.142^{*}	0.058^{**}	-0.519^{***}	0.146^{***}	-0.076^{***}
	(0.084)	(0.027)	(0.098)	(0.029)	(0.024)
Meningitis shock (C) x Epidemic year	0.325^{***}	-0.080^{***}	0.301^{***}	-0.073^{***}	0.008
	(0.082)	(0.024)	(0.084)	(0.021)	(0.016)
Mean of outcome	-1.583	0.388	-1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (C)	0.049^{***}	0.129^{**}	0.122^{**}	0.022	0.335^{***}
	(0.012)	(0.050)	(0.048)	(0.020)	(0.121)
Epidemic year	0.016	0.093	0.095	0.117^{***}	0.313^{*}
	(0.018)	(0.067)	(0.078)	(0.039)	(0.184)
Meningitis shock (C) x Epidemic year	-0.060^{***}	-0.184^{***}	-0.178^{***}	-0.045^{*}	-0.479^{***}
	(0.015)	(0.059)	(0.058)	(0.023)	(0.147)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock (C) is the continuous z-score based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A8: Robustness to marginal changes in shock cutoff: Effect of meningitis shock (> 0.5) on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (0.5)	-0.253^{**}	0.054	-0.192^{*}	0.052^{**}	0.009
	(0.125)	(0.034)	(0.107)	(0.025)	(0.025)
Epidemic year	-0.227^{***}	0.072^{**}	-0.571^{***}	0.161^{***}	-0.052^{***}
	(0.082)	(0.029)	(0.111)	(0.032)	(0.020)
Meningitis shock (0.5) x Epidemic year	0.486^{***}	-0.123^{***}	0.480^{***}	-0.119^{***}	-0.016
	(0.153)	(0.045)	(0.147)	(0.037)	(0.028)
Mean of outcome	-1.583	0.388	-1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (0.5)	0.064^{***}	0.131^{*}	0.114	0.029	0.353^{*}
	(0.021)	(0.079)	(0.076)	(0.034)	(0.191)
Epidemic year	0.034^{*}	0.145^{**}	0.145^{*}	0.126^{***}	0.447^{**}
	(0.021)	(0.067)	(0.080)	(0.039)	(0.189)
Meningitis shock (0.5) x Epidemic year	-0.087^{***}	-0.247^{**}	-0.230^{**}	-0.074	-0.651^{**}
	(0.029)	(0.109)	(0.112)	(0.046)	(0.278)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock (0.5) is the z-score indicator based on the district-level mean weekly meningitis cases, where the indicator equals one if $z > 0.5$. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A9: Robustness to marginal changes in shock cutoff: Effect of meningitis shock (> 0.7) on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (0.7)	-0.358^{*}	0.070	-0.311^{**}	0.077^{**}	0.010
	(0.186)	(0.049)	(0.146)	(0.036)	(0.037)
Epidemic year	-0.237^{***}	0.077^{***}	-0.577^{***}	0.165^{***}	-0.076^{***}
	(0.076)	(0.026)	(0.106)	(0.030)	(0.023)
Meningitis shock (0.7) x Epidemic year	0.620^{***}	-0.152^{**}	0.621^{***}	-0.154^{***}	-0.016
	(0.202)	(0.058)	(0.168)	(0.044)	(0.040)
Mean of outcome	-1.583	0.388	-1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (0.7)	0.089^{***}	0.133	0.108	-0.001	0.362
	(0.029)	(0.119)	(0.118)	(0.048)	(0.292)
Epidemic year	0.037^{*}	0.155^{**}	0.155^{**}	0.128^{***}	0.473^{**}
	(0.020)	(0.065)	(0.078)	(0.039)	(0.184)
Meningitis shock (0.7) x Epidemic year	-0.118^{***}	-0.273^{*}	-0.250^{*}	-0.050	-0.723^{**}
	(0.036)	(0.141)	(0.146)	(0.059)	(0.359)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock (0.7) is the z-score indicator based on the district-level mean weekly meningitis cases, where the indicator equals one if $z > 0.7$. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A10: Robustness to marginal changes in shock cutoff: Effect of meningitis shock (> 1) on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (1)	0.218	−0.055	0.099	0.008	0.029
	(0.294)	(0.093)	(0.231)	(0.054)	(0.068)
Epidemic year	−0.222***	0.076***	−0.564***	0.161***	−0.077***
	(0.078)	(0.026)	(0.105)	(0.031)	(0.023)
Meningitis shock (1) x Epidemic year	0.042	−0.034	0.219	−0.086	−0.038
	(0.305)	(0.099)	(0.255)	(0.063)	(0.070)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock (1)	0.015	−0.096	−0.037	−0.128**	−0.242
	(0.051)	(0.160)	(0.152)	(0.058)	(0.374)
Epidemic year	0.035*	0.148**	0.151**	0.119***	0.451**
	(0.020)	(0.062)	(0.075)	(0.038)	(0.177)
Meningitis shock (1) x Epidemic year	−0.041	−0.048	−0.114	0.087	−0.120
	(0.053)	(0.168)	(0.162)	(0.065)	(0.400)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock (0.7) is the z-score indicator based on the district-level mean weekly meningitis cases, where the indicator equals one if $z > 1$. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A11: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality (country-year FE)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.059	0.018	−0.116*	0.034**	−0.015
	(0.049)	(0.018)	(0.061)	(0.017)	(0.011)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.020	0.044	0.055	0.021	0.152
	(0.013)	(0.036)	(0.039)	(0.020)	(0.098)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Country x year fixed effects (FE) are country x survey year FE. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A12: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years (country-year FE)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.176**	0.043*	−0.178**	0.046**	−0.009
	(0.081)	(0.022)	(0.079)	(0.020)	(0.018)
Epidemic year	−0.217**	0.061*	−0.543***	0.157***	−0.055***
	(0.101)	(0.036)	(0.126)	(0.037)	(0.019)
Meningitis shock x Epidemic year	0.288**	−0.066*	0.301***	−0.076**	0.009
	(0.119)	(0.036)	(0.114)	(0.034)	(0.021)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.047**	0.120**	0.118*	0.014	0.309*
	(0.018)	(0.060)	(0.061)	(0.037)	(0.166)
Epidemic year	0.048**	0.164**	0.145	0.113***	0.461**
	(0.022)	(0.075)	(0.091)	(0.041)	(0.216)
Meningitis shock x Epidemic year	−0.068**	−0.198**	−0.167	−0.024	−0.454*
	(0.027)	(0.094)	(0.103)	(0.052)	(0.261)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Country x year fixed effects (FE) are country x survey year FE. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A13: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality (country-year FE and time trends)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.063	0.011	−0.075	0.026	−0.015
	(0.059)	(0.020)	(0.071)	(0.018)	(0.012)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.026**	0.066*	0.071*	0.027	0.208**
	(0.011)	(0.038)	(0.043)	(0.018)	(0.099)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Country x year fixed effects (FE) are country x survey year FE. Country x year FE subsumes the standalone Year FE. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Linear time trends (D) are district specific time trends. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A14: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years (country-year FE and time trends)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.209**	0.041	−0.156*	0.044**	−0.008
	(0.094)	(0.027)	(0.082)	(0.020)	(0.018)
Epidemic year	−0.245**	0.072**	−0.614***	0.174***	−0.058***
	(0.103)	(0.036)	(0.119)	(0.034)	(0.020)
Meningitis shock x Epidemic year	0.353**	−0.082*	0.388***	−0.100***	0.010
	(0.139)	(0.042)	(0.124)	(0.036)	(0.020)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.065***	0.183***	0.174***	0.035	0.476***
	(0.016)	(0.062)	(0.064)	(0.033)	(0.160)
Epidemic year	0.053**	0.194**	0.175*	0.131***	0.549**
	(0.022)	(0.076)	(0.091)	(0.042)	(0.216)
Meningitis shock x Epidemic year	−0.092***	−0.293***	−0.259**	−0.067	−0.719***
	(0.026)	(0.095)	(0.108)	(0.052)	(0.265)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Country x year fixed effects (FE) are country x survey year FE. Country x year FE subsumes the standalone Year FE. Linear time trends (D) are district specific time trends. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A15: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality (district and year FE)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.057	0.017	−0.112*	0.034**	−0.015
	(0.049)	(0.017)	(0.062)	(0.017)	(0.011)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.020	0.044	0.056	0.021	0.153
	(0.013)	(0.036)	(0.039)	(0.020)	(0.098)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A16: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality in epidemic versus non-epidemic years (district and year FE)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.177**	0.043*	−0.178**	0.046**	−0.008
	(0.080)	(0.022)	(0.078)	(0.020)	(0.018)
Epidemic year	−0.229**	0.060*	−0.558***	0.157***	−0.077***
	(0.098)	(0.035)	(0.125)	(0.036)	(0.023)
Meningitis shock x Epidemic year	0.295**	−0.066*	0.310***	−0.076***	0.006
	(0.118)	(0.036)	(0.113)	(0.034)	(0.021)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.046**	0.116*	0.115**	0.013	0.301*
	(0.019)	(0.062)	(0.061)	(0.038)	(0.168)
Epidemic year	0.042*	0.148**	0.126	0.109***	0.417**
	(0.022)	(0.074)	(0.089)	(0.040)	(0.212)
Meningitis shock x Epidemic year	−0.063**	−0.185*	−0.152	−0.021	−0.419
	(0.027)	(0.094)	(0.104)	(0.051)	(0.262)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A17: Placebo tests for Epidemic year: Changing epidemic year cutoff

	Child Weight		**Child Height**	
	WFA z	Underweight	HFA z	Stunted
	(1)	(2)	(3)	(4)
Meningitis shock	−0.197	0.053	−0.000	−0.050
	(0.172)	(0.067)	(0.159)	(0.056)
Epidemic year (> 5)	−0.214	0.099	−0.513***	0.042
	(0.196)	(0.075)	(0.184)	(0.061)
Meningitis shock x Epidemic year (> 5)	0.147	−0.049	−0.044	0.071
	(0.205)	(0.077)	(0.197)	(0.065)
Mean of outcome	−1.583	0.388	−1.476	0.362
Observations	15,032	15,032	15,032	15,032
Clusters	135	135	135	135
Mother's controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Epidemic year is an indicator that equals 1 if the number of meningitis cases is greater than 5 per 100,000 population in the year. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Meningitis shock is z-score indicator based on district-level mean as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A18: Inference Robustness: Effect of meningitis shock on child health outcomes in epidemic versus non-epidemic years

	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	-0.209^{**}	0.041	-0.156^{*}	0.044^{**}	-0.008
SE: Clustered by district	(0.094)	(0.027)	(0.082)	(0.020)	(0.018)
SE: Two-way clustered by district and year	[0.119]	[0.035]	[0.099]	[0.026]	[0.010]
SE: Conley [1999] spatial errors (100km window)	[0.072]	[0.022]	[0.071]	[0.017]	[0.017]
Epidemic year	-0.245^{**}	0.072^{**}	-0.614^{***}	0.174^{***}	-0.058^{***}
SE: Clustered by district	(0.103)	(0.036)	(0.119)	(0.034)	(0.020)
SE: Two-way clustered by district and year	[0.247]	[0.086]	[0.169]	[0.051]	[0.019]
SE: Conley [1999] spatial errors (100km window)	[0.086]	[0.030]	[0.094]	[0.027]	[0.017]
Meningitis shock x Epidemic year	0.353^{**}	-0.082^{*}	0.388^{***}	-0.100^{***}	0.010
SE: Clustered by district	(0.139)	(0.042)	(0.124)	(0.036)	(0.020)
SE: Two-way clustered by district and year	[0.161]	[0.044]	[0.178]	[0.041]	[0.012]
SE: Conley [1999] spatial errors (100km window)	[0.114]	[0.035]	[0.110]	[0.029]	[0.021]
Mean of outcome	-1.583	0.388	-1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Standard errors from alternative inference procedures, (i) two-way clustering by district and year and (ii) Conley (1999) spatial errors, are shown in square brackets. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Linear time trends (D) are district specific time trends. Year FE are survey year fixed effects. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Epidemic year is an indicator that equals one if the WHO declares an epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A19: Robustness: Effect of meningitis shock on child current weight and height outcomes, at/near birth (bcg, polio, dpt) versus non-at/near birth recommended (measles) child vaccinations, total vaccinations and infant mortality by wealth status (country-year FE)

	Panel A: Child Health and Infant Mortality Outcomes				
	Child Weight		**Child Height**		**Infant Mortality**
	WFA z	Underweight	HFA z	Stunted	Mortality
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.019	−0.005	−0.036	0.018	−0.036**
	(0.058)	(0.022)	(0.079)	(0.021)	(0.017)
Lower wealth	−0.178***	0.073***	−0.239***	0.067***	−0.029**
	(0.043)	(0.015)	(0.057)	(0.014)	(0.012)
Meningitis shock x Lower wealth	−0.155***	0.045**	−0.158*	0.032	0.041**
	(0.056)	(0.022)	(0.083)	(0.024)	(0.019)
Mean of outcome	−1.583	0.388	−1.476	0.362	0.374
Observations	15,032	15,032	15,032	15,032	14,842
Clusters	135	135	135	135	223
	Panel B: Child Vaccination Outcomes				
	BCG	Nos. Polio	DPT	Measles	Total Vaccines
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.014	−0.015	0.001	0.007	−0.002
	(0.014)	(0.041)	(0.046)	(0.022)	(0.110)
Lower wealth	−0.200***	−0.474***	−0.507***	−0.136***	−1.340***
	(0.024)	(0.056)	(0.059)	(0.016)	(0.150)
Meningitis shock x Lower wealth	0.067***	0.116**	0.108**	0.027	0.308**
	(0.019)	(0.047)	(0.050)	(0.019)	(0.123)
Mean of outcome	0.591	1.375	1.328	0.406	3.674
Observations	19,581	19,606	19,548	19,258	19,151
Clusters	136	136	136	136	136
Mother's controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variables are child health outcomes described in text from 8 African countries. Mother's controls include mother's age at birth and level of education. Country x year fixed effects (FE) are country x survey year FE. Year of birth FE and District FE are year of birth fixed effects and district fixed effects respectively. Meningitis shock is the z-score indicator based on the district-level mean weekly meningitis cases as described in text. Lower wealth is an indicator that equals one if the household is in less than the third quintile for wealth in the sample based on the wealth index calculated from the DHS using principal component analysis of asset ownership, as described in text. The wealth index is a 1 to 5 categorical variable where 1 is the poorest quintile and 5 is the richest quintile. So Lower wealth is an indicator that equals one if the household wealth index is less than 3. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

A.1.1 Wealth Index

The wealth index is constructed from ownership of 10 assets using principal component analysis of asset ownership from the DHS. The assets include: bicycles, motorcycles, cars/trucks, flush toilets, ventilated improved pit latrines, traditional pit latrines, electricity, radio, tv, fridge. The wealth index is a 1 to 5 categorical variable where 1 is the poorest quintile and 5 is the richest quintile. Lower wealth is an indicator that equals one if the household wealth index is less than 3.

A.2 Selective Migration

To what extent does migration rationalize our results? We investigate the possibility that unhealthy individuals (i.e., with low WFA z, low HFA z, etc) might have moved from areas affected by meningitis to unaffected areas and as a result, unaffected areas experience low economic outcomes relative to the affected areas. The dual, though prima facie less plausible, statement is that more "healthy" individuals might have moved from areas unaffected by meningitis to the affected areas and as result, unaffected areas experience low economic outcomes. Thus, instead of assuming limited (selective) internal migration between districts for identification, we relax this assumption and examine it as an alternative explanation for our results.

A.2.1 Migration Estimates

We evaluate the extent of migration across districts to gauge its likely effects. Because detailed micro data on internal migration over the entire sample period (1986 to 2008) is absent, we provide estimates based on the ACMI (aggregate crude migration index) and net migration rate (NMR) values calculated from 1988 to 1992 in Bocquier and Traoré (1998). In the demography literature, ACMI is a widely-used measure of internal migration and captures the share of the population that has changed address averaged over a specified time period. Specifically, the ACMI is a global average based on the specification:

$$CMI_n = \sum_i \sum_{j \neq i} M_{ij} / \sum_i P_i$$

where M_{ij} is the total number of migrants (or migrations) between origin area $i = 1, ...n$ and destination area $j = 1, ...n$; and P_i is the population of each area i at risk of migrating (Bell et al., 2015; Bernard and Bell, 2018). The population assessed here is the population over the age of 15 (Bocquier and Traoré, 1998). The NMR measures the difference between incoming and outgoing migrants in a particular locality.

Table A20 shows the ACMI and NMR (%) values, and indicates extremely low values. Overall, ACMI averages at 0.09 while NMR averages at -0.72%. This means that just 9% of the population report changing their place of residence within their country over the four-year interval (1988 to 1992) with a net movement of -0.72%. The evidence suggests limited internal migration in the study region.

Table A20: Internal Migration Statistics for Selected Countries in the Meningitis Belt, 1988-1992, Source: Bocquier and Traore (1998)

Country	ACMI (4-yr avg)	NIMR (%)			
		Capital city	Principal towns	Secondary towns	Rural
Burkina Faso	0.03	1.86	0.29	-0.79	-0.09
Cote d'Ivoire	0.16	0.43	-2.24	-2.74	0.99
Guinea	0.05	1.21	-1.94	-2.14	-0.04
Mali	0.09	0.85	0.31	0.23	-0.19
Mauritania	0.08				
Senegal	0.12	0.5	0.36	-0.6	-0.25
Niger	0.06	-0.06	0.91	-0.22	-0.04
West Africa (8)	0.09	0.8	-0.39	-1.04	0.06
Sample years	1988-1992	1988-1992	1988-1992	1988-1992	1988-1992

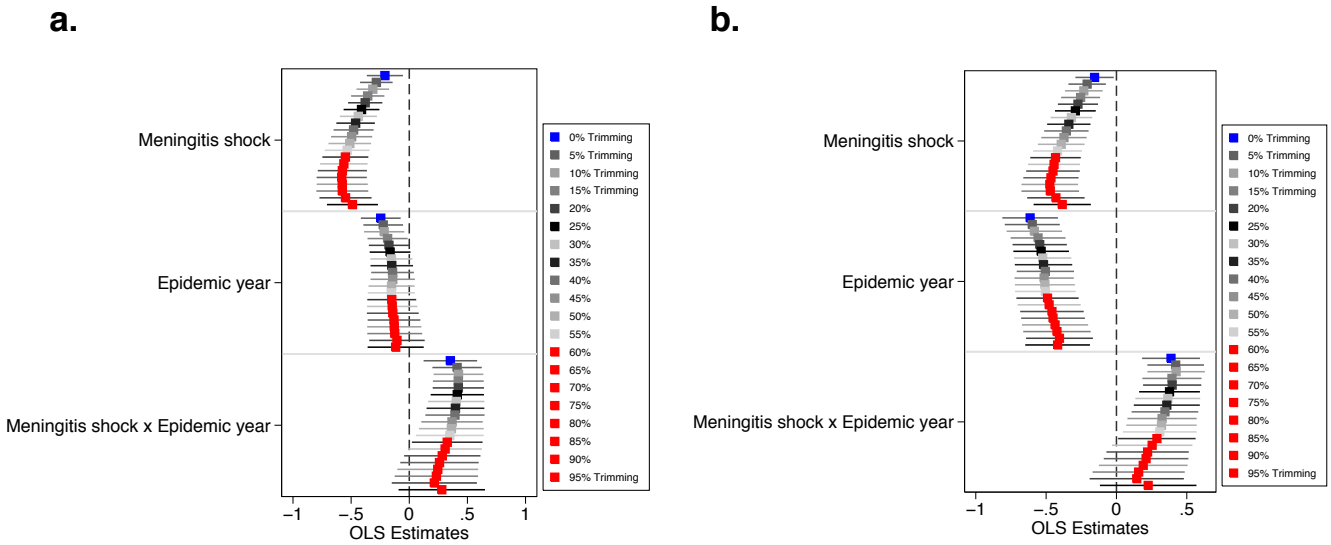
Notes: ACMI is the aggregate crude migration intensity ratio described in the text. NIMR is the net internal migration rate in percentages. It is calculated for each region. Regional classification of 'principal' or 'secondary' towns differs for each country and is based on population size. For Niger, principal towns are regional capital cities, and secondary towns are all remaining settlements of over 5000 people (Beauchemin and Bocquier, 2004).

A.2.2 Empirical Test: Role of Selective Migration

To test our conjecture that (selective) migration is not driving the results, we conduct a series of trimming exercises. We begin with the supposition that migration is indeed selective, and then ask "what level of such selective migration would be needed to make our results insignificant?". We reclassify the districts as either meningitis affected (if the observed meningitis cases are above the sample average) or unaffected (if the observed meningitis cases are below the sample average) year to year. We then trim the outcomes using different migration rates in increments of 5%. That is, we recursively drop the top 5%, 10%, 15%, ... of the data with the highest outcomes- reflecting the most healthy individuals- only in the meningitis affected districts. In each step, we re-estimate our baseline model, and continue the process until the effects for our main interaction term,"Meningitis shock x Epidemic year", become insignificant.

Figure A3 shows the results. We focus on two main outcomes, WFA z and HFA z[28]. WFA z and HFA z correlate strongly with the other child health outcomes (a simple regression of WFA z and HFA z on the other health outcomes shows large and significant correlations, $p < 0.01$). As shown, for WFA z and HFA z, a selective migration rate of 55% is required to render our effects insignificant. . The coefficient signs remain unchanged across all specifications. Our trimming exercise results suggest that migration would have to, differentially, rise by at least 55% to explain the results, which is very unlikely given the empirical evidence in Section A.2.1. This evidence is consistent with the fact that most of the districts are rural where (selective) migration may be difficult to achieve. The results are consistent with other papers showing a lack of selective migration in developing country settings (Bazzi et al., 2016).

[28]The results are consistent and available for other outcomes upon request.



Notes: Figure plots the distribution of estimates under various trimming values. Regressions (a total of 20) are estimated by OLS. Dependent variables are child health, weight-for-age WFA z and height-for age HFA z, in (a) and (b) respectively. Meningitis shock is z-score indicator based on district level mean. Models include full set of fixed effects and district level linear time trends. Robust standard errors in parentheses clustered by district. 90% confidence intervals are shown by horizontal lines, separately for each regression. Color codes: blue denotes the baseline model (with no trimming), and red denotes insignificant estimates for the main interaction term- showing the trimming level that interaction term turns insignificant.

Figure A3: Selective Migration Tests: (a) OLS effect of meningitis shock on child health in epidemic vs non-epidemic years with trimming of highest weight-for-age (WFA z) in meningitis affected districts; (b) OLS effect of meningitis shock on child health in epidemic vs non-epidemic years with trimming of highest height-for-age (HFA z) in meningitis affected districts

A.3 Meningitis Epidemics, Economic Activity and World Bank Aid

Meningitis shocks may affect economic activity directly through either income effects on households, as discussed previously, or through their effects on triggering an inflow of aid in declared epidemic years. We examine the relationship between meningitis shocks and economic activity. Following the literature using night light density as a proxy for economic activity (Henderson, Storeygard, and Weil, 2011; Michalopoulos and Papaioannou, 2013), we use data on night light density from the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) to measure economic activity in the absence of detailed microlevel income estimates for the study countries. Night light density data from the NOAA is available from 1992, and we use data from 1992 to 2008 to match meningitis case data from our study region. Since a notable fraction of the district level observations take on the value of zero, following previous literature, we use the log of night light density, adding a small number (ln (0.01+ Light Density)) as our measure of night light density (Michalopoulos and Papaioannou, 2013). The log transformation allows us to use all observations and account for outliers in the luminosity data (Michalopoulos and Papaioannou, 2013). In alternate specifications, we use different transformations of the night light density measure, like the arcsine transformation. While the results using the arcsine transformation are qualitatively similar, they are not robust, and hence, results using the log night light density measure should be interpreted with caution.

A.3.1 Results for Night Light Density

Table A21 reports estimates from Equation 1 on the effects of meningitis shocks on the night light density outcome. On average meningitis shocks reduce economic activity, as measured by night light density by around 6% (columns (1) and (2)). The results are significant in the country-year FE model, while the estimate is noisier in the linear time trends model,

although the estimate remains stable at around 6% in both. We conduct falsification tests to see if changing the shock year erroneously with lags (columns (3) and (4)) or leads (columns (5) and (6)) have any effects on the night light density outcomes. Across all specifications of lags and leads, meningitis shocks in erroneous years have no significant effects on economic activity.

Table A22 reports estimates from Equation 2 with the night light density outcome. First, we interpret the results from the country-year FE model. Meningitis shocks increase economic activity by around 17.1% in epidemic years and reduce economic activity by 14.2% in non-epidemic years. The effect of meningitis shocks during epidemic years is effectively reversed, with an increase in economic activity of up to 2.9% in meningitis shock districts during declared epidemic years. The results are nearly identical in the linear time trend specification from Equation 2, and the estimates are largely stable, if slightly underpowered, as shown in columns (3) and (4).

We can benchmark these nightlight density results to GDP growth rate figures using a simple back of the envelope calculation based on estimates from Henderson, Storeygard, and Weil (2011) where a 1% increase in nightlight density increases GDP growth rates by about 0.3% in low and middle income countries. Back of the envelope calculations show that meningitis shocks can reduce GDP growth rates by between 2% and 4.3% in the absence of a WHO epidemic declaration.

The results are striking, in that although the average effect of meningitis shocks is negative, there is significant heterogeneity in the effects of these shocks depending on whether or not the WHO declares an epidemic year. Given the high share of health expenditure sourced from donor aid in the majority of the study countries as discussed in Section 3, a major mechanism explaining this result may be an influx of disaster aid when the WHO declares an epidemic year.

Table A21: Effect of meningitis shock on economic activity, including a robustness test with lags and leads

	Log Night Light Density					
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	−0.058	−0.065*				
	(0.044)	(0.036)				
Meningitis shock, t-1			−0.027	−0.013		
			(0.041)	(0.034)		
Meningitis shock, t+1					0.035	0.032
					(0.030)	(0.027)
Mean of outcome	-2.741	-2.741	-2.741	-2.741	-2.741	-2.741
Observations	1,141	1,141	903	903	903	903
Clusters	242	242	242	242	242	242
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trends (D)	Yes	No	Yes	No	Yes	No
Country x year FE	No	Yes	No	Yes	No	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Outcome is at the district level. Dependent variable is log night light density described in text from 8 African countries from 1992 to 2008. Meningitis shock is Z score indicator based on district level mean as described in text. Meningitis shock, t-1 is the lagged indicator from the previous year, t-1 Meningitis shock, t+1 is the leading indicator from the following year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A22: Effect of meningitis shock on economic activity in epidemic vs non-epidemic years (Models: country x year FE and district specific time trends)

	Log Night Light Density			
	(1)	(2)	(3)	(4)
Meningitis shock	-0.075^{**}	-0.065^{*}	-0.142^{**}	-0.142^{*}
	(0.033)	(0.036)	(0.064)	(0.088)
Meningitis shock x Epidemic year			0.171^{**}	$0.159^{\cdot}$
			(0.082)	(0.099)
Mean of outcome	-2.741	-2.741	-2.741	-2.741
Observations	1,141	1,141	1,141	1,141
Clusters	242	242	242	242
District FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes
Linear time trends (D)	No	No	No	Yes
Country x year FE	No	Yes	Yes	No

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district.Two models estimated with country-year FE in columns (1) to (3) and district specific time trends in column (4) as described in text. The Epidemic year coefficient is omitted in the model with country x year FE. The Epidemic year coefficient in column (4) with district time trends is -0.030 and insignificant at conventional levels. Dependent variables are log night light density described in text from 8 African countries from 1992 to 2008. Meningitis shock is Z score indicator based on district level mean as described in text. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level. $^{\cdot}$ Significant near 10 percent level with $p \approx 0.1$.

A.3.2 Health Aid in Epidemic and Non-Epidemic Years

Although we do not have detailed data on total amounts disbursed to health projects in each year, we can test whether or not meningitis shock districts that receive a greater share of health aid projects experience increases in economic activity directly by re-estimating the models in Equation 2 with country-year FE to account for the small sample, and interacting the meningitis shock variable with the share of health projects funded in each district. The results are shown in Table A23[29]. Meningitis shock districts that receive a greater share of health aid projects and more health aid committed and disbursed experience an increase in their economic activity as measured by night light density and shown in columns (1)-(3). The effect is driven by health specific aid not non-health aid as shown in columns (4) and (5).

A.4 Health Expenditures and Aid in the Meningitis Belt

Table A24 reports results on the effects of meningitis epidemics on private health expenditures. There is a significant increase in prepaid private health expenditures[30] in the 20 meningitis belt study countries between 1995 and 2008. Domestic government health spending, in contrast, remains unchanged in response to epidemics. This is perhaps unsurprising given that government health spending accounted for just over 23% of health spending among meningitis belt countries, while out of pocket expenditures made up 47% of total health spending as of 2017 by World Bank estimates. Meningitis epidemics are a notable negative income shock to households in the belt. Given that these shocks pose a significant private cost to households and the fact that 23% of health spending in the belt comes from external, donor sources, do these donors/lenders respond with increased financing to belt countries during epidemics?

[29]There is not enough power for a triple interaction or split sample approach including the declared epidemic year.

[30]Prepaid private spending includes private insurance and non-governmental agency spending.

Table A23: Effect of meningitis shock on night light density outcomes by World Bank aid share of health projects, and total committed and disbursed aid

	Log Night Light Density				
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	−0.094*	−0.103*	−0.103*	0.767	−0.153
	(0.058)	(0.061)	(0.061)	(1.578)	(0.310)
Share health	0.055				
	(0.222)				
Comm. health		−0.130			
		(0.117)			
Disb. health			−0.131		
			(0.117)		
Comm. non-health				−0.002	
				(0.006)	
Disb. non-health					−0.002
					(0.007)
Meningitis shock x Share health	0.188*				
	(0.095)				
Meningitis shock x Comm. health		0.009*			
		(0.005)			
Meningitis shock x Disb. health			0.009*		
			(0.005)		
Meningitis shock x Comm. non-health				−0.010*	
				(0.006)	
Meningitis shock x Disb. non-health					−0.007
					(0.006)
Mean of outcome	−3.056	−3.056	−3.056	−3.056	−3.056
District FE	Yes	Yes	Yes	Yes	Yes
Country x year FE	Yes	Yes	Yes	Yes	Yes
Observations	147	147	147	147	147

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is Log night light density described in text from 8 African countries. Meningitis shock is Z score indicator based on district level mean as described in text. Results qualitatively similar with district specific time trends (D). ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A25 reports results on the effects of epidemics on ODA aid flows committed to meningitis belt countries. There is no effect of epidemic year declarations on total aid committed to belt countries during the epidemic year as shown in column (2). The share of aid committed to health or to infectious disease control in particular is not significantly associated with epidemic year declarations as shown in column (1). On the other hand, epidemic year declarations are strongly positively associated with the total amount committed to infectious disease control and the share of infectious disease spending in total aid committed in the following year as shown in column (3) and column (4) of Table A25. National government donor aid agencies are slow to respond to epidemics in recipient countries. Additionally, there is no increase in overall aid committed in the following year, suggesting targeted increases in infectious disease spending only and potential crowd-out of non-health spending following an epidemic year.

In contrast, international financial organizations like the World Bank are quicker to respond to epidemic declarations with crisis financing as shown in Table 6. The World Bank funds more health projects during epidemic years, and increases the total amount committed and disbursed to countries during the epidemic year. The results do not show the same lag in funding from the Bank as in the national government donor agencies. There is similar crowd-out, with World Bank aid funding distributing away from non-health projects towards health projects.

A.4.1 Domestic Government Effort

We explore the possibility that the reversal in meningitis shock effects following WHO epidemic declarations may be driven by national governments domestic efforts. We define government effort as potential investments in the health sector. We draw on country-level panel data on health from World Bank's World Development Indicators to derive two alternative measures of government's domestic health sector effort, which include (i) domestic

general government health expenditure (% of current health expenditure) and (ii) domestic general government health expenditure (% of general government expenditure). Using these as outcomes, we estimate a modified version of the baseline regression model to test for the potential role of government effort in mitigating the epidemic effect. Table A26 shows the results and indicates no meaningful evidence of governments' domestic efforts/investment.

Figure A4: World Bank project approval example snapshot

Top 5 WB Project titles by Epidemic year and Health classification	Health project= 0	**Health project=1**
Epidemic year= 0	• Transport sector project • Transport sector program support project • Urban infrastructure rehabilitation project • Transport infrastructure rehabilitation project • Local urban infrastructure development project	• Community action program • Social fund • Health, fertility and nutrition project
Epidemic year=1	• Road Transport project • Pilot private irrigation promotion project • Post-Primary education • Regional Hydropower development project • Village infrastructure project	• Health sector development program • Economic recovery and adjustment credit (ERAC) project

Figure A5: Top 5 World Bank health and non-health projects funded by project title in epidemic and non-epidemic years

Table A24: Reduced Form Relationship Between Epidemic Year and Health Expenditures for Meningitis Belt Countries, 1995-2008

	Panel: Prepaid Private Spending (PPP) and Government Health Spending (GHES)					
	PPP/THE	PPP/GDP	PPP/CAP	GHES/THE	GHES/GDP	GHES/CAP
	(1)	(2)	(3)	(4)	(5)	(6)
Epidemic Year	0.005*	0.0003**	0.455**	0.014	0.001	1.471
	(0.003)	(0.0001)	(0.198)	(0.016)	(0.001)	(1.136)
Mean of outcome	0.038	0.002	2.510	0.285	0.015	22.626
Observations	107	107	107	107	107	107
R^2	0.970	0.938	0.975	0.810	0.827	0.893
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses. Observations are 20 meningitis belt countries for which data is available over 1995 to 2008 including: Benin, Burkina Faso, Cameroon, CAR, Cote d'Ivoire, DRC, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan, and Togo. CAP is per capita. GDP is per GDP in 2015 USD PPP. Country and year fixed effects included in all specifications. Source: Global Burden of Disease Health Financing Collaborator Network. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A25: Effect of meningitis epidemics on ODA aid flows committed to belt countries, 1995-2008

	Concurrent Spending, t			**Spending, t+1**		
	Infectious/Total	Comm. Total	Comm. Infectious	Infectious/Total	Health/Total	Comm. Total
	(1)	(2)	(3)	(4)	(5)	(6)
Epidemic Year	−0.003	−0.033	0.895***	0.005**	−0.008	−0.153
	(0.003)	(0.091)	(0.331)	(0.003)	(0.010)	(0.100)
Mean of outcome	0.009	20.430	14.446	0.009	0.064	20.420
Observations	78	112	60	60	91	91
R^2	0.609	0.920	0.818	0.557	0.406	0.950
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses. Observations are 20 meningitis belt countries for which data is available over 1995 to 2008 including: Benin, Burkina Faso, Cameroon, CAR, Cote d'Ivoire, DRC, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan, and Togo. *ConcurrentSpending* is same year spending in columns (1) and (2). $Spending, t+1$ is spending in the following year. Comm. Total is log (total committed real (2010) dollars). Comm. Infectious is log (1+ total committed real dollars to infectious disease control). Source: OECD CRS data ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A26: Domestic government health expenditure

	Govt. health exp. (% of current health exp.)			Govt. health exp. (% of general govt. exp.)		
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock		−0.448	0.129		−0.089	0.049
		(0.303)	(0.601)		(0.057)	(0.116)
Epidemic year	−0.634**		−0.725*	−0.130**		−0.156**
	(0.268)		(0.418)	(0.051)		(0.079)
Meningitis shock x Epidemic year			0.018			−0.014
			(0.424)			(0.082)
Constant	29.900***	29.550***	29.960***	6.496***	6.423***	6.511***
	(0.296)	(0.256)	(0.359)	(0.110)	(0.106)	(0.118)
Observations	15,032	15,032	15,032	15,032	15,141	15,141
R^2	0.915	0.915	0.915	0.916	0.915	0.916
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Regressions estimated by OLS. Robust standard errors in parentheses. Regressions estimated by OLS. Dependent variables are two alternative measures of government's domestic health sector effort: (i) domestic general government health expenditure (% of current health expenditure) and (ii) domestic general government health expenditure (% of general government expenditure). Country-level panel data on (i) and (ii) from World Bank's World Development Indicators merged with WHO national epidemic declarations and district-level measures on Meningitis shock for the 8 African countries. Year FE are survey year fixed effects. Meningitis shock is z-score indicator based on district-level mean and equal to 1 if the z-score is greater than 0. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.