# ‘An Ill Wind that Blows No Girl Any Good’: The Impacts of Climate-Induced Disease on Gender Inequality*

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## Abstract

Disease epidemics with climate links can worsen social inequality by increasing gender gaps in educational attainment through raising the direct and opportunity costs of investing in girls, particularly in poorer countries in the tropics. We investigate this hypothesis by examining the effects of sudden exposure to the 1986 meningitis epidemic in Niger on the gender gap in education. We document a significant reduction in years of education for school-aged girls relative to boys following the epidemic. We explore several channels underlying the results and find evidence highlighting income effects of epidemics on households and increased early marriage of girls.

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# 1 Introduction

> *"In my community work I soon learned more about the barriers for girls in school. If families are going through a financial rough patch, they're more likely to pay fees for boys rather than for girls. If girls drop out of school, the family is eager to marry them off rather than have them sit around the house all day."*
>
> \- Natasha Annie Tonthhola, *BBC News, October 25, 2016*

In almost every region of the world, negative shocks to societies disproportionately harm women. Disease epidemics induced by changes in climate are one such shock. While there is a growing literature on the science and economic impacts of climate change, there is relatively little research understanding how the effects of future warming will affect social inequality, particularly through increasing gender gaps in human capital investment. Given the prevalence of disease environments in poorer regions in the tropics, there is also relatively little work done to understand the relationship between disease environments worsened by climate and gender inequality (Glewwe and Miguel, 2007). While the economic gains from educating girls are significant, health costs from worsened disease environments due to global warming, can impose significant financial costs on households, which might lessen relative investment in girls' education. This may be particularly true in a developing country context if parents have lower expected return from investment in girls' human capital (Schultz, 2002; Barro and Lee, 2013)[1].

In this study, we ask how disease epidemics induced by climate affect gender gaps in educational attainment in a developing country context. We focus on the influence of early school-age disease burdens induced by climate conditions because of the robust evi-

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[1] Although gaps in primary school enrollment have been closing, largely due to national policies promoting free primary education, gaps in educational attainment still remain, partly driven by lower primary completion rates and lower secondary school enrollment rates for girls relative to boys in poorer countries concentrated in Africa and Asia. Source: OECD "Closing the Gender Gap" report.

dence that experiences early in life have large, lasting impacts on human capital[2], and a separate, growing body of research on how climatic conditions influence health and society (Carleton and Hsiang, 2016). More specifically, we exploit variation in exposure to the 1986 meningitis epidemic in Niger to examine the impacts of the epidemic on the gender gap in educational attainment. We use different datasets, combining representative surveys for our human capital outcomes with micro-level data on meningitis cases from the World Health Organization (WHO) and climate information from high resolution NASA data on the Harmattan season in Africa. The Harmattan season is the dry season in much of sub-Saharan Africa, and the Harmattan are dry northeasterly trade winds that blow dust across the Sahara. We show that meningitis epidemics are robustly driven by climate conditions signaling the onset of the Harmattan season in Africa. We take advantage of three unique features of this environment: (i) Niger has some of the largest gender gaps in education in the world (OECD, 2012; Barro and Lee, 2013); (ii) it presents a novel and large quasi-experiment of a climate-induced disease- the 1986 Meningitis epidemic- that allows us to cleanly identify the effects of a significant health shock; (iii) as we discuss in later sections, Niger is a homogeneous environment, further allowing for clean identification since we can credibly control for any differences across disease exposed units or districts, which will be our main unit of randomization.

We exploit variation in exposure to the 1986 meningitis epidemic and the Harmattan season for school-aged children. We estimate a difference-in-differences model that interacts an indicator for gender with a continuous cohort-based measure of meningitis exposure during the 1986 epidemic, and find that higher meningitis exposure reduced years of education for school-aged girls. There is no significant difference in the education of boys exposed to higher or lower meningitis incidence during the epidemic. Substantively, a case increase in the mean weekly meningitis cases per 100,000 population in each district is associated with a 3% to 4%

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[2] See Heckman (2006, 2007); Almond, Edlund, and Palme (2009); Archibong and Annan (2017) for details.

decrease in years of education completed disproportionately for primary-school-aged girls, relative to the mean educational attainment. The decrease in a sample of secondary-school-aged girls is 2% to 3%. The effects are robust to several alternate model specifications, the influence of concurrent shocks, and falsification tests.

What drives the estimated impacts of meningitis epidemics on gender gaps in educational attainments? There are at least two channels through which climate-induced health shocks can differentially affect educational investments and attainments by gender: direct health and biological effects versus indirect economic impacts on households. The direct channels may reflect whether girls are biologically more likely to die from meningitis, or the differential effects by gender on cognitive development from the disease, resulting in lower educational attainment for girls relative to boys (Janghorbani et al., 1993; Sen, 1998; Jayachandran and Lleras-Muney, 2009; Almond, Edlund, and Palme, 2009). We do not find evidence for the direct channels here.

We find evidence in support of indirect economic impacts driving the increased gender gap results, where the high economic costs of disease burdens during epidemic years induce households to marry off their daughters at earlier ages. This finding is consistent with recent studies suggesting that in bride price societies (as in our study area), early marriage of girls can increase in response to negative income shocks where income and wealth transfers are made from the groom's family to the bride's family upon marriage (Corno and Voena, 2016; Corno, Hildebrandt, and Voena, 2017). Predictions from a framework that explores climate-induced health events as liquidity shocks and the practice of marrying-off daughters in the aftermath of income shocks as an outside option for households are congruent with the empirical results.

Next, we examine the connection between meningitis, wealth and early marriage. Using data on assets from the Demographic and Health Surveys (DHS), we construct a wealth index and define liquidity or asset constrained households as those located in the lower parts of the asset distribution. Heterogeneity analysis suggests that the estimated gender impacts are concentrated among the liquidity constrained households, lending further support for the income effects and early marriage channel following meningitis epidemics. Finally, we use high resolution NASA data to show that meningitis epidemics are robustly driven by climate conditions, specifically winds and dust, signaling the onset of the dry, Harmattan season in Africa.

We add to several distinct literatures. First, our work is related to the economics literature on early life shocks/ interventions and human capital formation (Currie and Almond, 2011; Heckman, 2006, 2007). These studies show that changes in early life exposure can affect a wide variety of outcomes, including mental distress (Adhvaryu, Fenske, and Nyshadham, 2018), physical health (Hoynes, Schanzenbach, and Almond, 2016; Adhvaryu et al., 2016), and school enrollment, performance and attainment (Aizer and Cunha, 2012; Bharadwaj, Løken, and Neilson, 2013; Bleakley, 2007; Archibong and Annan, 2017; Autor et al., 2019), and labor market outcomes (Almond, 2006; Gould, Lavy, and Paserman, 2011; Bhalotra and Venkataramani, 2015). Second, our work is related to the growing literature on the social and economic impact of climate. Previous work has documented the influence of climate conditions such as temperature, rainfall and violent storms on health, agriculture, economic growth, conflict, migration, and demographics (Carleton and Hsiang, 2016). The literature has also explored the relationship between yearly variability in meningitis outbreaks and climate variables during the most intense part of the dry, Harmattan season in sub-Saharan Africa (García-Pando et al., 2014; Yaka et al., 2008).

Our work contributes to these previous studies in economics and environmental health in several important ways. First, we highlight and provide evidence of the meningitis, educational and early marriage market impacts of the Harmattan season. In doing so, we also examine the linkages between standard theories of intrahousehold resource allocation (Becker, Murphy, and Tamura, 1990) and the relatively thin economics literature on norms within arranged market institutions (Fafchamps and Quisumbing, 2007; Anderson, 2007; Tertilt, 2005; Vogl, 2013; Behrman et al., 1999). We expand these literatures by demonstrating that disease burdens induced by climate conditions during early school age have large causal effects on differential educational attainments by gender. This allows us to document the potential role of adverse climatic conditions in exacerbating social inequality, weighed in parallel to the potential efficiency gains of closing the educational gender gap. While Archibong and Annan (2017) documents the impacts of meningitis epidemics on gender gaps in education, here, we show additionally that epidemics are driven by climate through the Harmattan season, and educational gender gaps likely operate through changes in the marriage market. We formulate a model yielding predictions that are consistent with the empirical findings. We also add to the growing evidence in this area by examining a developing country setting whereas most previous studies focus on developed countries.

Finally, estimating the contribution of health shocks driven by climatic conditions to differential human capital investment by gender is especially important for developing countries in Africa and Asia where the combination of notable gender gaps in educational attainment and higher disease burdens in the tropics can impose a double cost for economic development. Our results have important implications: first, health shocks disproportionately impact investment in girls' education, as the direct and opportunity costs of investing in girls' education are higher during shocks, with significant implications for marriage market outcomes. Second, a focus on improving attainment through free, mandatory primary education programs means that most of the investment in educating girls will occur at the primary level in poorer countries. Thus, disease shocks will have disproportionate effects on primary-school-aged girls, decreasing the likelihood of primary school completion and resulting in lower attainment for girls relative to boys. Third, our findings highlight the need for policies targeting health, education and climate concurrently to close the gap in educational attainment and maximize economic returns from the associated gains in human capital investment, particularly for poorer countries located in tropical areas with higher disease burdens.

The rest of the paper is organized as follows. Section 2 outlines a conceptual framework that motivates and guides our empirical analysis. Section 3 provides background on the relationship between climate, the Harmattan season, and epidemics in the meningitis belt focusing on the 1986 meningitis epidemic in Niger. Section 4 describes the data. Section 5 outlines our empirical strategy. Section 6 provides quantitative estimates on the impacts of the epidemic on the gender gap in education. Section 7 explores direct and indirect channels, examines the impact of the epidemic on early marriage of girls and evaluates alternative explanations for the results. Section 8 discusses the effect of the Harmattan season on the occurrence and incidence of meningitis outbreaks during epidemic years. Section 9 concludes.

## 2 Conceptual Framework

This paper tests the hypothesis that aggregate health shocks can have differential impacts on male and female human capital investment choices and outcomes. There are two primary channels through which health can differentially affect human capital, broadly categorized as direct- through health and biology- and indirect channels- through economic impacts on households. Through the direct channel, a health shock like a meningitis epidemic can have different biological effects on male and female infected persons. If, for instance, girls are biologically more likely to die from meningitis, then the evidence could show fewer years of education during the epidemic year for girls relative to their male counterparts (Janghorbani et al., 1993; Sen, 1998; Jayachandran and Lleras-Muney, 2009). Another way the direct health channel could operate is if there are differential effects by gender on cognitive development from the disease, resulting in lowered educational attainment for girls relative to boys (Almond, Edlund, and Palme, 2009).

Through the indirect channel, a health shock like a meningitis epidemic has income effects on the household. The household is modeled as a unitary entity with liquidity and credit constraints. The health shock acts as a negative income shock to the household, raising health expenditures, resulting in missed work days/forgone income and raising the costs of domestic care for sick household members. This leads the household to attempt to smooth consumption by reducing expenditures on certain consumption bundles and selling off available assets (Islam and Maitra, 2012). In many communities, these "assets" include female children.

Early marriage of girls can increase in response to a negative income shock in bride price societies where income and wealth transfers are made from the groom's family to the bride's family upon marriage (Corno and Voena, 2016; Corno, Hildebrandt, and Voena, 2017). Corno, Hildebrandt, and Voena (2017) outline a model and provide evidence for an increase in early marriages (a reduction in the age at first marriage) in response to income shocks in bride price societies[3]. Lowered age at first marriage is associated with lower educational attainment and subsequent lower earnings in a standard Mincerian model of returns to education[4], with girls often dropping out of school or completing less schooling at the time of marriage (Corno and Voena, 2016; Corno, Hildebrandt, and Voena, 2017). The early marriage channel could explain a widened gender gap in educational attainment following a meningitis epidemic.

We present a simple framework of schooling and marriage choices to guide the empirical

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[3] Corno, Hildebrandt, and Voena (2017) contrast this effect of negative income shocks increasing rates of early marriage in bride price societies in SSA with the effect in dowry communities like India, where both the direction of marriage payments and the effect on early marriage are reversed.

[4] The benefits of educating female children extend beyond earnings to potential improvements in health and higher bargaining power within households among other returns modeled implicitly in this framework (Jayachandran and Lleras-Muney, 2009).

analysis. Our goal is to understand [i] the relationship between climate-induced health shocks (via tightening of household budget constraints) and gender gaps in educational attainment, and [ii] how the practice of marrying off daughters may affect educational investments for girls relative to boys in the aftermath of income or budgetary shocks.

For [i], the basic framework is adapted from Björkman-Nyqvist (2013). In this setup, there is a family $i$, that has two children who vary by gender with boys denoted by the subscript $b$ and girls by the subscript $g$. Within a unitary household model, for each family $i$, parents maximize discounted expected utility over two periods and choose to invest in schooling for girls (denoted $s_g$) and boys (denoted $s_b$). In period 1, the child works at home, goes to school or both. In period 2, the child is an adult and works for a wage. The parents' optimization problem is as follows

$$maxU_i = u(c_1^i) + \delta c_2^i$$

$$s.t.$$

$$c_1^i = y_1 - pe_b^i - pe_g^i + \eta_b(1 - s_b^i) + \eta_g(1 - s_g^i)$$

$$and$$

$$c_2^i = y_2 + \gamma_b y_b^{ai} + \gamma_g y_g^{ai}$$

where $a_s^i = \alpha_s^i s_s^i$; $s_s^i \in [0,1]$; $y^{ai} = \omega_s a_s^i$ ($\omega_b > \omega_g$ and $\gamma_b > \gamma_g$); $\eta_g > \eta_b$; $\theta_s = \delta\gamma_s\omega_s$ and $\theta_g < \theta_b$ and $c_t^i$ is parent $i$'s consumption in period $t$, $u$ is a concave utility function and $\delta$ is a discount factor. $a_s^i$ are cognitive skills with $\alpha_s^i$ denoted as the learning efficiency of a child of gender $s$ in family $i$ and which is assumed to be equal for boys and girls. $s_s^i$ is the fraction of time in period 1 spent in school by a child from family $i$ of gender $s$ and defined over the interval [0,1]. $y_t$ is (exogenous) parental income and $p$ is the schooling price for a child. $e_s^i$ is an indicator variable that takes 1 if family $i$ sends a child of gender $s$ to school. $\eta_s(1 - s_s^i)$ is the income provided from home production in period 2; we assume, based on the evidence from the anthropological literature in this region, that parents perceive girls' labor in home production to be of greater value than that of boys (Björkman-Nyqvist, 2013; Hartmann-Mahmud, 2011)[5].

$\gamma_s y_s^{ai}$ is the share of the child's income transferred to her parents, with the expected share transferred greater for boys than for girls in societies with patrilocal exogamy where girls typically leave their natal households upon marriage while boys remain. $\omega_s$ is the return to education of a child of gender $s$, with the assumption being that parents or male heads of households expect higher private returns for boys[6]. Given simple restrictions on the parameters above[7] and outlined in Björkman-Nyqvist (2013), the first order condition for household $i$, after maximizing the parent's expected utility will be:

$$FOC : -u'(c_1)\eta_s + \alpha_s^i \theta_s^i \leq 0 \quad \text{for} \quad s_s \in [0,1]$$

and parents will choose to invest in schooling for a child up to where the marginal cost of more schooling, in the form of forgone time for domestic production or forgone income from early marriage for girls, is equal to the marginal benefit, in the form of higher transfers from a more educated and subsequently higher paid adult. An implication of the model is

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[5] Tasks in home production typically assigned to female household members in this region include "taking care of younger siblings and domestic chores such as food preparation, fetching water, collecting firewood, washing clothes, and taking care of the sick and the old" (Björkman-Nyqvist, 2013; Hartmann-Mahmud, 2011).

[6] See the discussion outlined in Björkman-Nyqvist (2013). While there is limited empirical evidence on parental expectations around returns to education by child gender, the anthropological literature documents evidence of this phenomenon in this region (Hartmann-Mahmud, 2011).

[7] Without loss of generality, to simplify the notation, we normalize $\theta_b$ and $\eta_b$ to 1 and assume $p = 1$ (Björkman-Nyqvist, 2013).

"if both $s_b$ and $s_g$ are greater than 0, a reduction in parental income, $y_1$, will on the margin only reduce investment in girls' education" (Björkman-Nyqvist, 2013).

***Prediction 1:*** *A reduction in parental income* $y_1$ *will result in a disproportionate reduction in investment in only girls' education on the margin.*

[ii] We extend the standard framework with budget constraints to include marriage arrangements, which are prevalent in bride price societies and act as outside options and possible avenues for households to cope with income shocks. This extension is similar to the framework in Vogl (2013). For each period, there is a probability $\lambda \in (0,1)$ that the bride's family or parents can search and find a relatively well-to-do man to marry their daughter in exchange for a transfer of wealth $q$ from the man, where $q$ is drawn from the distribution $\mathcal{F}$[8].

To simplify the exposition, we assume that the terms of the marriage contract are enforceable, and that $Pr(Marriage|g) > Pr(Marriage|b)$, where $Pr(Marriage|g)$ is the probability of early marriage (before the age of 18) for girls. The justification for this is that it is not customary to marry younger boys, aged 0 to 18, in the societies that we study (Corno and Voena, 2016). Next, the marriage happens with probability $\pi$ — i.e., the groom (man) accepts the terms of the marriage contract. To link income shocks and marriage arrangements, we introduce the following plausible condition:

***Relevancy condition:*** $\pi(Shock) \geq \pi(no\ Shock)$.

This states that the conditional probability that a marriage happens is higher in the event of an income shock compared to when there is no shock. The justification for this is that more brides should become available and thus likely cheaper in the aftermath of a shock (assuming stable demand for brides)[9].

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[8] While not explicitly modeled, our illustration extends to polygamous settings.

[9] See Corno, Hildebrandt, and Voena (2017) for a more formal exposition of this condition.

Finally, the bride's family mutually accepts the marriage contract if the transfer $q$ exceeds their reservation level, denoted $\underline{q}$. In practice, $\underline{q}$ may reflect a transfer size that is greater than the value of having the bride unmarried to remain at home to engage in home production or other activities. Within this framework, marriage contracts are successfully executed with probability

$$\lambda\pi[1 - \mathcal{F}(\underline{q})]$$

which is the product of the probabilities that the bride's family finds a relatively well-to-do man, the groom accepts the bride, and the transfer of wealth between the groom and the bride's family exceeds their reservation level. We can use this to analyze gender-differentiated marriage rates by defining the difference between marriage probabilities with and without the budgetary shock, $\triangle_s$, as

$$\triangle_s = \lambda[1 - \mathcal{F}(\underline{q})] \times \{\pi(Shock) - \pi(no\ Shock)\}$$

Since $\{\pi(Shock) - \pi(no\ Shock)\} \geq 0$, it follows that marriage rates are higher in the event of budgetary shocks irrespective of the child's gender: either male or female. Because $Pr(Marriage|g) > Pr(Marriage|b)$, it also follows that in the event of income shocks, rates of early marriage will be higher for girls compared to boys. This can be seen by multiplying $\triangle_s$ with the gender differentiated marriage rates $\{Pr(Marriage|g) - Pr(Marriage|b)\} > 0$ since it is more customary for males to marry younger girls in this context, with the reverse being much less common.[10]

***Prediction 2:*** *$\forall$ g,b: the marriage probability is higher in the event of an income shock compared to the no shock scenario.*

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[10] We show this in the results using evidence from Niger. An implication of our analysis is: $\frac{\partial \triangle_s}{\partial \underline{q}} \leq 0$. This suggests that marriage rates could be lower if brides' families increase their reservation price over the marital transfers $q$.

***Prediction 3:*** *In the event of an income shock, the early marriage probability is higher for girls compared to boys.*

## 3 Climate, the Harmattan Season and Epidemics in the Meningitis Belt

Meningococcal meningitis is a disease so endemic in the sub-Saharan Africa (SSA) region that a group of 23 countries from Senegal to Ethiopia- home to more than 700 million individuals- has been labeled the "meningitis belt" due to recurrent exposure to meningitis epidemics as shown in Figure 1. The epidemic[11] form of the disease is caused by the bacterium *Neisseria meningitidis* and is typified by an infection of the thin lining, known as the meninges, covering the brain and spinal cord.

Symptoms associated with meningitis infection include pain, fever, reduced cognitive function, and in the most severe cases, permanent disability, long-term neurological damage and death. The World Health Organization (WHO) states that around 30,000 cases of the disease are reported each year, with case figures increasing significantly during epidemic years[12]. Meningococcal meningitis can have high fatality rates, up to 50% if left untreated according to WHO estimates[13]. Although vaccines have been introduced to counter the disease since the first recorded cases in 1909 for SSA, effectiveness of the vaccines has been limited due to the mutation and virulence tendencies of the bacterium (LaForce et al., 2009).

Although the epidemiology of the disease is complex, the epidemic form of the disease is thought to have a significant climate driver, with greater incidence associated with increased wind speeds, dust concentrations and lower temperatures that arrive with the on-

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[11] Epidemics are defined in the SSA context as greater than 100 cases per 100,000 population nationally within a year by the World Health Organization (WHO) (LaForce et al., 2009).

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

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

set of the dry, Harmattan season in SSA (LaForce et al., 2009; García-Pando et al., 2014). The Harmattan season itself generally extends from October till March, with the harshest part of the season in the first few months from October to December (García-Pando et al., 2014). The season is typified by hot, dry northeasterly trade winds blowing dust from the Sahara throughout West Africa. Recent scientific literature has provided evidence that higher temperatures, lower precipitation, and humidity associated with future warming and climate change might increase the incidence of meningitis epidemics in the meningitis belt (Abdussalam et al., 2014; Sultan et al., 2005).

While the mechanisms of disease transmission are not completely understood, direct transmission of meningitis is believed to occur through contact with respiratory droplets or throat secretions from infected individuals. During the Harmattan season in SSA, the dust particles carried by the Harmattan winds are supposed to make the mucus membranes of the nose of the region's inhabitants more sensitive, thus increasing the risk of meningitis infection (Yaka et al., 2008). Young children and adolescents are particularly at risk of infection from the epidemic form of the disease.

Niger is one of the worst affected countries in the meningitis belt as more than 95% of the country's population resides in the belt (Yaka et al., 2008). Yaka et al. (2008) find that 25% of the yearly variance in meningitis incidence in the country can be explained by the Harmattan climate. The country has experienced six epidemics since 1986, with the longest lag occurring between the 1986 and 1993 epidemics[14] (Archibong and Annan, 2017). The periodicity of epidemics in Niger is around 8 to 10 years, with epidemic waves in the meningitis belt occurring every 8 to 14 years (Yaka et al., 2008). In one of the most acute instances in the country's recorded disease history, the 1986 epidemic registered 15,823

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[14] Though there is no subnational record of epidemics available prior to 1986, historical records suggest that the most recent epidemic prior to 1986 occurred in 1979 in Niger (Yaka et al., 2008; Broome et al., 1983).

reported cases per 100,000 population and a mortality rate of approximately 4%[15](Archibong and Annan, 2017). The size of Niger's young population, with the median national age remaining at 15 years for more than a decade, has historically placed a significant share of the country at risk during epidemics[16].

Documented data on health expenditure of countries in the meningitis belt show that households spend a significant portion of their incomes on direct and indirect costs stemming from meningitis epidemics (Colombini et al., 2009). In Burkina Faso, Niger's neighbor in the meningitis belt, households spent some $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 rose to as high as $154 per case. Costs were associated with direct medical expenses from spending on prescriptions and medicines[17] 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 school) (Colombini et al., 2009). Meningitis epidemics are a notable negative income shock to households in the belt.

Domestic, interdistrict migration is limited in Niger[18] and population size across districts has been stable with the distribution almost entirely unchanged since 1986 and a correlation of .99 and .97 ($p < .001$) between 1986 district populations and 1992 and 1998 populations respectively[19]. Given low levels of interdistrict migration in the country, we assess individual exposure to the 1986 meningitis epidemic using a geographically based assignment at the district level (Archibong and Annan, 2017).

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[15] Calculated from WHO data, details presented in Section 4.

[16] Source: DHS and UNICEF statistics.

[17] Vaccines are technically free during epidemics, however information asymmetry among health care workers and shortages of vaccines often raise the price of medication (Colombini et al., 2009).

[18] The majority of migration consists of young male seasonal migrants in the northern desert regions traveling to neighboring countries for work during during dry months (Afifi, 2011).

[19] Source: Authors' estimates from DHS data.

# 4 Data and Descriptive Statistics

We combine data from multiple sources. Data on meningitis exposure comes from the World Health Organization (WHO) and Niger's Ministry of Public Health (MPH) for 1986 and 1990. This reflects district-level records on meningitis cases per 100,000 population, which we combine with individual and district level data on education and demographics from the Nigerien Demographic and Health Surveys (DHS). The district-level DHS data are available for 2 survey rounds in 1992 and 1998 and provide records for individuals in all 36 districts across the country including the capital, Niamey. Our main outcome measure is the years of education completed by an individual, and we limit our sample to the cohort born between 1960 and 1992 which allows us to include cohorts that were of school age during the 1986 meningitis epidemic.

Figure 2 and Figure 3 show the distribution of meningitis cases by district for the epidemic year, 1986, versus a non-epidemic year, 1990, as a comparison[20]. There is significant variation in exposure to the meningitis epidemic across districts, with a mean of around 10 weekly cases per 100,000 population during the 1986 epidemic year versus 1.6 weekly cases per 100,000 population during the 1990 non-epidemic year. Using data from Niger also allows us to exploit homogeneity in religious, ethnic, and income characteristics across individuals in the country to more cleanly capture the effect of meningitis epidemic exposure[21]. District level data on mortality rates from meningitis is available in aggregate form only, and not available by gender.

We rely on information about the birth year to construct school-aged specific cohorts and their exposure to the 1986 meningitis epidemic. Three categories are defined that include

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[20] Results are similar when other non-epidemic years, 1988 and 1989 for example, are used.

[21] Niger is 98% Muslim, over 50% Hausa and most of the population is poor and employed in the agricultural sector. Source: US Department of State, CIA.

individuals aged 0-5, 6-12 and 13-20 with reference to 1986. These age bands reference the Nigerien school-going requirements/context where the 6-12 and 13-20 cohorts correspond to primary and secondary school-going ages respectively, whereas 0-5 are non-school going. While the mandatory age for starting school is 7, we allow our primary school category to start at 6 to control for early school-going children. The bands contain enough observations to ensure that estimations are not performed on empty cells and also help to control for age misreporting in the sample.

Table 1 shows the distribution of our sample and schooling along with a snapshot of variable means for our meningitis cohort-case measure (MENIN) and years of education, our outcome variable, by cohort and gender. Notably, our sample is fairly distributed across age cohorts and gender. About 24% of the sample is contained in the 0-5 age category, 19% in the 6-12 age category, and 17% in 13-20 age category. This distribution is even similar conditional on gender. For example, about 20% of the sample is contained in the 6-12 age category for females, compared to 19% for males. For educational attainment, the 0-5 age category has an average of about 1.1 years, the 6-12 category averaged 2.1 years while the 13-20 category averaged 2 years of schooling. The distribution is also similar conditional on gender as shown in Figure 4[22]. Our overall results are insensitive to marginal changes in the age cutoffs. We predict that the largest magnitudes in reduction of female education during the epidemic will be for primary school-aged-going children given statistics on low secondary school enrollment rates in the country[23]. Conversely, we should see no or little effect of meningitis exposure on years of education for non-school-aged girls (between ages 0-5) during the epidemic year.

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[22] In Figure 4, we display the density functions of educational attainment across the various cohorts and genders. The figures show similar distributional patterns across gender, similar to the average schooling results shown in Table 1. This suggests that our empirical findings are not driven by differences in cohort-level distributional patterns.

[23] Source: UNICEF statistics.

We also appeal to the scientific literature documenting the linkages between the Harmattan season and meningitis outbreaks in the meningitis belt to explore the potential implications of Harmattan for observed gender gap in human capital investment. We use data from NASA's Modern Era Retrospective Analysis for Research and Applications (MERRA-2)[24]. Following the environmental health literature on the climate factors associated with meningitis incidence in Niger, we examine district monthly mean wind speeds (measured in $m/s$), temperatures ($Kelvin$), and dust concentrations ($kg/m^3$). Perez Garcia Pando et al. (2014) highlight the importance of the previous year October-December cycle of these variables, and wind speed in particular, as important climatic predictors of meningitis outbreaks.

The distribution of these variables against meningitis case data during the epidemic year (1985-1986) versus a non-epidemic year (1989-1990) is shown in Figure 5. Consistent with the results in Perez Garcia Pando et al. (2014), wind speeds peak in the more intense part of the Harmattan season preceding the epidemic year (October-December), and fall during the less intense part of the Harmattan season (January-March) during the epidemic year. The trend is much weaker during the non-epidemic years, as shown using the 1989-1990 test case in Figure 5. Figure A1 in the Appendix also displays district-level mean wind speeds during the more intense part of the Harmattan season (October-December) versus the less intense part of the Harmattan season (January-March) during the epidemic period.

Finally, to test hypotheses on the likelihood of early marriage of girls rising during meningitis epidemic years and leading to lowered educational attainment, we use data from the DHS men's and women's subsamples with details provided in Section 7.1.1.

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[24] MERRA-2 is an atmospheric reanalysis data product that assimilates historical observation data over an extended period. https://disc.sci.gsfc.nasa.gov/datasets.

# 5 Empirical Strategy

## 5.1 Intuition

The intuition for our identification strategy is that in an environment that is homogeneous with limited interdistrict migration, households in districts affected by the 1986 meningitis induced by Harmattan, experience the epidemic as either an income or direct health shock, while households in the other districts remained unaffected. Children who were of school-going age during the epidemic and living in meningitis affected districts will experience the impacts, with disproportionately lower investment in girls' education since they act as household insurance through their early marriage and associated bride price transfers during adverse times[25]. This phenomenon could have large and long-range impacts on observed gender gaps in educational attainments.

## 5.2 Model Specification

Our empirical strategy uses differential distribution in meningitis cases per 100,000 population across districts in Niger as a source of variation in cohort-specific meningitis exposure. We estimate panel regressions of school-aged specific cohorts $a$ linking years of education for individual $i$ in district $d$ at survey round $r$ to measures of meningitis exposure $\text{MENIN}_{adt}$ that are interacted with the gender of the individual $\text{female}_{ig}$:

$$\text{education}_{iadrg} = \beta_g \text{female}_{ig} + \beta_a \text{MENIN}_{adt} + \gamma_{ag} \text{MENIN}_{adt} \times \text{female}_{ig} + \mu_d + \delta_r + \delta_t + \epsilon_{iadrg} \tag{1}$$

where $t$ and $g$ index the birth year and gender respectively. This specification includes

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[25] With much higher incidences of girls never starting school or dropping out of school in more highly affected districts.

district fixed effects $\mu_d$ which capture unobserved differences that are fixed across districts. The birth year and survey round fixed effects, $\delta_t$ and $\delta_r$ respectively, control for changes in national policies (e.g. immunization campaigns), potential life cycle changes across cohorts and other macro factors. Note that the birth year fixed effect subsumes cohort specific dummies since cohorts are defined based on birth year and the meningitis reference year 1986. The model also includes uninteracted terms for gender and meningitis exposure.

Our key parameter of interest is $\gamma_{ag}$, which is allowed to vary across cohorts. This measures the impact of MENIN on female respondents' education relative to their male counterparts, using variation across districts and the 1986 meningitis epidemic and identified based on standard assumptions in a difference-in-differences model. MENIN is measured in two ways. In the first case, we calculate the mean weekly cases of meningitis per 100,000 population recorded in a district (MENIN Cases). The second case modifies the first measure by interacting it with the number of months for which meningitis incidence is strictly positive (MENIN Intensity). The implied key variable of interest in Equation 1 is therefore constructed by interacting the MENIN measures with gender. Estimations are done using OLS and standard errors are clustered at the district level. Robustness checks and falsification tests on our identifying assumptions are presented in the results section.

To test hypotheses concerning age at first marriage and meningitis exposure, we estimate OLS regressions of meningitis cases per 100,000 population on age at first marriage using district, year and year of birth fixed effects where possible. In the proceeding sections, we begin with a formal assessment of the effect of Harmattan seasonality on meningitis, then proceed to evaluate the impact of Harmattan on educational attainments by gender, along with the potential mechanisms underlying the estimated gender gaps.

## 6 Effects of Meningitis Exposure on Gender Gap in Years of Education

Results from the baseline specification in Equation 1, examining the gender-differentiated educational impacts of the meningitis epidemic, are discussed in this section.

### 6.1 Main Results

Table 2 reports estimates from two specifications for our two measures of meningitis exposure (i.e., MENIN Cases; MENIN Intensity) using 1960 to 1992 birth-year cohorts. Columns 1a and 1c display results for the linkages between educational attainment, gender, and meningitis exposure at cohort-level. The gender variable is negative and significant in both columns, documenting the existing gender gap between males and females in favor of males. Meningitis exposure across almost all cohorts is negative and insignificant. It is barely significant at 10% only in the MENIN Intensity measure for primary school cohorts.

Our main results are in Columns 1b and 1d of Table 2 where we interact the meningitis exposure measures with gender to examine gender-differentiated impacts of the meningitis burden on educational investments. Gender is negative and significant. What is striking is that only interaction terms for the school-going cohorts are negative and strongly significant at conventional levels. The interaction estimates are economically large in magnitude, especially in the MENIN Cases measure. Interpreting the results from the MENIN Cases measure in Column 1b, a case increase in the mean weekly meningitis cases per 100,000 population in each district is associated with a reduction of -.044 years of schooling or a 3% to 4% decrease in years of education[26] per case exposure, relative to the mean for female respondents of primary school going age during the epidemic year. Primary school-aged female respondents in higher case exposure districts experience significant reductions in their

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[26] Relative to the unconditional and conditional mean years of education respectively.

years of education relative to their counterparts in lower case exposure districts during the epidemic year.

Similar results are found for the secondary-school-aged female sample, with increases in meningitis case exposure associated with a reduction of -.03 years of schooling or 2% to 3% decrease in years of education, per case exposure relative to the mean for the female cohort. Reassuringly, the interaction is not significant for non-school-going-aged female respondents at the time of the epidemic[27].

### 6.2 Falsification Checks

We conduct various falsification/sensitivity tests. First, the results are robust to small changes/modifications in cohort age cutoffs (Table 3). Our main results are derived using the definition of cohorts based on the 1986 epidemic. In alternate specifications presented in Table 4, we examine school-going and non-school-going-aged cohorts based on the 1990 non-epidemic year. Table 4 reports estimates for cohorts defined based a reference non-epidemic year 1990. We find no effect of meningitis exposure for the primary-school-aged category across all relevant specifications, which is what we would expect[28]. There is evidence of effects for the secondary school aged category. The secondary cohorts are essentially capturing effects of initial exposure to the 1986 epidemic when such cohorts were in primary school[29]. The sign on the 0-5 group is significantly positive which suggests positive investment in

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[27] We also assess the potential role of the Harmattan season via the reduced form link between Harmattan and education. We regressed educational outcomes on our preferred measure of Harmattan seasonality (with the cohort interactions). Results are reported in Table A1. The coefficient of the "female" variable is negative across all model specifications, suggesting significant gender gaps in education. The interaction between female and Harmattan variables (dust concentration, wind speed) is never significant for non-school-age-going cohorts. However, it is negative and significant for the school-age cohorts. Overall, the evidence is consistent with climate or Harmattan playing a significant role in the incidence of meningitis and contributing to the widening of gender gaps in human capital, with disproportionate negative impact on investment in girls' education.

[28] Note since attainment is cumulative, some of this effect captures a long run effect of initial exposure in 1986. The primary school-aged cohort in 1990 includes some of the non school-aged populations in 1986.

[29] Again due to slight serial correlation between 1986 and 1990 exposure as explained in the previous footnote.

education during non-epidemic years[30]. These robustness checks and falsification results make it less likely that we are picking up any spurious/confounding effects in our main results [31].

Our results suggest that meningitis epidemic health shocks disproportionately impact investment in girls' education potentially due to increases in the direct and opportunity costs of parental investment in girls' education during epidemic years. Epidemic years and higher than expected meningitis exposure might mean a contraction of the household budget due to lost wages and increased health costs associated with the epidemic. Direct costs associated with fees might be higher when the household budget constraint shifts inward. Opportunity costs might rise with girls' labor increasingly commanded to care for sick family members or act as substitute labor for sick family members during the epidemic years[32]. One way that parents might respond to rising costs is by selling off "assets"- or female children- to reduce consumption burdens and accrue income from bride price transfers from grooms' families to brides' families as discussed in Section 2.

# 7 Possible Mechanisms: Income Effects and Early Marriage of Girls

Section 2 outlined the expected direct and indirect channels through which health shocks like the meningitis epidemic might be expected to affect gender gaps in human capital investment. The following subsections explore these mechanisms and find evidence in favor of the indirect economic channel. The high economic costs of disease burdens during epidemic years induce

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[30] It could also suggest a reversal in district exposure during the 1993-1996 epidemics for respondents from these districts who would be in the primary-school-aged categories during that period. We address the subject of cumulative effects in ongoing work.

[31] We replicate this falsification test for two other non-epidemic years, 1988 and 1989, finding results very similar to 1990 with tables provided in the Appendix.

[32] Hartmann-Mahmud (2011) documents this phenomenon in her case study research interviewing Nigerien women.

households to marry off their daughters at earlier ages.

## 7.1 Indirect Channels: Economic Responses and Gender Gaps

As discussed in Section 3, comparable households in countries in the meningitis belt spend a significant fraction of their incomes on costs from meningitis infections during epidemic years (up to 34% of per capita GDP (Colombini et al., 2009)). In the presence of these high costs, studies have documented that one way parents try to smooth consumption is to reduce investment in girls' human capital relative to their male siblings (Barcellos, Carvalho, and Lleras-Muney, 2014; Corno, Hildebrandt, and Voena, 2017). We examine one important method of doing this in the following section: increased early marriage of girls.

### 7.1.1 Income Effects: Meningitis Epidemics, Early Marriage and Educational Attainment

Niger has the highest rates of early marriage in the world, with 75% of girls married before the age of eighteen (Loaiza Sr and Wong, 2012). Niger is also one of several countries in the world, particularly in sub-Saharan Africa, that engages in bride price transfers of wealth from grooms' families to brides' families at the time of marriage (Murdock, 1967). Polygamy or polygyny[33], in particular, is legal in the country; about one-third of marriages are polygamous and having more than one wife has been viewed, historically, as a "status symbol demonstrating wealth and social prestige" (Peterson, 1999; Boye et al., 1991). Previous studies have documented increases in the likelihood of early marriage following negative income shocks to households (Corno, Hildebrandt, and Voena, 2017). There is also a small but growing economic and wider social science literature that has examined the determinants and drivers of bride price payments in societies around the world (Anderson, 2007; Quale, 1988; Tertilt, 2005).

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[33] Involving the marriage of one man to multiple women.

While data on marriage payments in the form of bride price are not available, the military government in 1977 set the maximum bride price amount at 50,000 Central African francs (CFA) or around \$215 for a never-married woman, 35,000 CFA or around \$150, for a divorced woman without children, and 15,000 CFA or around \$65 for a divorced woman with children (Boye et al., 1991). With per capita income at \$250 in 1986 by World Bank estimates[34], the maximum bride price for a young never-married female child would amount to some 86% of the yearly average income during the 1986 epidemic year. Given these figures highlighting that bride price might present a significant income boost to households during periods of negative shocks- particularly for poorer households- and the empirical evidence on the impact of shocks on early marriage, we examine the relationship between the age at first marriage and meningitis exposure during epidemic and non-epidemic years. We provide evidence of a reduction in the age at first marriage for women in highly affected districts following the epidemic, in line with the predictions of the economic and social science literature on the effects of economic shocks in bride price societies[35].

Summary statistics on the age at first marriage and other covariates from the DHS men and women's sample for respondents who were school going aged (SGA) in 1986- the epidemic year- and 1990- a comparison non-epidemic year- are shown in Table 5. First, we confirm findings from the literature on age at first marriage and document positive, significant associations between age at first marriage and years of education for school-going-aged female populations during the epidemic (1986) and non-epidemic (1990) years in Table 6. The coefficients remain stable, strongly significant, and positive at around .3 for school going aged female populations during the epidemic and non-epidemic years as shown in Columns (1)-(2) and (5)-(6). Interestingly, for the male sample, while there is a significant and positive but much smaller coefficient of association (around .06) between age

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[34] In nominal prices

[35] See Corno, Hildebrandt, and Voena (2017) for a detailed analysis on the effects of shocks in dowry versus bride price societies.

at first marriage and years of education for males who where school-going-aged during the epidemic year, there is no significant association between age at first marriage and years of education for males who were school-going-aged during the non-epidemic year as shown in Column (8) of Table 6. The results suggest that the association between age at first marriage and years of education is much stronger for women than for men in the sample.

Next, to explore the relationship between age at first marriage and meningitis exposure, particularly during epidemic years, we chart age at first marriage cumulative hazards with results shown in Figure 6. Figure 6 shows age at first marriage cumulative hazard for male and female school going aged populations by meningitis exposure in epidemic (1986) and non-epidemic years (1990). In above the national average meningitis districts (denoted as 'High Menin' in the figure), hazard rates are noticeably higher for both male and female respondents during the epidemic year. The magnitude is larger for female respondents during the epidemic year, who are typically also married at earlier ages (the mean age at first marriage is about 15 years old as shown in Table 5 for women versus about 21 years for men in the school-going-aged cohort during the 1986 epidemic year) than their male counterparts. Quantitatively, female respondents who were school-going-aged during the 1986 epidemic year are almost two times more likely to marry earlier in high (above the national mean) meningitis-exposed districts than in low (below the national mean) meningitis-exposed districts.

The trend in the 1990 non-epidemic year is reversed, with age at first marriage higher in high meningitis exposed districts for school-going-aged males and females during the 1990 non-epidemic year. Given these trends in the raw data we assess significance, estimating regressions with OLS, with results shown in Table 7. The first set of results in Column (3) of Table 7 shows significant negative associations (about -.024) between meningitis cases and age at first marriage for the female school-going-aged sample as of the time of the epidemic, with no significant effect for the comparable male sample. In contrast, there is no significant association between meningitis cases and age at first marriage for either the female or male school-going-aged samples during the non-epidemic test year, 1990 as shown in Column (6). The results provide support for the indirect channel discussed in Section 2 where the epidemic acts as a negative income shock leading households to smooth consumption by "selling" their daughters for a bride price, reflected in the lowered age at first marriage during epidemic years but not non-epidemic years and with the effects significant for girls but not for boys.

An explanation for the trends shown in the age at first marriage results- where the age at first marriage falls for women in higher meningitis exposed districts and not their male counterparts during the epidemic year, can be gleaned from Table 5. First, note that the median man in the sample is not marrying a woman within his age cohort, with average age gaps between couples at around 12 years, as reported in the 1986 and 1990 SGA women's sample. Second, since polygyny is legal is Niger, as mentioned previously, another explanation is that there is an increase in one to many matchings with relatively wealthier men marrying more than one wife during the shock year. To test this hypothesis, we examine the relationship between the number of wives and meningitis exposure during the epidemic and non-epidemic years.

The results reported in Table A2 show a positive and significant relationship between meningitis exposure and the number of wives reported by school-going-aged women during the 1986 epidemic year, with no statistically significant relationship between meningitis and the number of wives for their male counterparts during the epidemic or the 1990 non-epidemic year. While the differences between the number of wives result for men and women in the same cohort appear puzzling on the surface, an important note for interpreting these results is that there appears to be measurement error in the reporting of the number of wives in the men's and women's samples in the DHS subpopulations examined. As shown in Table 5, while the maximum number of wives reported by women who were school-going-aged during the 1986 epidemic is 7, the maximum number of wives reported by men in the same cohort is 4. Given that Islamic law prohibits men from having more than 4 wives, and Niger is a largely Muslim country, this might explain reporting mismatch between the male and female samples, biasing the number of wives results.

In subsequent analysis, we examine the heterogeneity in the impacts of meningitis epidemics on the age at first marriage by wealth status of women's households. to test the hypothesis that the effect of the shock is largely concentrated on asset-constrained households.

### 7.1.2 Meningitis, Wealth and Age at First Marriage

In Section 7.1.1, we argue that the primary channel underlying the differential gender impacts of meningitis is that girls are married off, particularly at early ages. This would be especially true for liquidity-constrained households. We reaffirm this by estimating a model that links age at first marriage with liquidity. Using data on assets from the DHS[36], we construct a wealth index and define liquidity or asset-constrained households as those located in the lower parts of the asset distribution.

The results are reported in Table 8. The first column excludes interactions between meningitis and asset quintiles; the second includes the interactions. As expected, Column 1 shows that age at first marriage for female respondents is likely higher in the less liquidity-constrained households (above the third quintile) as compared to the constrained. There is

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[36] The wealth index is based on ownership of the following 20 assets in the DHS women's sample: electricity, durables (e.g. radio, tv, fridge, car, bicycle), water and sanitation infrastructure and housing structure (e.g. dirt floor, cement floor). For lack of DHS data for 1986, we proxy the wealth status using available data for 1992 and 1998. This assumes that the wealth of current respondents is strongly correlated with their previous households. This might be a strong assumption but seems reasonable in Niger since distributional measures, like the Gini coefficient, have remained largely unchanged over the past two decades. http://povertydata.worldbank.org/poverty/country/NER.

a significant negative effect of sudden exposure to meningitis on the age at first marriage for women belonging to asset constrained households. Estimates from the second column show that the impact of meningitis exposure on asset-constrained households is significantly larger. In particular, meningitis has limited impact on the age at first marriage for the less constrained. Note that the estimate for the less constrained categories are similar in both specifications. Finally, Columns 3 and 4 replicate the analysis using a non-epidemic year, 1990. There is no evidence that meningitis impacts the age at first marriage of female respondents with wealth/assets, lending further support for the early marriage channel following meningitis epidemics.

### 7.2 Direct Channels: Health and Gender Gaps

On the direct, health channel, given the lack of data on infection and mortality rates by gender, we refer to the epidemiology and health literature on the biology of meningitis infection. First, there is little documented evidence on differential infection and mortality rates from meningitis by gender (Trotter and Greenwood, 2007). A simple regression on the female share by district and mortality rates during the epidemic year reveals no direct trends as shown in Table 9, although this is unsurprising given that the magnitude of the mortality effect to see a response in female populations would have to be extremely large. Another way the direct health channel might operate is if girls, when they are sick, are less likely to be treated or treated as quickly as boys because of gender bias in parental investment in children as has been documented in other studies (Barcellos, Carvalho, and Lleras-Muney, 2014). This might also lead to differential mortality by gender during the epidemic, though the size of this effect is difficult to estimate given the paucity of data. Similarly, if treatment or time to treatment differs by gender, then there might be more incidences of long-term neurological damage in girls relative to boys, which in turn, might affect school investment choices and lead to lower attainment as well[37].

In addition, there could be effects on children who were exposed to some form of meningitis at a very young age (i.e., preschool), deteriorating their cognitive abilities and affecting later educational outcomes. Table 2 provides a test for such a biological channel, where the hypothesis is rejected. If this channel is meaningful, then one would expect the effect of the 1986 meningitis exposure on education to be large and significant for the 0-5 age cohort. The effects are nearly zero and rejected at all conventional levels of significance.

### 7.3 Evaluation of Alternative Hypotheses

This section further evaluates the robustness of the estimated effects of meningitis exposure on the gender gap in years of education, and the relationship between the age at first marriage and meningitis exposure. We explore two primary alternative explanations of the results presented here: the impact of concurrent weather shocks and the potential role of gender biased care work for sick family members.

#### 7.3.1 Impact of Concurrent Shocks

One potential hypothesis is that concurrent rainfall shocks, common in SSA, might explain the relationship between meningitis and the gender gap in education during the years identified in this paper. To test this, we re-estimate Equation 1 by interacting the various cohorts with precipitation shocks. Precipitation shocks are defined in two ways: as the average district-level precipitation differenced from the national mean during the 1986 epidemic year, and the difference between district level rainfall and the district specific prior five year mean rainfall using available data from MERRA-2, which starts in 1980. The results for each method are reported in Table 10 and Table 11 respectively. Each column in the table

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[37] While this is a plausible channel, one hypothesis and potential result of the conceptual framework is that in bride price societies healthy girls may be more valued, muting differential effects on infection and mortality rates.

denotes different model specifications, with and without controls for temperature[38]. The results show no effect of concurrent precipitation shocks on gender gaps in education across all cohorts, lending further support to the estimated effect of meningitis exposure during the epidemic year.

### 7.3.2 Differential Care Work

Following our conceptual framework, one explanation for the results shown here is that girls engage in disproportionate amounts of home production and care work for sick household members, relative to their male counterparts, during an epidemic year. While there is no available time use data to test this hypothesis, there is qualitative evidence that women and girls in Niger and across countries in the meningitis belt, do perform the majority of home production and care work (Hartmann-Mahmud, 2011). More missed days of school as a result of increased care work might then lower the likelihood of accumulating more years of education. This explanation is not at odds with the early marriage evidence provided here and in the social science literature (Jensen and Thornton, 2003; Otoo-Oyortey and Pobi, 2003) since households might still choose to marry off daughters earlier for the bride-price, when the net benefit of maintaining a female child in the household is low relative to the forgone bride-price.

## 8 Effects of Harmattan Seasonality on Meningitis Epidemics

To what extent do climatic conditions, signaling the onset of the dry, Harmattan season drive meningitis epidemics? In section 3, we discussed how previous work has attributed episodes of meningitis epidemics to the Harmattan season. Here, we document this empirically by drawing on high resolution NASA data that allow us to characterize the seasonality of Har-

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[38] Controlling for temperature is important since it is correlated with precipitation (Schlenker and Roberts, 2009).

mattan across the region. We explore a model that links changes in measures of meningitis exposure $MENIN_{dt}$ to the Harmattan season $H_{dt}$. For district $d$ at year $t$, the simple model we estimate is:

$$\mathrm{MENIN}_{dt} = +\rho \mathrm{H}_{dt} + c_d + v_{dt} \tag{2}$$

where the vector $H_{dt}$ contains a pre-meningitis year (specifically, 1985) Harmattan winds and dust concentration, as well as the 1986 current year weather variables: temperature and precipitation. A set of unrestricted district dummies, denoted by $c_d$, are included to capture time-invariant district factors such as closeness to health amenities. MENIN is measured in two ways, as described in Section 5.2.

Our parameter of interest $\rho$ is identified by district-level variation in Harmattan season conditions[39] which are plausibly exogenous since we use the previous year Harmattan realizations while controlling for contemporaneous weather changes. Note that the weather controls are necessary since transmission in the atmosphere, and thus wind speed and dust concentration, could depend on the prevailing weather condition. Finally, the winds are generally correlated with the dry season of the Sahel which starts in September. Thus, we are careful with our definition of the "Harmattan season": we focus on the last quarter of the pre-epidemic year, allowing us to overcome concerns about potential effects of other climatic events, seasons or both[40]. All standard errors are clustered at the district level.

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[39] From baseline district differences.

[40] A direct but possibly naive alternate definition of Harmattan seasonality is to focus on wind and dust concentration during the entire pre-epidemic year. While not reported here, the sign of $\rho$ is positive and significant, similar to the approach we use in this paper. However, the magnitude of the estimates are slightly smaller if we define seasonality over the entire pre-epidemic year.

### 8.1 Results

The Harmattan season in the pre-epidemic period induces significant variation in households' exposure to meningitis. Tables 12 and 13 report the results from estimation of Equation 2 for the two measures of meningitis exposure: MENIN Cases and MENIN Intensity. For each meningitis measure, we present four sets of results that reflect four different model specifications. Columns (1) and (3) exclude the weather controls, while in Columns (2) and (4), these are included in linear and interactive forms, respectively. The tables also report results for an F-test under the null hypothesis that all coefficients of the Harmattan season conditions and weather variables are jointly zero.

The estimated effect of wind speed ($m/s$) is positive and significant across all specifications. Similarly, the coefficient for dust concentration ($kg/m^3$) is positive and significant, but this becomes negative after controlling for weather[41]. In the two models that specify Harmattan seasonality as a product of dust and winds, the parameter estimates are positive throughout. Next, the null that all coefficients of the Harmattan season and weather conditions are jointly zero can be rejected at all conventional significance levels. Overall, these results are consistent across our two measures of meningitis exposure, and also congruent with the related environmental health literature highlighting the association of climate factors and meningitis incidence (Perez Garcia Pando et al., 2014).

## 9 Conclusions

Recent scientific literature has provided evidence that future warming and climate change have the potential to significantly increase meningitis epidemics and alter the distribution

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[41] The change in the sign on the dust concentration measure may be attributed to the complex interaction between weather variables and dust as has been emphasized in the climate science literature. Much of the environmental health literature has focused on wind as a major predictor of meningitis epidemics (Perez Garcia Pando et al., 2014).

of the disease across the meningitis belt (Abdussalam et al., 2014; Sultan et al., 2005). This will have potentially devastating consequences for this region, with particularly disutility accruing to women.

Our analysis of the effects of exposure to the 1986 meningitis epidemic on educational attainment of school-aged girls in Niger, reveals that the gender gap widened during the epidemic year. The effect is particularly significant for primary-school-aged girls at the time of the epidemic, since most of the investment in education happens at the primary level. We find a significant decrease in years of education for school aged female respondents at the time of the epidemic with no significant effect for their male counterparts. Given the evidence on the intergenerational returns to female education and the potential economic returns to closing the gender gap, these results highlight the need for multi-pronged policy addressing education, health, and climate to target the gender gap in educational attainment. We provide evidence for the linkages between meningitis outbreaks and Harmattan season intensity, prompting further discussion on the role of climate-induced disease in worsening social inequality.

We provide evidence for an indirect economic interpretation, whereby the epidemic acts as a negative income shock prompting households to smooth consumption by cutting back on education expenditures for girls and “selling” daughters in exchange for bride price wealth transfers. A consequence of this is lowered age at first marriage for girls during epidemic years and fewer years of education, which would explain the widened gender gap during the epidemic year. An important contribution of the paper is to show that disease burdens and health shocks contribute significantly to widening gender gaps in educational attainment with associated implications for development in poorer countries. This line of research has broader implications for climate-induced disease effects on social inequality.

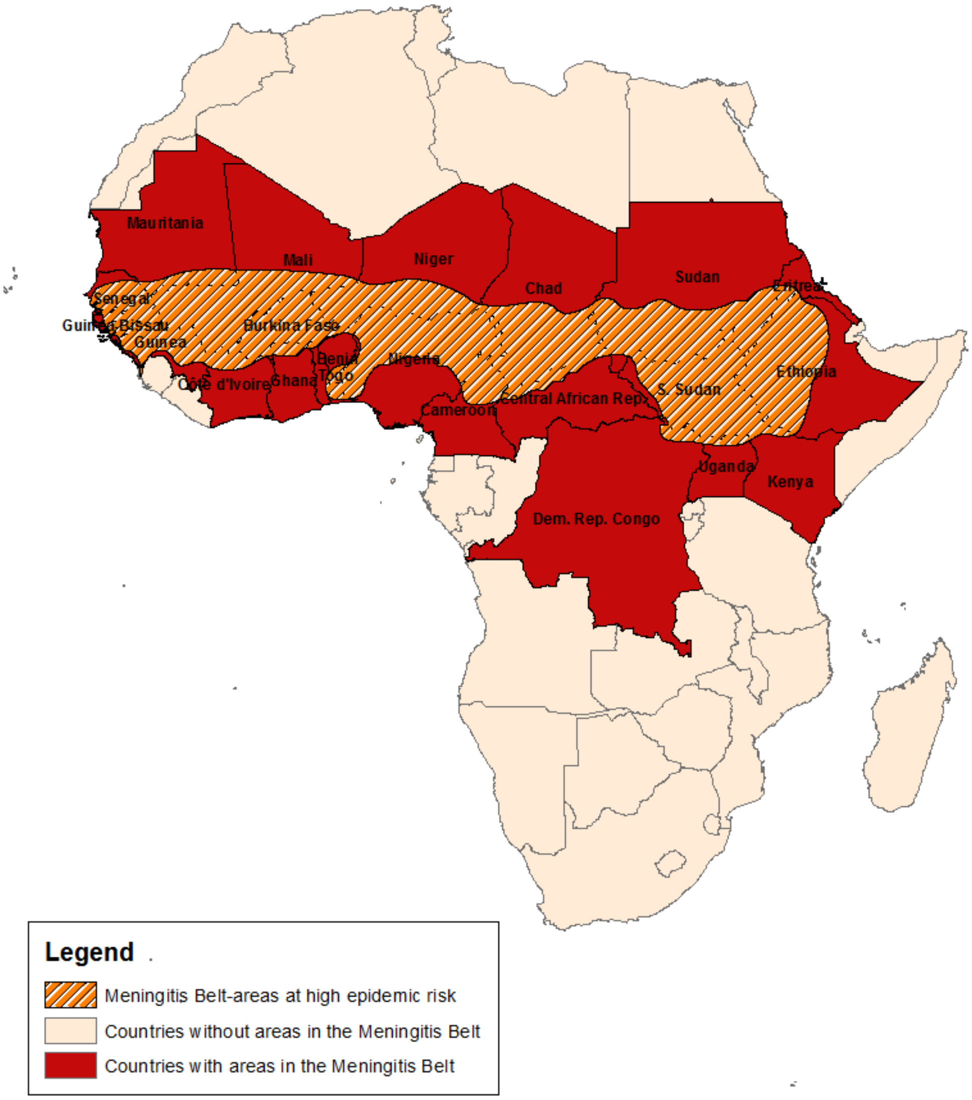


Figure 1: Areas with Frequent Epidemics of Meningococcal Meningitis (“Meningitis Belt”)

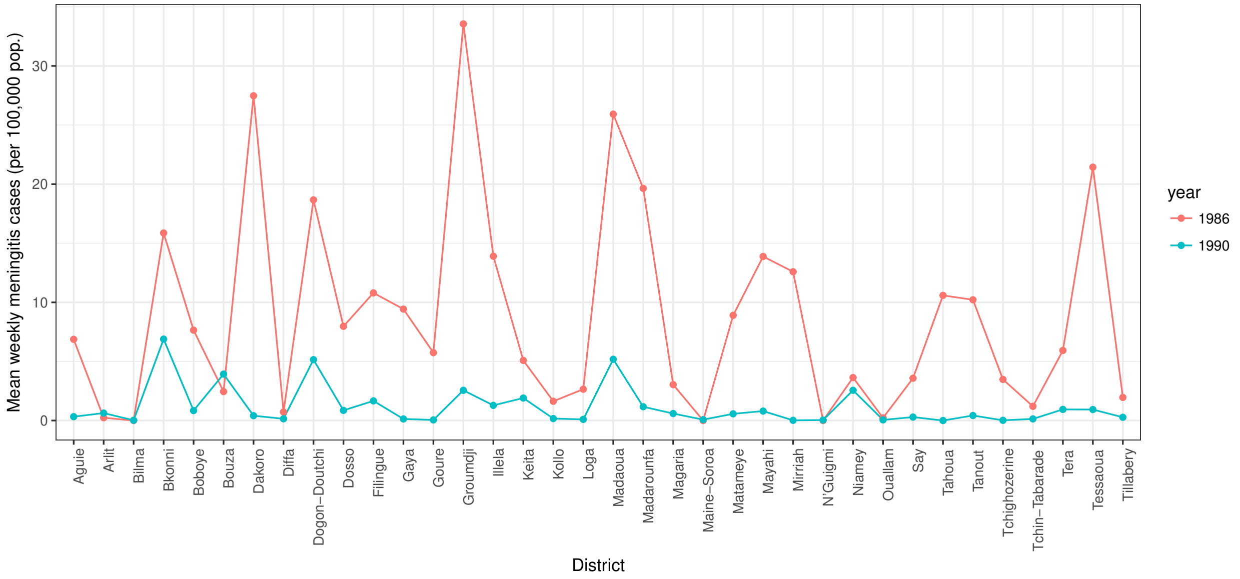


Figure 2: Niger Meningitis Cases by District in Epidemic (1986) and Non-epidemic (1990) Years

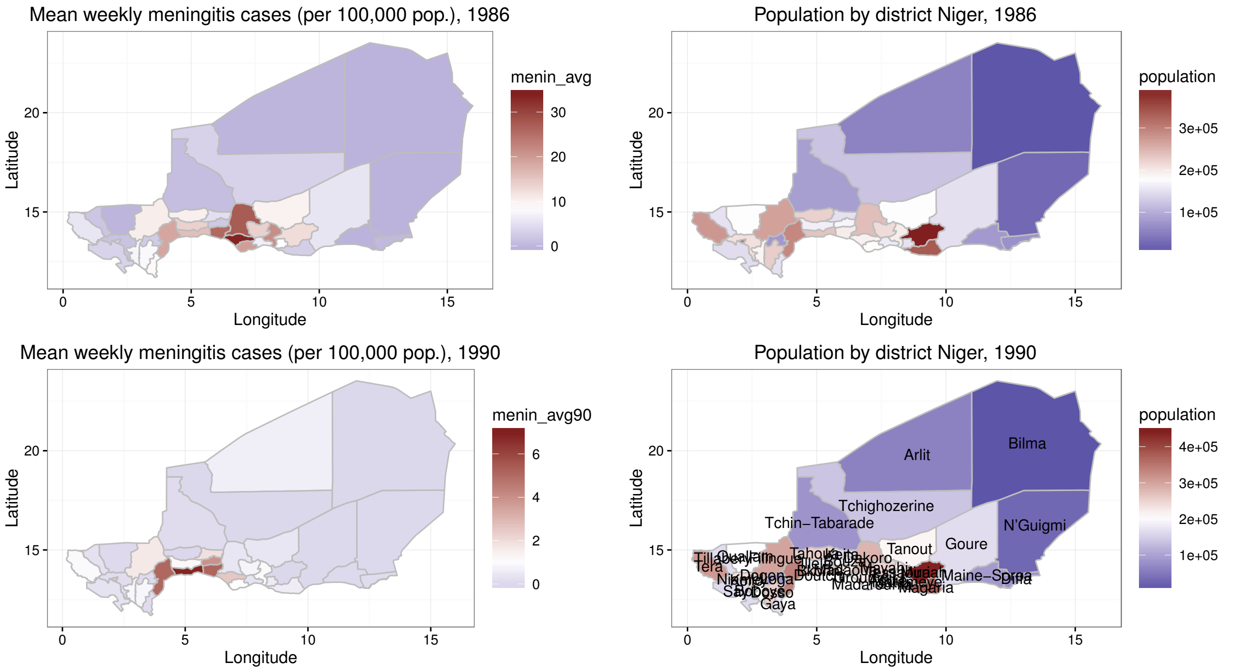
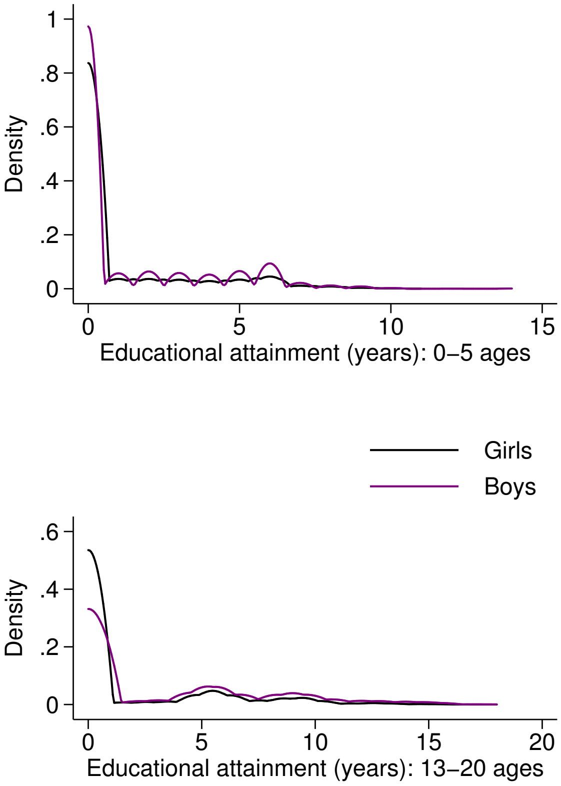


Figure 3: Niger Meningitis Cases and Population by District in Epidemic (1986) and Non-epidemic (1990) Years

Table 1: Variable Means

| | Total population | | | Males | | | Females | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 1998 | 1992-1998 | 1992 | 1998 | 1992-1998 | 1992 | 1998 | 1992-1998 |
| Population | | | | | | | | | |
| percent age 0-5 in 1986 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.23 | 0.23 |
| percent age 6-12 in 1986 | 0.21 | 0.18 | 0.19 | 0.21 | 0.17 | 0.19 | 0.21 | 0.19 | 0.2 |
| percent age 13-20 in 1986 | 0.16 | 0.18 | 0.17 | 0.15 | 0.16 | 0.15 | 0.18 | 0.20 | 0.19 |
| Meningitis cases cohort exposure | | | | | | | | | |
| age 0-5 in 1986 | 2.47 | 2.54 | 2.5 | 2.51 | 2.67 | 2.58 | 2.43 | 2.42 | 2.43 |
| age 6-12 in 1986 | 2 | 1.84 | 1.93 | 2.10 | 1.68 | 1.91 | 1.91 | 1.98 | 1.94 |
| age 13-20 in 1986 | 1.52 | 1.99 | 1.73 | 1.36 | 1.77 | 1.54 | 1.67 | 2.19 | 1.91 |
| Years of education | | | | | | | | | |
| Control Cohorts: age 0-5 in 1986 | 0.40 | 1.95 | 1.09 | 0.46 | 2.33 | 1.3 | 0.33 | 1.58 | 0.89 |
| Treated Cohorts: age 6-12 in 1986 | 1.85 | 2.38 | 2.07 | 2.26 | 3.22 | 2.63 | 1.46 | 1.72 | 1.57 |
| Treated Cohorts: age 13-20 in 1986 | 1.99 | 1.83 | 1.91 | 2.69 | 2.58 | 2.64 | 1.43 | 1.32 | 1.37 |



NOTE: We reject the null that the distributions are different at 5% level across the various age cohorts.

Figure 4: Distribution of Schooling Across Cohorts and Gender

Table 2: Difference in Difference Estimates of the Differential Impact of Meningitis Exposure on Education (1986 Epidemic Year), MENIN x Female

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | MENIN Cases | | MENIN Intensity | |
| | (1a) | (1b) | (1c) | (1d) |
| Female | −0.646$^{***}$ | −0.498$^{***}$ | −0.646$^{***}$ | −0.513$^{***}$ |
| | (0.050) | (0.076) | (0.050) | (0.071) |
| Meningitis exposure at ages 0-5 | −0.002 | 0.001 | −0.0002 | 0.0001 |
| | (0.003) | (0.004) | (0.0003) | (0.0004) |
| x Female | | −0.006 | | −0.0005 |
| | | (0.006) | | (0.001) |
| Meningitis exposure at ages 6-12 | −0.027 | −0.004 | −0.003$^{*}$ | −0.001 |
| | (0.017) | (0.021) | (0.001) | (0.002) |
| x Female | | −0.044$^{***}$ | | −0.004$^{***}$ |
| | | (0.012) | | (0.001) |
| Meningitis exposure at ages 13-20 | −0.047 | −0.029 | −0.004 | −0.002 |
| | (0.031) | (0.030) | (0.003) | (0.003) |
| x Female | | −0.032$^{***}$ | | −0.003$^{***}$ |
| | | (0.011) | | (0.001) |
| Constant | 1.032$^{***}$ | 0.953$^{***}$ | 1.003$^{***}$ | 0.932$^{***}$ |
| | (0.199) | (0.215) | (0.185) | (0.197) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 |
| R$^2$ | 0.208 | 0.210 | 0.208 | 0.209 |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1986 epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1986 meningitis epidemic year multiplied by number of months of exposure (with greater than zero cases). Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. The estimates represent 3% to 4% and 2% to 3% reduction in education for girls in the primary school going age sample (ages 6-12) and secondary school going age sample (ages 13-20) respectively relative to the unconditional and conditional means. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters, with results provided in the appendix. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table 3: Difference in Difference Estimates of the Differential Impact of Meningitis Exposure on Education (1986 Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | MENIN Cases | | MENIN Intensity | |
| | (2a) | (2b) | (2c) | (2d) |
| Female | −0.644*** | −0.535*** | −0.645*** | −0.546*** |
| | (0.049) | (0.067) | (0.049) | (0.064) |
| Meningitis exposure at ages 0-4 | 0.006 | 0.005* | 0.001 | 0.0005* |
| | (0.004) | (0.003) | (0.0004) | (0.0003) |
| x Female | | 0.0005 | | 0.0001 |
| | | (0.006) | | (0.001) |
| Meningitis exposure at ages 7-12 | −0.025 | −0.003 | −0.002* | −0.0004 |
| | (0.016) | (0.020) | (0.001) | (0.002) |
| x Female | | −0.042*** | | −0.004*** |
| | | (0.012) | | (0.001) |
| Meningitis exposure at ages 14-21 | −0.046 | −0.028 | −0.004 | −0.002 |
| | (0.030) | (0.029) | (0.003) | (0.002) |
| x Female | | −0.031*** | | −0.003*** |
| | | (0.009) | | (0.001) |
| Constant | 1.038*** | 0.982*** | 1.018*** | 0.966*** |
| | (0.199) | (0.210) | (0.187) | (0.195) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 |
| R$^2$ | 0.208 | 0.210 | 0.208 | 0.209 |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1986 epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1986 meningitis epidemic year multiplied by number of months of exposure (with greater than zero cases). ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 4: Difference in Difference Estimates of the Differential Impact of Meningitis Exposure on Education (1990 Non-Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | MENIN Cases | | MENIN Intensity | |
| | (3a) | (3b) | (3c) | (3d) |
| Female | −0.644$^{***}$ | −0.652$^{***}$ | −0.643$^{***}$ | −0.654$^{***}$ |
| | (0.050) | (0.076) | (0.049) | (0.074) |
| Meningitis exposure at ages 0-5 | −0.070 | −0.129 | −0.011 | −0.017 |
| | (0.096) | (0.118) | (0.012) | (0.014) |
| x Female | | 0.117$^{**}$ | | 0.011$^{**}$ |
| | | (0.047) | | (0.005) |
| Meningitis exposure at ages 6-12 | −0.006 | 0.011 | −0.002 | −0.001 |
| | (0.042) | (0.057) | (0.004) | (0.006) |
| x Female | | −0.032 | | −0.002 |
| | | (0.041) | | (0.004) |
| Meningitis exposure at ages 13-20 | 0.011 | 0.072 | 0.003 | 0.009 |
| | (0.050) | (0.061) | (0.006) | (0.007) |
| x Female | | −0.111$^{***}$ | | −0.010$^{***}$ |
| | | (0.038) | | (0.003) |
| Constant | 1.038$^{***}$ | 1.042$^{***}$ | 1.018$^{***}$ | 1.024$^{***}$ |
| | (0.181) | (0.193) | (0.169) | (0.181) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 |
| R$^2$ | 0.205 | 0.207 | 0.206 | 0.207 |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1990 non-epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1990 non-epidemic year multiplied by number of months of exposure (with greater than zero cases). Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters, with results provided in the appendix. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table 5: DHS Subsamples: Men and Women's Sample Variable Means

| Statistic | N | Mean | St. Dev. | Min | Max |
|---|---|---|---|---|---|
| DHS Women's Sample, SGA 1986 | | | | | |
| Age at First Marriage | 5,898 | 15.061 | 2.533 | 8 | 31 |
| Years of Education | 7,255 | 1.557 | 3.064 | 0 | 16 |
| Meningitis Cases 1986 | 7,255 | 9.634 | 7.951 | 0.000 | 31.231 |
| Age | 7,255 | 22.458 | 4.504 | 15 | 32 |
| Nos. of Wives | 5,573 | 0.354 | 0.594 | 0 | 7 |
| Age at First Birth | 5,280 | 17.250 | 2.609 | 10 | 31 |
| Age Gap Husband | 4,136 | 12.128 | 7.930 | −5 | 70 |
| DHS Men's Sample, SGA 1986 | | | | | |
| Age at First Marriage | 954 | 20.755 | 3.557 | 10 | 31 |
| Years of Education | 1,657 | 1.750 | 2.413 | 0 | 13 |
| Meningitis Cases 1986 | 1,657 | 10.291 | 8.562 | 0.000 | 31.231 |
| Age | 1,657 | 24.180 | 4.223 | 17 | 32 |
| Nos of Wives | 906 | 1.086 | 0.300 | 1 | 4 |
| DHS Women's Sample, SGA 1990 | | | | | |
| Age at First Marriage | 4,550 | 14.989 | 2.257 | 8 | 27 |
| Years of Education | 6,447 | 1.680 | 3.071 | 0 | 16 |
| Meningitis Cases 1990 | 6,447 | 1.575 | 1.720 | 0.000 | 6.769 |
| Age | 6,447 | 19.892 | 3.704 | 15 | 28 |
| Nos. of Wives | 4,322 | 0.303 | 0.563 | 0 | 7 |
| Age at First Birth | 3,681 | 16.987 | 2.337 | 10 | 28 |
| Age Gap Husband | 2,907 | 12.194 | 7.803 | −5 | 70 |
| DHS Men's Sample, SGA 1990 | | | | | |
| Age at First Marriage | 551 | 19.920 | 3.003 | 12 | 28 |
| Years of Education | 1,728 | 1.799 | 2.366 | 0 | 10 |
| Meningitis Cases 1990 | 1,728 | 1.631 | 1.663 | 0.000 | 6.769 |
| Age | 1,728 | 20.509 | 3.987 | 15 | 28 |
| Nos. of Wives | 515 | 1.070 | 0.263 | 1 | 3 |

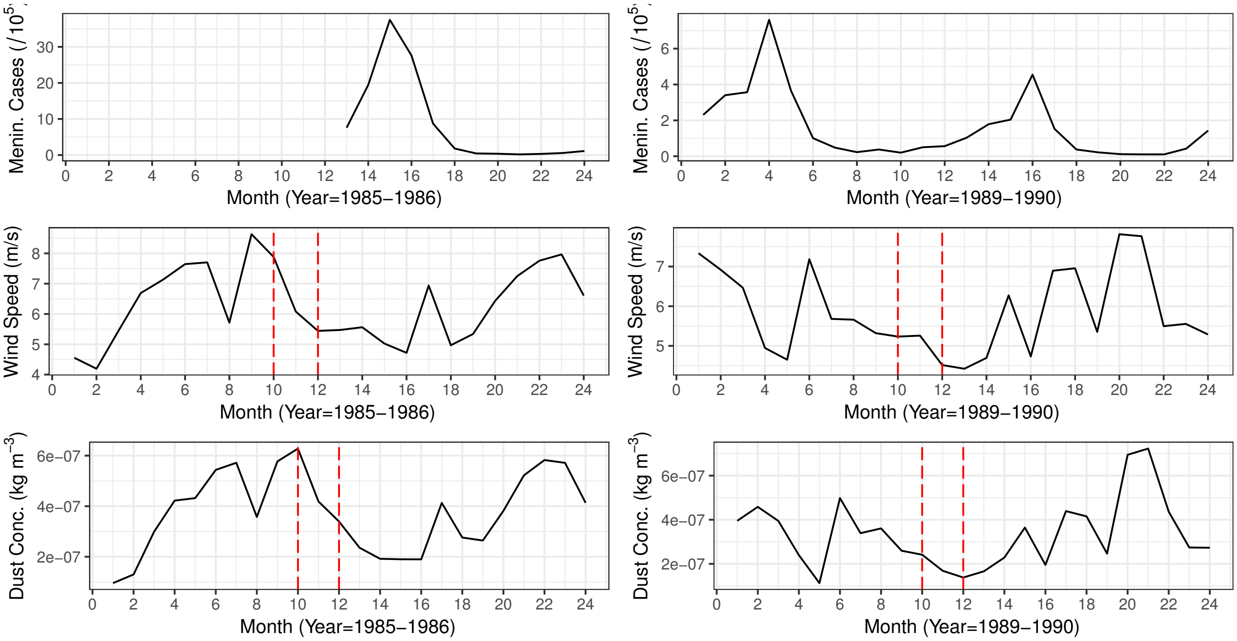


Figure 5: Harmattan and Meningitis Response

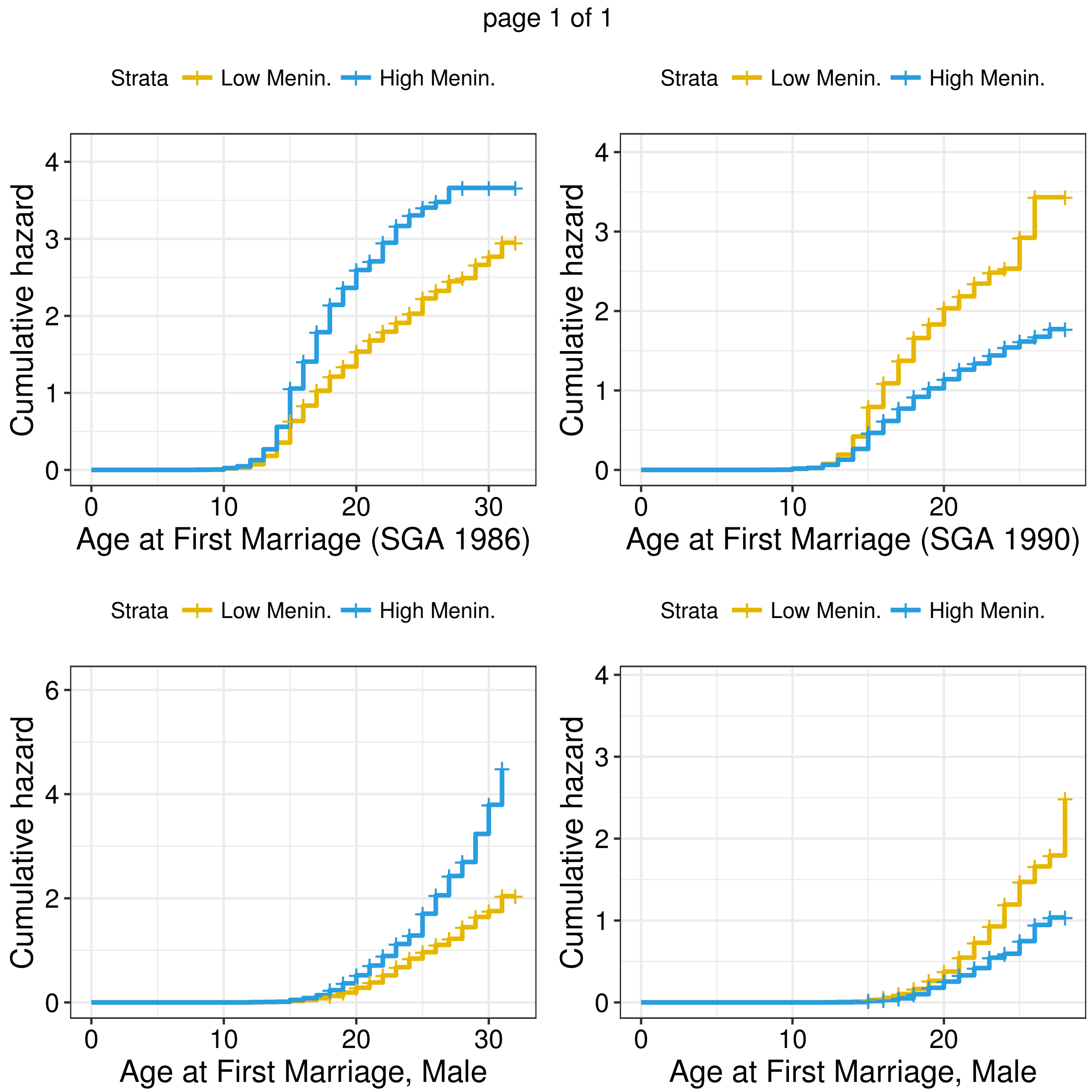


Figure 6: Age of First Marriage Cumulative Hazard for School-Going Aged (SGA) Populations by Meningitis Exposure in Epidemic (1986) and Non-epidemic (1990) Years

Table 6: Correlation between Age at First Marriage and Years of Education for School-Going Aged Respondents during Epidemic (1986) and Non-epidemic (1990) Years

| | Dependent Variable: Years of Education | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SGA 1986 F | | SGA 1986 M | | SGA 1990 F | | SGA 1990 M | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Age at First Marriage | 0.365*** | 0.313*** | 0.078*** | 0.065** | 0.305*** | 0.263*** | 0.057 | 0.028 |
| | (0.094) | (0.067) | (0.023) | (0.026) | (0.080) | (0.053) | (0.038) | (0.042) |
| Constant | −4.506*** | −4.307*** | −0.417 | −0.267 | −3.672*** | −3.325*** | −0.010 | 0.421 |
| | (1.234) | (0.974) | (0.437) | (0.657) | (1.047) | (0.768) | (0.716) | (0.848) |
| Observations | 5,898 | 5,898 | 954 | 954 | 4,550 | 4,550 | 551 | 551 |
| Adjusted $R^2$ | 0.143 | 0.209 | 0.014 | 0.035 | 0.094 | 0.163 | 0.005 | 0.025 |
| District FE | No | Yes | No | Yes | No | Yes | No | Yes |
| Year FE | No | Yes | No | Yes | No | Yes | No | Yes |
| Year of birth FE | No | Yes | No | Yes | No | Yes | No | Yes |

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is years of education completed for school going aged respondents (between 6 and 20 years old) during the 1986 epidemic and 1990 non-epidemic year for the male (M) and female (F) DHS samples. SGA is School going aged sample. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 7: Impact of Meningitis Exposure on Age at First Marriage for School-Going Aged Respondents Married during Epidemic (1986) and Non-Epidemic (1990) Years

| | Dependent Variable: Age at First Marriage | | | | | |
|---|---|---|---|---|---|---|
| | SGA 1986 | | | SGA 1990 | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Meningitis Cases, F (OLS) | $-0.040^{**}$ | $-0.044^{**}$ | $-0.024^{**}$ | 0.018 | 0.014 | $-0.027$ |
| | (0.019) | (0.019) | (0.010) | (0.060) | (0.058) | (0.042) |
| Constant | $15.470^{***}$ | $15.098^{***}$ | $14.598^{***}$ | $14.962^{***}$ | $14.511^{***}$ | $14.352^{***}$ |
| | (0.343) | (0.449) | (0.177) | (0.135) | (0.258) | (0.176) |
| Observations | 5,898 | 5,898 | 5,898 | 4,550 | 4,550 | 4,550 |
| $R^2$ | 0.016 | 0.054 | 0.093 | 0.0002 | 0.058 | 0.091 |
| Meningitis Cases, M (OLS) | $-0.043^{**}$ | $-0.025$ | $-0.020$ | 0.031 | 0.012 | $-0.003$ |
| | (0.018) | (0.017) | (0.019) | (0.088) | (0.081) | (0.077) |
| Constant | $21.275^{***}$ | $21.183^{***}$ | $21.087^{***}$ | $19.873^{***}$ | $18.724^{***}$ | $18.661^{***}$ |
| | (0.359) | (0.454) | (0.490) | (0.306) | (0.514) | (0.497) |
| Observations | 954 | 954 | 954 | 551 | 551 | 551 |
| $R^2$ | 0.012 | 0.159 | 0.161 | 0.0003 | 0.175 | 0.178 |
| Niamey FE | No | No | Yes | No | No | Yes |
| Year FE | No | Yes | Yes | No | Yes | Yes |
| Year of birth FE | No | Yes | Yes | No | Yes | Yes |

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is age at first marriage for school going aged respondents (between 6 and 20 years old) during the 1986 epidemic and 1990 non-epidemic years. SGA is School going aged sample. Meningitis Cases are mean weekly meningitis cases by district for 1986 and 1990. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 8: Meningitis Exposure, Wealth and Age at First Marriage for Female School-Going Aged Respondents Married during Epidemic (1986) and Non-Epidemic (1990) Years, Robustness Check

| | Dependent Variable: Age at First Marriage | | | |
|---|---|---|---|---|
| | SGA 1986 | | SGA 1990 | |
| | (1) | (2) | (3) | (4) |
| Meningitis Cases | $-0.027^{***}$ | $-0.019^{*}$ | $-0.018$ | $-0.046$ |
| | (0.009) | (0.010) | (0.035) | (0.040) |
| Wealth Quintile 2 (WQ2) | 0.074 | $0.389^{**}$ | 0.042 | 0.133 |
| | (0.111) | (0.186) | (0.142) | (0.206) |
| Wealth Quintile 3 (WQ3) | $-0.022$ | 0.029 | 0.058 | $-0.023$ |
| | (0.099) | (0.189) | (0.122) | (0.154) |
| Wealth Quintile 4 (WQ4) | $0.301^{***}$ | $0.439^{**}$ | $0.279^{**}$ | 0.208 |
| | (0.105) | (0.175) | (0.116) | (0.149) |
| Wealth Quintile 5 (WQ5) | $1.363^{***}$ | $1.488^{***}$ | $1.158^{***}$ | $1.038^{***}$ |
| | (0.152) | (0.285) | (0.141) | (0.159) |
| Meningitis Cases x WQ2 | | $-0.025^{***}$ | | $-0.067$ |
| | | (0.009) | | (0.062) |
| Meningitis Cases x WQ3 | | $-0.004$ | | 0.057 |
| | | (0.011) | | (0.037) |
| Meningitis Cases x WQ4 | | $-0.012$ | | 0.050 |
| | | (0.010) | | (0.057) |
| Meningitis Cases x WQ5 | | $-0.011$ | | 0.088 |
| | | (0.018) | | (0.092) |
| Constant | $14.280^{***}$ | $14.193^{***}$ | $13.998^{***}$ | $14.039^{***}$ |
| | (0.159) | (0.160) | (0.161) | (0.163) |
| Observations | 5,838 | 5,838 | 4,500 | 4,500 |
| $R^2$ | 0.128 | 0.129 | 0.119 | 0.120 |
| Niamey FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Year of birth FE | Yes | Yes | Yes | Yes |

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is age at first marriage for school going aged respondents (between 6 and 20 years old) during the 1986 epidemic and 1990 non-epidemic years. SGA is School going aged sample. Meningitis Cases are mean weekly meningitis cases by district for 1986 and 1990. Wealth quintiles are estimated from wealth scores from principal components analysis. WQ1 is dropped as the comparison group. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table 9: Mechanism Check: Correlation Between District Mortality Rate During 1986 Epidemic and 1992-1998 District Level Share of Female Respondents

| | Dependent Variable: District Mortality Rate, 1986 Epidemic |
|---|---|
| Share Female in District | 0.163 |
| | (0.413) |
| Constant | −0.043 |
| | (0.215) |
| Observations | 32 |
| $R^2$ | 0.005 |
| *Note:* | $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$ |

Table 10: Impact of Precipitation Shocks on Education (1986 Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | Precipitation Shocks | | | |
| | (1) | (2) | (3) | (4) |
| Female | $-0.627^{***}$ | $-0.586^{***}$ | $-0.629^{***}$ | $-0.588^{***}$ |
| | (0.054) | (0.051) | (0.055) | (0.052) |
| Precipitation exposure at ages 0-5 | 4,418.914 | 4,177.179 | 3,631.882 | 3,489.979 |
| | (10,535.300) | (14,663.360) | (10,685.870) | (14,982.720) |
| x Female | | 302.557 | | 103.632 |
| | | (23,790.900) | | (23,891.740) |
| Precipitation exposure at ages 6-12 | −6,873.454 | 16,197.320 | −7,076.934 | 14,918.590 |
| | (36,673.780) | (44,305.270) | (36,943.370) | (44,219.350) |
| x Female | | −43,598.290 | | −41,565.950 |
| | | (29,754.670) | | (29,652.610) |
| Precipitation exposure at ages 13-20 | 18,666.090 | 75,568.230 | 19,082.770 | 76,856.420 |
| | (60,021.180) | (93,851.200) | (60,384.590) | (94,692.870) |
| x Female | | −95,606.920 | | −97,078.000 |
| | | (62,286.980) | | (62,969.290) |
| Constant | $1.056^{***}$ | $1.036^{***}$ | $1.139^{***}$ | $1.119^{***}$ |
| | (0.180) | (0.180) | (0.230) | (0.229) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Temperature quartile dummies | No | No | Yes | Yes |
| Observations | 43,814 | 43,814 | 43,814 | 43,814 |
| $R^2$ | 0.210 | 0.211 | 0.214 | 0.215 |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. The Precipitation exposure explanatory variable is precipitation deviation exposure, defined as average district level precipitation in 1986 differenced from national mean level precipitation for cohort at specified ages during the 1986 epidemic year. Precipitation units are in $kgm^{-}2s^{-}1$. Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table 11: Impact of Precipitation Shocks (Standardized Deviations from 1980-85 District Mean) to on Education (1986 Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | Precipitation Shocks | | | |
| | (1) | (2) | (3) | (4) |
| Female | $-0.625^{***}$ | $-0.628^{***}$ | $-0.625^{***}$ | $-0.628^{***}$ |
| | (0.051) | (0.055) | (0.051) | (0.055) |
| Precipitation exposure at ages 0-5 | $-0.396$ | $1.684^{**}$ | $-0.400$ | $1.676^{**}$ |
| | (0.663) | (0.832) | (0.665) | (0.830) |
| x Female | | $-4.114^{***}$ | | $-4.109^{***}$ |
| | | (1.090) | | (1.081) |
| Precipitation exposure at ages 6-12 | $-6.227^{**}$ | $-4.657$ | $-6.242^{**}$ | $-4.676$ |
| | (3.063) | (3.622) | (3.059) | (3.623) |
| x Female | | $-3.011$ | | $-3.005$ |
| | | (1.896) | | (1.902) |
| Precipitation exposure at ages 13-20 | $-10.600^{*}$ | $-12.584$ | $-10.606^{*}$ | $-12.596$ |
| | (6.015) | (8.491) | (6.008) | (8.475) |
| x Female | | 3.462 | | 3.470 |
| | | (4.688) | | (4.671) |
| Constant | $1.367^{***}$ | $1.368^{***}$ | $1.364^{***}$ | $1.365^{***}$ |
| | (0.378) | (0.378) | (0.374) | (0.375) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Temperature quartile dummies | No | No | Yes | Yes |
| Observations | 43,814 | 43,814 | 43,814 | 43,814 |
| R$^2$ | 0.216 | 0.217 | 0.216 | 0.217 |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. The Precipitation exposure explanatory variable is precipitation deviation exposure, defined as the standard deviation of district level precipitation in 1986 from the prior five year district mean from 1980 to 1985 (for years of available MERRA-2 satellite data) for cohort at specified ages during the 1986 epidemic year. Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

## Table 12: Impact of Harmattan Season on Meningitis Incidence-Cases

| | Dependent Variable: Meningitis Exposure, Cases | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Dusts | $5.082e+08^{***}$ | $-7.668e+08^{***}$ | | |
| | (0.001) | (0.021) | | |
| Winds | $26.453^{***}$ | $225.758^{***}$ | | |
| | $(< 0.0001)$ | $(5.82e-09)$ | | |
| Temperature | | $93.534^{***}$ | | |
| | | $(2.55e-09)$ | | |
| Precipitation | | $7.421e+06^{***}$ | | |
| | | (.0002) | | |
| Dusts x Winds | | | $3.508e+07^{***}$ | $5.425e+07^{***}$ |
| | | | $(9.20e-05)$ | $(2.09e-05)$ |
| Temperature x Precipitation | | | | $-2,609.691^{***}$ |
| | | | | $(4.49e-09)$ |
| Constant | $-402.459^{***}$ | $-29,333.630^{***}$ | $-101.599^{***}$ | $-149.335^{***}$ |
| | $(4.25e-10)$ | $(7.98e-07)$ | $(2.78e-10)$ | $(7.67e-11)$ |
| Observations | 165 | 165 | 165 | 165 |
| District fixed effects | Yes | Yes | Yes | Yes |
| Harmattan | 1985Q4 Winds+ | 1985Q4 Winds+ | 1985Q4 Winds+ | 1985Q4 Winds+ |
| F-test: statistic | 5.020e+23 | 9.180e+20 | 1.450e+23 | 5.840e+24 |
| F-test: p-value | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Notes: Table reports the results from regressions of meningitis incidence cases on Harmattan season at the district level. Dust concentration units in $kg/m^3$, wind speeds units in $m/s$, temperature units in $Kelvin$, precipitation units in $kgm^{-}2s^{-}1$. Columns (1)-(4) differ based on the inclusion of weather controls and construction of Harmattan. Columns (1) and (3) exclude the weather controls, while columns (2) and (4) includes Harmattan season variables in linear and interactive forms, respectively. F-test under the null hypothesis that all coefficients of the Harmattan season conditions and weather variables are jointly zero are displayed. Errors are clustered at the district level. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

## Table 13: Impact of Harmattan Season on Meningitis Incidence-Intensity

| | Dependent Variable: Meningitis Exposure, Intensity | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Dusts | $7.165e+09^{***}$ | $-1.026e+10^{***}$ | | |
| | (0.0104) | (0.285) | | |
| Winds | $318.2^{***}$ | $2.948^{***}$ | | |
| | $(2.41e-10)$ | $(7.79e-08)$ | | |
| Temperature | | $1,237^{***}$ | | |
| | | $(3.41e-08)$ | | |
| Precipitation | | $9.468e+07^{***}$ | | |
| | | (0.00234) | | |
| Dusts x Winds | | | $2.105e+08^{***}$ | $6.253e+08^{***}$ |
| | | | (0.000603) | (0.000232) |
| Temperature x Precipitation | | | | $-56,476^{***}$ |
| | | | | $(4.49e-08)$ |
| Constant | $-5,344^{***}$ | $-387,484^{***}$ | $-609.6^{***}$ | $-1,643^{***}$ |
| | $(6.16e-09)$ | $(1.07e-05)$ | $(1.82e-09)$ | $(8.50e-10)$ |
| Observations | 165 | 165 | 165 | 165 |
| District fixed effects | Yes | Yes | Yes | Yes |
| Harmattan | 1985Q4 Winds+ | 1985Q4 Winds+ | 1985Q4 Winds+ | 1985Q4 Winds+ |
| F-test: statistic | 4.750e+23 | 7.610e+20 | 1.220e+23 | 7.870e+24 |
| F-test: p-value | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Notes: Table reports the results from regressions of meningitis incidence 'intensity', as described in text, on Harmattan season at the district level. Dust concentration units in $kg/m^3$, wind speeds units in $m/s$, temperature units in $Kelvin$, precipitation units in $kgm^{-}2s^{-}1$. Columns (1)-(4) differ based on the inclusion of weather controls and construction of Harmattan. Columns (1) and (3) exclude the weather controls, while columns (2) and (4) includes Harmattan season variables in linear and interactive forms, respectively. F-test under the null hypothesis that all coefficients of the Harmattan season conditions and weather variables are jointly zero are displayed. Errors are clustered at the district level. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

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# A Appendix

Table A1: Reduced Form: Direct Effect of Harmattan on Educational Gender Gaps

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | Winds, $m/s$ | | Dusts, $kg/m^3$ | |
| | (1) | (2) | (3) | (4) |
| Female | $-0.6222^{***}$ | $-0.3439^{***}$ | $-0.6274^{***}$ | $-0.3804^{***}$ |
| | (0.05062) | (0.0823) | (0.0556) | (0.0767) |
| Harmattan at ages 0-5 | $-0.0820^{*}$ | $-0.0708$ | 242233.8 | 288659.6 |
| | (0.0439) | (0.0431) | (527181.7)) | (528353.8) |
| x Female | | $-0.018215$ | | $-139158.7$ |
| | | (0.0185) | | (259727.9) |
| Harmattan at ages 6-12 | $-0.4648$ | $-0.4159$ | $-228145$ | 387979.2 |
| | (0.2901) | (0.2942) | (991882.1) | (1026905) |
| x Female | | $-0.0984^{***}$ | | $-1307362^{***}$ |
| | | (0.0199) | | (304792.7) |
| Harmattan at ages 13-20 | $-0.8467$ | $-0.7677$ | $-704554.9$ | 275932.9 |
| | (0.5667) | (0.5521) | (1237784) | (1244591) |
| x Female | | $-0.1123^{***}$ | | $-1610260^{***}$ |
| | | (0.0182) | | (317255.8) |
| Constant | $-58.4782^{**}$ | $-61.2189^{**}$ | $-69.9017^{***}$ | $-69.8805^{***}$ |
| | (24.1090) | (23.84826) | (5.445593) | (9.5391) |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Current weather controls | Yes | Yes | Yes | Yes |
| Harmattan correlate control | Dusts, $kg/m^3$ | Dusts, $kg/m^3$ | Winds, $m/s$ | Winds, $m/s$ |
| Observations | 43,814 | 43,814 | 43,814 | 43,814 |
| $R^2$ | 0.215 | 0.218 | 0.210 | 0.213 |

Notes: Reduced form link between educational outcomes and Harmattan. Table reports the results from regressions of educational attainment on Harmattan season at the district level. Columns (1)-(4) differ based on the inclusion of interaction terms and weather controls. Columns (2) and (4) include the interaction terms between cohort level Harmattan season variables (1985Q4: winds and dust) and gender, while columns (1) and (3) omit the interactions. Errors are clustered at the district level. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table A2: Impact of Meningitis Exposure on Number of Wives for School-Going Aged Respondents Married during Epidemic (1986) and Non-epidemic (1990) Years

| | Dependent Variable: Nos. of Wives | | | |
|---|---|---|---|---|
| | SGA 1986 F | SGA 1986 M | SGA 1990 F | SGA 1990 M |
| | (1) | (2) | (3) | (4) |
| Meningitis Cases | 0.006*** | 0.0003 | −0.001 | 0.005 |
| | (0.002) | (0.002) | (0.007) | (0.007) |
| Constant | 0.414*** | 1.094*** | 0.302*** | 1.017*** |
| | (0.037) | (0.051) | (0.048) | (0.028) |
| Observations | 5,573 | 906 | 4,322 | 515 |
| $R^2$ | 0.032 | 0.042 | 0.023 | 0.051 |
| Niamey FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Year of birth FE | Yes | Yes | Yes | Yes |

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is number of wives for school going aged respondents (between 6 and 20 years old) during the 1986 epidemic and 1990 non-epidemic year for the male (M) and female (F) DHS samples. SGA is School going aged sample. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

# Table A3: Difference in Difference Estimates of the Impact of Meningitis Exposure on Education in Non-Epidemic Years, Robustness Check

| | Dependent Variable: Years of Education | | | | | |
|---|---|---|---|---|---|---|
| | MENIN Cases 1990 | | MENIN Cases 1988 | | MENIN Cases 1989 | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Female | $-0.644^{***}$ | $-0.652^{***}$ | $-0.636^{***}$ | $-0.601^{***}$ | $-0.645^{***}$ | $-0.653^{***}$ |
| | (0.050) | (0.076) | (0.046) | (0.072) | (0.051) | (0.060) |
| Meningitis exposure at ages 0-5, 1990 | $-0.070$ | $-0.129$ | | | | |
| | (0.096) | (0.118) | | | | |
| Meningitis exposure at ages 6-12, 1990 | $-0.006$ | 0.011 | | | | |
| | (0.042) | (0.057) | | | | |
| Meningitis exposure at ages 13-20, 1990 | 0.011 | 0.072 | | | | |
| | (0.050) | (0.061) | | | | |
| Meningitis exposure at ages 0-5 x Female, 1990 | | $0.117^{**}$ | | | | |
| | | (0.047) | | | | |
| Meningitis exposure at ages 6-12 x Female, 1990 | | $-0.032$ | | | | |
| | | (0.041) | | | | |
| Meningitis exposure at ages 13-20 x Female, 1990 | | $-0.111^{***}$ | | | | |
| | | (0.038) | | | | |
| Meningitis exposure at ages 0-5, 1988 | | | $-0.092$ | $-0.141$ | | |
| | | | (0.084) | (0.105) | | |
| Meningitis exposure at ages 6-12, 1988 | | | $0.084^{***}$ | $0.116^{***}$ | | |
| | | | (0.029) | (0.023) | | |
| Meningitis exposure at ages 13-20, 1988 | | | $0.219^{*}$ | $0.297^{***}$ | | |
| | | | (0.119) | (0.114) | | |
| Meningitis exposure at ages 0-5 x Female, 1988 | | | | $0.094^{**}$ | | |
| | | | | (0.041) | | |
| Meningitis exposure at ages 6-12 x Female, 1988 | | | | $-0.060$ | | |
| | | | | (0.042) | | |
| Meningitis exposure at ages 13-20 x Female, 1988 | | | | $-0.155^{***}$ | | |
| | | | | (0.028) | | |
| Meningitis exposure at ages 0-5, 1989 | | | | | 0.013 | $-0.010$ |
| | | | | | (0.015) | (0.012) |
| Meningitis exposure at ages 6-12, 1989 | | | | | $-0.0005$ | 0.009 |
| | | | | | (0.005) | (0.009) |
| Meningitis exposure at ages 13-20, 1989 | | | | | $-0.040^{**}$ | $-0.023$ |
| | | | | | (0.018) | (0.019) |
| Meningitis exposure at ages 0-5 x Female, 1989 | | | | | | $0.046^{*}$ |
| | | | | | | (0.024) |
| Meningitis exposure at ages 6-12 x Female, 1989 | | | | | | $-0.019$ |
| | | | | | | (0.015) |
| Meningitis exposure at ages 13-20 x Female, 1989 | | | | | | $-0.029$ |
| | | | | | | (0.031) |
| Constant | $1.038^{***}$ | $1.042^{***}$ | $1.123^{***}$ | $1.103^{***}$ | $1.053^{***}$ | $1.056^{***}$ |
| | (0.181) | (0.193) | (0.226) | (0.239) | (0.201) | (0.206) |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 | 47,697 | 47,697 |
| $R^2$ | 0.205 | 0.207 | 0.211 | 0.213 | 0.206 | 0.206 |
| District fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Years of Education is years of education outcome with meningitis exposure defined as average district level monthly case (per 100,000 population) exposure for cohort at specified ages during the specified non-epidemic years in 1990, 1988 and 1989. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level.

Table A4: Difference in Difference Estimates of the Differential Impact of Meningitis Exposure on Education (1986 Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | MENIN Cases | | MENIN Intensity | |
| | (3a) | (3b) | (3c) | (3d) |
| Female | $-0.644^{***}$ | $-0.535^{***}$ | $-0.645^{***}$ | $-0.546^{***}$ |
| | [<.001] | [<.001] | [<.001] | [<.001] |
| Meningitis exposure at ages 0-4 | 0.006 | $0.005^{*}$ | 0.001 | $0.0005^{*}$ |
| | [0.576] | [0.751] | [0.590] | [0.868] |
| x Female | | 0.0005 | | 0.0001 |
| | | [0.399] | | [0.430] |
| Meningitis exposure at ages 7-12 | −0.025 | −0.003 | $-0.002^{*}$ | −0.0004 |
| | [0.241] | [0.894] | [0.184] | [0.814] |
| x Female | | $-0.042^{***}$ | | $-0.004^{***}$ |
| | | [< 0.001] | | [0.003] |
| Meningitis exposure at ages 14-21 | −0.046 | −0.028 | −0.004 | −0.002 |
| | [0.252] | [0.592] | [0.246] | [0.542] |
| x Female | | $-0.031^{***}$ | | $-0.003^{***}$ |
| | | [< 0.001] | | [0.001] |
| Constant | $1.038^{***}$ | $0.982^{***}$ | $1.018^{***}$ | $0.966^{***}$ |
| | [< 0.001] | [< 0.001] | [0.003] | [0.006] |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 |
| $R^2$ | 0.205 | 0.207 | 0.206 | 0.207 |

Notes: Regressions estimated by OLS. Dependent variable is years of education across all specifications. Cluster wild bootstrap-t (by district) p-values are in brackets. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1986 epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1986 epidemic year multiplied by number of months of exposure (with greater than zero cases). Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level using clustered standard errors by district.

Table A5: Difference in Difference Estimates of the Differential Impact of Meningitis Exposure on Education (1990 Non-Epidemic Year), Robustness Check

| | Dependent Variable: Years of Education | | | |
|---|---|---|---|---|
| | MENIN Cases | | MENIN Intensity | |
| | (3a) | (3b) | (3c) | (3d) |
| Female | −0.644$^{***}$ | −0.652$^{***}$ | −0.643$^{***}$ | −0.654$^{***}$ |
| | [< 0.001] | [< 0.001] | [< 0.001] | [< 0.001] |
| Meningitis exposure at ages 0-5 | −0.070 | −0.129 | −0.011 | −0.017 |
| | [0.591] | [0.336] | [0.532] | [0.176] |
| x Female | | 0.117$^{**}$ | | 0.011$^{**}$ |
| | | [< 0.001] | | [0.005] |
| Meningitis exposure at ages 6-12 | −0.006 | 0.011 | −0.002 | −0.001 |
| | [0.901] | [0.776] | [0.648] | [0.854] |
| x Female | | −0.032 | | −0.002 |
| | | [0.517] | | [0.641] |
| Meningitis exposure at ages 13-20 | 0.011 | 0.072 | 0.003 | 0.009 |
| | [0.854] | [0.261] | [0.702] | [0.353] |
| x Female | | −0.111$^{***}$ | | −0.010$^{***}$ |
| | | [< 0.001] | | [0.001] |
| Constant | 1.038$^{***}$ | 1.042$^{***}$ | 1.018$^{***}$ | 1.024$^{***}$ |
| | [0.001] | [0.003] | [< 0.001] | [0.002] |
| District fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Year of birth fixed effects | Yes | Yes | Yes | Yes |
| Observations | 47,697 | 47,697 | 47,697 | 47,697 |
| $R^2$ | 0.205 | 0.207 | 0.206 | 0.207 |

Notes: Regressions estimated by OLS. Dependent variable is years of education across all specifications. Cluster wild bootstrap-t (by district) p-values are in brackets. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1990 non-epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1990 non-epidemic year multiplied by number of months of exposure (with greater than zero cases). Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level of education for girls in the sample is 0.94. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters, with results provided in the appendix. $^{***}$Significant at the 1 percent level, $^{**}$Significant at the 5 percent level, $^{*}$Significant at the 10 percent level using clustered standard errors by district.

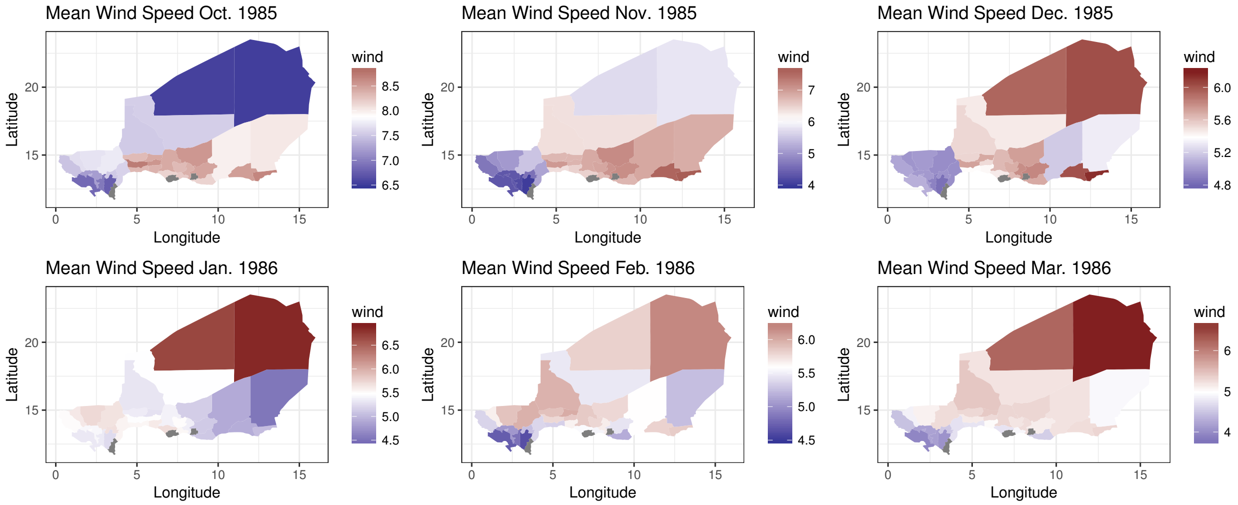

Figure A1: Harmattan Wind by District 1985-1986

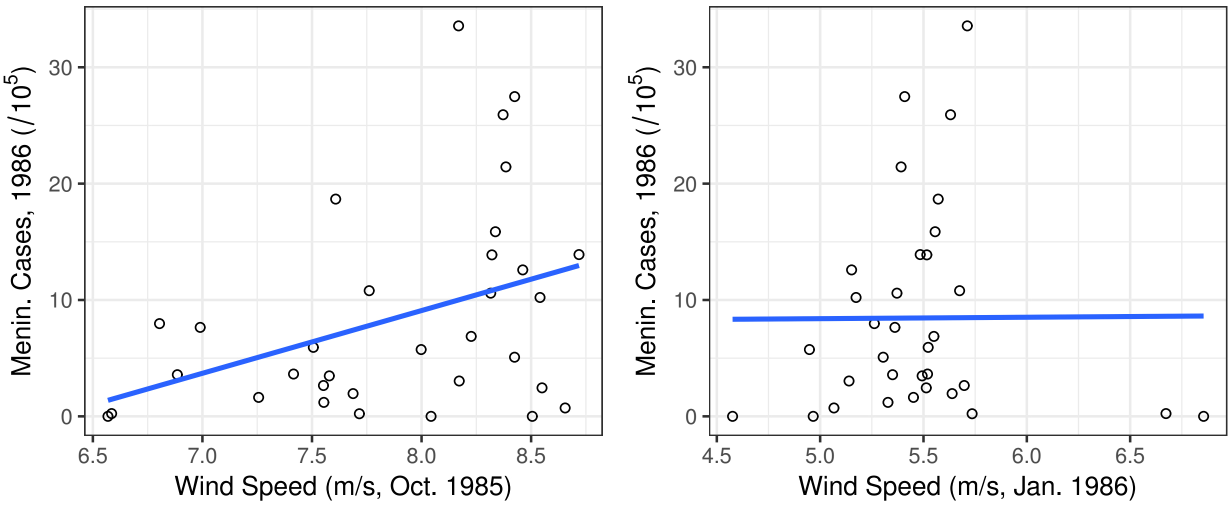

Figure A2: Harmattan Wind and Meningitis Outbreaks, 1985-1986

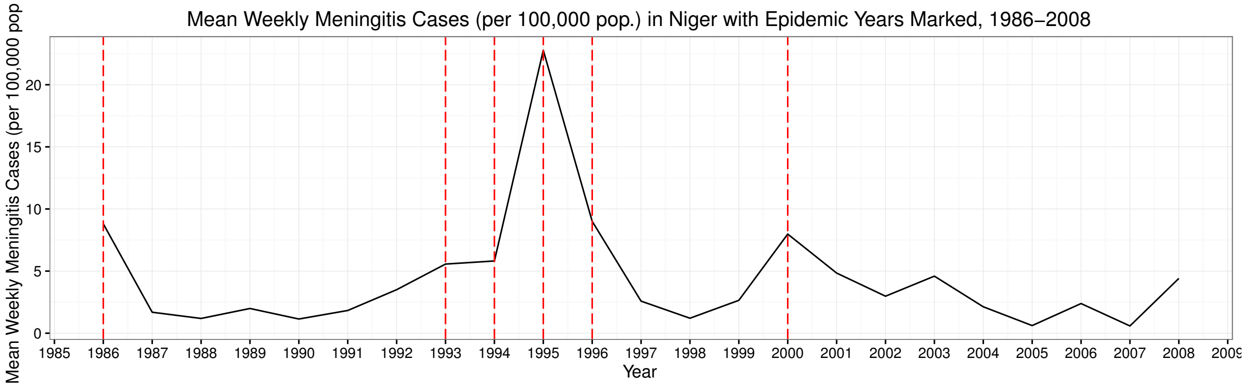

Figure A3: Niger Meningitis Cases with Epidemic Years Marked, 1986-2008