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Center for Development Economics and Policy

CDEP-CGEG WORKING PAPER SERIES

CDEP-CGEG WP No. 54

Schooling in Sickness and Health: The Effects of Epidemic Disease on Gender Inequality

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August 2020

COLUMBIA | SIPA
Center on Global Economic Governance

Schooling in Sickness and in Health: The Effects of Epidemic Disease on Gender Inequality*

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August 26, 2020

Abstract

Epidemics 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. 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.

JEL classification: I15, I24, J16, O12, Q54

Keywords: Epidemic, Education, Meningitis, Human Capital, Gender, Marriage, Bride-Price, Niger, Africa

*Thanks to Liz Ananat, Sandy Black, Rodrigo Soares, Bernard Salanie, Lalith Munasinghe, James Fenske, Cristian Pop-Eleches, Linda Loubert, Shari Eli, Steve Shore, Seema Jayachandran, Erica Field and participants at numerous meetings including the NBER Environmental and Energy Economics summer meeting, CSAE, AEA, EEA, LACDEV, IAFFE, EHA and APPAM conferences, Barnard Center for Research on Women (BCRW), IFPRI, Columbia University, Binghamton University, Vassar, Pomona College, Cornell University, and many others for useful comments and suggestions. We are grateful to Carlos Perez, Madeleine Thomson, Nita Bharti, the Ministry of Public Health in Niger and the World Health Organization (WHO) for the data on meningitis used in this study. Errors are our own.

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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 Tonthola, *BBC News, October 25, 2016*

In almost every region of the world, negative aggregate shocks disproportionately harm women. Epidemics of infectious disease are one such shock and the virulence and human cost of recent epidemics have reignited discussions about the economic burden of infectious disease. While the economic gains from educating girls are significant, health costs from worsened disease environments can impose significant financial burdens on households, which might lessen relative investment in girls' education (Glewwe and Miguel, 2007). This may be particularly true in a developing country context if parents have lower expected return from investment in girls' human capital[1] (Schultz, 2002; Barro and Lee, 2013).

In this study, we ask how aggregate shocks like epidemics affect gender gaps in educational attainment using evidence from a developing country context. We focus on the influence of early school-age disease burdens because of the robust evidence that experiences early in life have large, lasting impacts on human capital[2]. More specifically, we exploit variation in exposure to the 1986 meningitis epidemic in Niger to examine the effects of the epidemic on the gender gap in educational attainment[3].

[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.

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

[3]Meningitis is an illness caused by an infection of the meninges or the thin lining covering the brain and spinal cord. Direct transmission is through contact with respiratory droplets or throat secretions from infected individuals, and young children and adolscents are particularly at risk of infection (LaForce et al.,

To understand how significant costs[4] associated with epidemics might differentially affect women's wellbeing, 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). 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 epidemic disease in a developing country context- the 1986 meningitis epidemic- that allows us to identify the effects of a significant aggregate health shock; (iii) as we discuss in latter sections, our single country context of Niger allows us to credibly control for any differences across disease exposed units or districts, which will be our main unit of analysis.

Our identification strategy exploits variation in exposure to the 1986 meningitis epidemic for school-aged children using evidence on education from representative surveys in 1992 and 1998. We estimate a difference-in-differences model that interacts an indicator for gender with a cohort-based measure of meningitis exposure or meningitis shocks during the 1986 epidemic. Meningitis shock is measured as an indicator that equals 1 if the mean weekly meningitis cases (per 100,000 pop.) for a district is above the national average in the epidemic year. We find that meningitis shocks during the epidemic year reduced years of education for school-aged girls. There is no significant difference in the education of boys exposed to meningitis shocks during the epidemic. Substantively, meningitis shocks during the epidemic year significantly decreased years of education for girls, relative to their male counterparts, by 0.7 years and 0.4 years for primary school (aged 6-12) and secondary school (aged 13-20) aged girls respectively. The magnitude of the decrease corresponds to a 58% and 33% decrease in educational attainment for girls relative to low levels (1.2 years) of mean educational attainment in the sample. The effects are robust to several alternate

2009; García-Pando et al., 2014). We provide more details on the epidemiology of the disease in Section 3.

[4]Households report spending up to 34% of per capita GDP on direct and indirect costs stemming from meningitis epidemics (Colombini et al., 2009; Akweongo et al., 2013).

model specifications, the influence of concurrent weather shocks, and multiple falsification tests.

We address several possible concerns with the validity of our design: examining the effects of the epidemic on gender gaps in education in a cohort study setting, where meningitis exposure is assessed at the district level in Niger. First, we provide evidence for parallel trends or that in the absence of the 1986 epidemic, the gender differences in educational attainment would not have been systematically different between meningitis shock and less exposed districts, by estimating cohort-based differences in differences for school-going and non-school going individuals in 1986. We also show that baseline statistics of relevant variables (i.e., weather, geographic, and institutional features) are balanced across meningitis shock and less exposed districts during the epidemic year. Second, to assess the possibility that selective migration may be driving our results, we explore cross-district migration patterns and find that internal migration is extremely low in Niger with net internal migration rates at -0.04% in rural areas, where over 80% of the population reside over the period of study (Bocquier and Traoré, 1998). We conduct additional tests to examine the sensitivity of our results to selective migration. The results show no evidence of differential effects based on selective migration.

What drives the estimated effects of meningitis epidemics on gender gaps in educational attainments? There are at least two channels through which epidemic disease can differentially affect educational investments and attainments by gender: (i) direct health and biological effects and (ii) 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; Jayachandran and Lleras-Muney, 2009; Almond, Edlund, and Palme, 2009). We test hypotheses around differential treatment and infant mortality in meningitis shock districts during the epidemic year and find no evidence for the direct channels here.

We find suggestive evidence that indirect economic impacts may partly explain the increased gender gap results. The high economic costs of disease burdens during epidemic years may induce households to marry off their daughters at earlier ages; and we document significant negative correlations between educational attainment and the likelihood of early marriage, or marriage before the age of 18, of girls. School-aged girls during the epidemic year in more highly exposed, meningitis shock districts experience an increase in the likelihood of early marriage. Specifically, meningitis shocks increase the likelihood of early marriage for school-aged girls during the epidemic by 4.8 percentage points, lowering the age at first marriage for girls by almost a year from 15 years to 14 years old. There is no significant effect of meningitis shocks on early marriage of boys who were school going aged during the epidemic.

These findings are not only consistent with the prevailing local social norms[5], but are also in line 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, 2020; Ashraf et al., 2020). Predictions from a framework that explores health shocks, like disease epidemics, 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. Heterogeneity analysis suggests that the estimated gender impacts are concentrated among liquidity constrained households, lending further support for the income effects and early marriage channel following meningitis epidemics. We test alternative hypotheses and show that our results are

[5]Specifically, that it is not customary for boys to marry before the age of 18 (Masquelier, 2005).

not driven by concurrent weather shocks that may be relevant for regions, like SSA, where rain-fed agriculture is a major contributor to economic productivity.

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; Maccini and Yang, 2009). 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), and school enrollment, performance and attainment (Bharadwaj, Løken, and Neilson, 2013; Bleakley, 2007; Archibong and Annan, 2017; Alsan et al., 2017), and labor market outcomes (Almond, 2006; Gould, Lavy, and Paserman, 2011). Many of these studies also highlight the role of early differential parental investments in male and female children on latter life outcomes (Behrman et al., 1999; Autor et al., 2019; Jayachandran and Lleras-Muney, 2009; Maccini and Yang, 2009).

Our work contributes to these previous studies in several important ways. First, while previous work has focused on the effects of idiosyncratic household income shocks on human capital outcomes, here we highlight the effects of aggregate shocks like disease epidemics on gender gaps in education. Additionally, we provide evidence for the role of marriage market norms in partly explaining the results. In doing so, we also examine the linkages between standard theories of intrahousehold resource allocation (Becker, Murphy, and Tamura, 1990) and the growing economics literature on norms within marriage institutions (Fafchamps and Quisumbing, 2007; Anderson, 2007; Tertilt, 2005; Vogl, 2013; Behrman et al., 1999; Fernandez, Guner, and Knowles, 2005; Ashraf et al., 2020; Edlund, 2006; Giuliano, 2015). We expand these literatures by demonstrating that disease epidemics during early school age have large effects on differential educational attainments and marriage market outcomes by gender. While Archibong and Annan (2017) documents the impacts of meningitis epidemics on gender gaps in education, here, we use a new empirical framework and show additionally that associated educational gender gaps likely operate through changes in the marriage market. We also formulate a model yielding predictions that are consistent with the empirical findings. Estimating the contribution of aggregate shocks like epidemics to differential human capital investment by gender is especially important for poorer regions, where the combination of gender gaps in educational attainment and higher disease burdens can impose a double cost for economic development.

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 epidemiology of epidemic disease 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 of the effects of the epidemic on the gender gap in education. Section 7 explores direct and indirect channels, examines the effects of the epidemic on early marriage of girls and evaluates alternative explanations for the results. Section 8 concludes.

2 Conceptual Framework

This paper tests the hypothesis that aggregate health shocks, like disease epidemics, 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; 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 has income effects on the household (Bandiera et al., 2019). The household is modeled as a unitary entity with liquidity and credit constraints. The epidemic 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, 2020). Corno, Hildebrandt, and Voena (2020) outline a model and provide evidence for an increase in early marriages in response to income shocks in bride price societies[6]. Early marriage is associated with lower educational attainment and subsequent lower earnings in a standard Mincerian model of returns to education[7], with girls often dropping out of school or completing less schooling at the time of marriage (Corno and Voena, 2016; Corno, Hildebrandt, and Voena, 2020; Ashraf et al., 2020). The early marriage channel could explain a widened gender gap in educational attainment following an epidemic.

[6]Corno, Hildebrandt, and Voena (2020) 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.

[7]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; Qureshi, 2018).

We present a simple framework of schooling and marriage choices to guide the empirical analysis. Our goal is to understand [i] the relationship between 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 δ is a discount factor. a_s^i are cognitive skills with α_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)[8].

$\gamma_s y_s^{ai}$ 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. ω_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[9]. Given simple restrictions on the parameters above[10] 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

[8]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).

[9]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).

[10]Without loss of generality, to simplify the notation, we normalize θ_b and η_b to 1 and assume p= 1 (Björkman-Nyqvist, 2013).

from a more educated and subsequently higher paid adult. An implication of the model is "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 $\mathcal{F}$[11].

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 π — 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

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

(assuming stable demand for brides)[12].

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.[13]

[12]See Corno, Hildebrandt, and Voena (2020) for a more formal exposition of this condition.

[13]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 2: *$\forall$ g, b: the marriage probability is higher in the event of an income shock compared to the no shock scenario.*

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

3 Epidemiology and Costs of Epidemic Disease 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[14]. The epidemic 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) estimates that around 30,000 cases of the disease are reported each year, with case figures increasing significantly during epidemic years (Organization, 2018). Meningococcal meningitis can have high fatality rates, up to 50% if left untreated according to WHO estimates (Organization, 2018). 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)[15].

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

[15] The most recent vaccine MenAfriVac has been available in meningitis belt countries since 2010 and has been found to be effective against serogroup A, the strain of the bacterium most frequently associated with epidemics in the belt (Karachaliou et al., 2015). There has been a reduction in serogroup A cases in many

The epidemiology of the disease is complex. Direct transmission is through contact with respiratory droplets or throat secretions from infected individuals (LaForce et al., 2009; García-Pando et al., 2014). The majority of new cases are infected through exposure to asymptomatic carriers with relatively few through direct contact with active patients (Organization et al., 1998). The bacteria can be carried in the throat of healthy human beings and, for reasons not completely understood, subdue the body's immune system, facilitating the spread of infection through the bloodstream to the brain following a 3 to 7 day incubation period (Basta et al., 2018; Organization, 2018)[16]. Young children and adolescents are particularly at risk of infection (Zunt et al., 2018). The epidemic form of the disease is thought to have climate links, with greater incidence associated with increased wind speeds, dust concentrations and lower temperatures that arrive with the onset of the dry, Harmattan season in SSA, though the mechanisms of transmission are not well understood (LaForce et al., 2009; García-Pando et al., 2014).

In its 1998 report on meningococcal meningitis, the WHO recommended a number of government responses to meningitis epidemics (Organization et al., 1998). These include the creation of crisis committees with groups like the Ministry of Health and the WHO to coordinate epidemic responses like the dissemination of information to the general public, mass national vaccination campaigns and disbursing funds and antimicrobial drugs for treatment[17] (Organization et al., 1998). The costs of full antibacterial therapy treatment for bacterial meningitis ranged between just under \$10 to over \$250 (Organization et al., 1998).

countries since the introduction of the vaccine with the vaccine hailed as a success. Concerns have been raised about waning herd immunity over the next decade especially if the vaccine does not become part of routine childhood vaccinations; and an increase in serogroup C cases has been noted in other regions more recently prompting concerns about more epidemics from other serogroups of the bacterium (Karachaliou et al., 2015; Novak et al., 2019). There is currently no vaccine that prevents against all serogroups of *Neisseria meningitidis* (Novak et al., 2019).

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

[17] Unlike the COVID-19 pandemic, there were no recommendations for physical distancing or lockdowns in response to meningitis epidemics.

Niger is one of the worst affected countries in the meningitis belt as more than 95% of the country's population reside in the belt (Yaka et al., 2008). The country has experienced six epidemics since 1986, with the longest lag occurring between the 1986 and 1993 epidemics[18] (Archibong and Annan, 2017). The periodicity of epidemics for countries like Niger in the meningitis belt is around every 8 to 12 years (Yaka et al., 2008). In one of the most acute instances in the country's recorded disease history, the 1986 epidemic registered over 15,000 reported cases and a case fatality rate of approximately 4%[19] (Archibong and Annan, 2017). The size of Niger's young population, with the median age remaining at 15 years for more than a decade, has historically placed a significant share of the country at risk during epidemics[20].

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[21] 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.

[18] 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).

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

[20] Source: DHS and UNICEF statistics.

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

Domestic, internal migration is limited in Niger[22] 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[23]. We provide further evidence of low levels of internal migration in Section 5.3. Given limited internal 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).

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 geocoded, 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 more precisely identify 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[24]. There is significant variation in exposure to the meningitis epidemic across districts, with a mean of around 10

[22]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; Aker, PRINA, and WELCH, 2018).

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

[24]Results are similar when other non-epidemic years, 1991 and 1992, for example, are used.

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. District level data on fatality rates from meningitis are 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 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 main meningitis cohort-shock measure along with its underlying meningitis cohort-cases data, and years of education, our outcome variable, by cohort and gender. We describe these variables in detail in Section 5. 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 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 1.9 years of schooling. The distribution is also similar conditional on gender as shown in Figure 4[25].

[25]In Figure 4, we display the density functions of educational attainment across the various cohorts and genders, along with the results of a Kolmogorov-Smirnov (K-S) test. 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.

5 Empirical Strategy

5.1 Intuition

The intuition for our identification strategy is that in an environment with similar institutions[26] and limited internal migration, households in districts affected by the 1986 meningitis epidemic, experience the epidemic as either an income or direct health shock, while households in the other districts remained unaffected, following the conceptual framework in Section 2. 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. Girls may act as household insurance through their early marriage and associated bride price transfers during adverse times[27]. This phenomenon could have large and long-range effects on observed gender gaps in educational attainments. We outline the model specification in Section 5.2 and address potential concerns about the validity of the design in Section 5.3.

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 year round r to measures of sudden meningitis exposure, Meningitis Shock$_{adt}$, that are interacted with the gender of the individual female$_i$:

[26] Based on the authors' calculations from DHS data, Niger is 99% muslim and 57% of respondents are from the Hausa ethnic group.

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

$$\text{education}_{ia(t)dr} = \alpha\text{Female}_{ir} + \beta\text{Meningitis Shock}_{a(t)d} + \gamma\text{Meningitis Shock}_{a(t)d} \times \text{Female}_{ir} + \mu_d + \delta_r + \delta_t + \epsilon_{ia(t)dr} \quad (1)$$

where t indexes the birth year. This specification includes district fixed effects μ_d which capture unobserved differences that are fixed across districts. The birth year and survey round fixed effects, δ_t and δ_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 γ, which is allowed to vary across cohorts. This measures the effect of 'Meningitis Shock' 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. 'Meningitis Shock' is the main meningitis exposure variable and is measured as an indicator that equals 1 if the mean weekly meningitis cases (per 100,000 pop.) for a district is above the national average in the specified year. In alternate specifications, we use the continuous case exposure measure with the results unchanged and reported in the Appendix. The implied key variable of interest in Equation 1 is therefore constructed by interacting the 'Meningitis Shock' measure with gender. Estimations are done using OLS and standard errors are clustered at the district level.

5.3 Balance and Validity of Design

The difference-in-differences, cohort study strategy outlined in Equation 1 requires two key identifying assumptions. The first assumption is that in the absence of the 1986 epidemic, the gender differences in educational attainment would not have been systematically different between meningitis shock and less exposed districts (i.e. parallel trends). This assumption is not directly testable, but it has an implication that can be tested. Individuals who were not in school-going ages in 1986 were not directly impacted and so differences in education for them should not systematically differ across districts.

To test this implication, following Duflo (2001), we estimate cohort-based differences in differences for school-going and non-school going individuals in 1986. The results are shown in Figure 5 for the meningitis shock epidemic exposure measure[28]. The estimates are very close to 0 for the non-school-going aged (1981-1986) populations but significantly negative for the relevant school-going individuals (1966-1980) in 1986, in line with the assumptions of the difference-in-differences specification. There is one instance (i.e., 1981) where "early school attendance" led to the significance of the non-school going aged estimate (we show later that our results are robust to early or late school attendance). Thus, the results provide suggestive evidence that our difference-in-differences estimates are not likely driven by alternate assumptions (e.g., that, the observed gender difference in education is linked to something other than the 1986 epidemic; or reverse causality whereby pre-1986 changes in educational attainment causes the 1986 epidemic).

As an additional test of the plausibility of the first identifying assumption that meningitis shock and less exposed districts are comparable prior to the 1986 epidemic, we run the following regression on the 1980 to 1985 baseline data:

[28]Figure A1 in the Appendix replicates these results for the meningitis cases epidemic exposure measure.

$$y_d = \alpha + \xi \text{Meningitis Shock}_d + \epsilon_d \quad (2)$$

where, as before, Meningitis Shock$_d$ is an indicator that equals 1 if district d's mean weekly meningitis cases per 100,000 population was above the national average in the 1986 epidemic year. We consider various outcomes, y_d, spanning weather, geographic and institutional features, following previous literature on the relevance of these characteristics for development and meningitis incidence (Perez Garcia Pando et al., 2014; Michalopoulos and Papaioannou, 2013; Archibong, 2019). The results in Table 2 show no observable differences in outcomes across districts that experienced unexpectedly higher than the national average level of meningitis cases in the 1986 epidemic and those that did not.

The second important assumption for the cohort study strategy is that there is limited internal migration between districts between the 1986 epidemic year and the 1992 and 1998 survey years. Since the meningitis shock measure, is assessed at the district level, selective migration, if, for instance, high ability individuals were leaving more highly affected districts en masse post the epidemic, would bias the estimates. While there is little information on internal migration over the full sample from 1986 to 1998 in Niger, we provide estimates on internal migration based on the ACMI (aggregate crude migration index) and net internal migration rate (NIMR) values calculated from 1988 to 1992 in Bocquier and Traoré (1998) in Appendix A.3. Internal migration is extremely low in Niger, with just 6% of the population reporting changing their place of residence within the country over the four-year interval from 1988 to 1992 and net internal migration rates at -0.04% in rural areas, where over 80% of the population reside over the period of study (Bocquier and Traoré, 1998). Next, we relax the assumption about internal migration and examine the sensitivity of our results to selective migration in Appendix A.3. The results, in Table A14 and Table A15, show no evidence of differential effects based on selective migration.

6 Effects of the Meningitis Epidemic on Gender Gaps in 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 3 reports estimates of the effect of meningitis shocks on gender gaps in education during the 1986 epidemic using 1960 to 1992 birth-year cohorts. Columns 1 and 3 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 shock across all cohorts is negative and insignificant.

Our main results are in column 4 of Table 3 where we interact the meningitis shock measure with gender to examine gender-differentiated impacts of the meningitis burden on educational investments during the 1986 epidemic year. 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. Meningitis shocks during the epidemic year significantly decrease years of education for girls, relative to their male counterparts, by 0.7 years and 0.4 years for primary school (6-12) and secondary school (13-20) aged girls respectively. The magnitude of the decrease corresponds to a 58% and 33% decrease in educational attainment for girls relative to the unconditional sample mean of 1.2 years of education[29]. Reassuringly, the interaction is not significant for non-school-going-aged female respondents at the time of the

[29]The effects remain unchanged when the continuous meningitis case epidemic exposure measure is used as shown in Table A1 in the Appendix.

epidemic.

In line with Prediction 1, from the conceptual framework in Section 2, the effect of the meningitis shock on years of education is significantly negative for the female school-going aged population only, with no effect on their male counterparts. Meningitis shocks during the epidemic year significantly, disproportionately reduced years of education for school-going aged girls only.

6.2 Falsification Checks

We conduct various falsification/sensitivity tests. First, the results are robust to small changes/modifications in cohort age cutoffs as shown in Table 4. Our main results are derived using the definition of cohorts based on the 1986 epidemic. In alternate specifications presented in Table 5, we examine school-going and non-school-going-aged cohorts based on the 1990 non-epidemic year. Table 5 reports estimates for cohorts defined based a reference non-epidemic year 1990. We find no effect of meningitis shocks, or above national average meningitis case exposure, for the primary-school-aged category across all relevant specifications, which is what we would expect[30]. There is evidence of effects for the secondary school aged category. The secondary cohorts are essentially capturing some of the effects of initial exposure to the 1986 epidemic when such cohorts were in primary school[31]. The sign on the 0 to 5 group is significantly positive which suggests positive investment in education during non-epidemic years[32]. These robustness checks and falsification results make it less likely

[30]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.

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

[32]It could also suggest a reversal in district exposure during the 1993 to 1996 epidemics for respondents from these districts who would be in the primary-school-aged categories during that period. We get similar results when we examine the effects of the 1986 epidemic year on the 1990 school-going-aged cohort as shown in Table A4. Since we are partly observing the same individuals, the effect size is halved for the 6 to 12 age group in column (4) of Table A4 as the cohort of 6 to 8 year olds from from the 1986 are still in the 6 to 12 age cohort in 1990.

that we are picking up any spurious/confounding effects in our main results [33].

Our results suggest that disease epidemics 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[34]. 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 Suggestive Evidence on Possible Mechanisms: Income Effects and Early Marriage of Girls

Section 2 outlined the expected direct and indirect channels through which health shocks like epidemics might be expected to affect gender gaps in human capital investment. The following subsections explore these mechanisms and find suggestive evidence in favor of the indirect economic channel. The high economic costs of disease burdens during epidemic years can induce households to marry off their daughters at earlier ages.

[33] We replicate this falsification test for two other non-epidemic years, 1991 and 1992, finding results very similar to 1990 with tables provided in Table A5 in the Appendix.

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

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)). Although there is no detailed micro-level data on income and health expenditure for Niger during the 1986 epidemic year, evidence from prepaid private health expenditures[35] in twenty meningitis belt countries (including Niger) between 1995 and 2008 shows a significant increase in private health spending during epidemic years (Table A6)

In the presence of these high costs, studies have documented that one way parents may 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, 2020). We test the predictions of our conceptual framework and examine one possible method of doing this in the following sections: 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). Under Nigerien law, the legal age of marriage is 15 years for girls and 18 years for boys (Koffi et al., 2016). 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, 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

[35] Prepaid private spending includes private insurance and non-governmental agency spending (Dieleman et al., 2017)

"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, 2020). 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; Ashraf et al., 2020).

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 West African CFA 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[36], 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. These figures highlight the fact that bride price might present a significant income boost to households, especially poorer households, during periods of negative shocks. To evaluate the plausibility of the bride-price/marriage channel, we examine the effects of meningitis shocks on early marriage during epidemic and non-epidemic years. We provide evidence of an increase in early marriage for women in highly affected meningitis shock districts following the epidemic, in line with Prediction 2 and Prediction 3 from the conceptual framework and the predictions of the literature on the marriage effects of economic shocks in bride price societies[37].

To examine the effects of meningitis shocks during the epidemic on early marriage of girls, we modify the empirical framework to limit the sample to just the school going aged population during the 1986 epidemic year. Due to the nature of the DHS sampling, we are

[36]In nominal prices.

[37]See Corno, Hildebrandt, and Voena (2020) for a detailed analysis on the effects of shocks in dowry versus bride price societies.

unable to cleanly replicate the cohort level analysis in Section 5; so we re-estimate Equation 1 separately for the male and female school going aged cohorts during the epidemic year and report results of the effects of meningitis shock on early marriage[38].

Summary statistics on early 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 6. In line with the assumptions in the conceptual framework in Section 2, the rate of early marriage is much higher for women (86% and 89% in the female 1986 SGA and female 1990 SGA samples respectively) than men (17% and 21% in the male 1986 SGA and male 1990 SGA samples respectively). The age at first marriage is much lower for women (15 years) than men (around 20 years) in the samples.

First, we confirm findings from the robust literature on the links between age at first marriage and female educational attainment (Field and Ambrus, 2008) and document significant, negative associations between early marriage and years of education for school-going-aged female populations during the epidemic (1986) and non-epidemic (1990) years in Table 7. The coefficients remain stable, strongly significant, and positive at around -2 for school going aged female populations during the epidemic and non-epidemic years as shown in columns (1)-(2) and (5)-(6). There is no signifiant association between early marriage and years of education for school going aged male respondents as shown in column (4) and column (8) of Table 7. The results suggest that the association between early marriage and years of education is especially salient for women in the study region.

[38]The DHS reports marriage outcomes separately by gender in differently sampled men and women's surveys. It only samples women, in the women's survey, between the ages of 15 and 49 years at the time of the survey. In contrast, it surveys men between the ages of 15 and 90 years at the time of the survey. This means that the sample is unbalanced across cohorts, with for example, only 8% of the women's survey between the ages of 0 to 5 in 1986, versus 23% in the 6-12 age category and 28% in the 13-20 age cohort.The main early marriage results are largely unchanged when the cohort level analysis is used as shown in Table A7. Although results from Table A7 should be interpreted with caution due to the unbalanced nature of the sample.

Next, to explore the relationship between early marriage and meningitis shocks, particularly during epidemic years, we chart age at first marriage cumulative hazard curves 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 shock exposure in epidemic (1986) and non-epidemic years (1990). In meningitis shock districts (denoted as 'High Menin' in the figure), hazard rates are noticeably higher for both male and female respondents during the epidemic year. Quantitatively, female respondents who were school going aged during the 1986 epidemic year are almost two times more likely to marry earlier in highly exposed meningitis shock districts than in less exposed areas. The trend reverses in the 1990 non-epidemic year.

Given these trends in the raw data we assess significance, estimating regressions with OLS, with results shown in Table 8. The main result for the effects of meningitis shocks on early marriage of girls who were school going aged during the epidemic is shown in column (3) and Panel A of Table 8. Girls in meningitis shock districts are significantly more likely to marry earlier than their peers in less exposed districts during the epidemic year. Meningitis shocks increase the likelihood of early marriage for SGA girls during the epidemic by 4.8 percentage points (pp). There is no significant effect of meningitis shocks on early marriage of boys who were school going aged during the epidemic as shown in column (3) and Panel B of Table 8.

As a robustness check, we examine the effect of meningitis shocks, or above national average level of meningitis cases, on early marriage of male and female SGA respondents during the 1990 non-epidemic year. The results for the women's sample are shown in column (6) and Panel A of Table 8. There is no significant association between meningitis shocks and early marriage for female SGA respondents during the non-epidemic year. The comparison results for male SGA respondents during the 1990 non-epidemic year are shown in column

(6) and Panel B of Table 8. Interestingly, in line with the data distribution in Figure 6, meningitis shocks, or having above the national average level of meningitis cases in a non-epidemic year, are significantly negatively associated with the rate of early marriage for male SGA respondents (a reduction of 6.9 pp). The results are suggestive of differential marriage responses to higher meningitis burdens during aggregate shocks like epidemics versus more idiosyncratic disease shocks in non-epidemic years. Men in bride-price societies may be more likely to delay the timing of marriage in response to idiosyncratic shocks, where female respondents experience increases in the rate of early marriage in response to aggregate shocks like epidemics.

The results are in line with Prediction 2 and Prediction 3 from the conceptual framework and provide suggestive evidence for the indirect channel discussed in Section 2 where the epidemic acts as a negative income shock and may lead households to smooth consumption by "selling" their daughters for a bride price, reflected in the increased rate of early marriage during epidemic years but not non-epidemic years and with the effects significant for girls but not for boys. The consequence of the increased likelihood of early marriage for female SGA respondents in meningitis shock districts during the epidemic year is reflected in their increased total fertility at the time of the survey as shown in Table A8 in the Appendix; meningitis shocks increases the number of children born to women who were school going aged during the 1986 epidemic year. There is no effect of meningitis shocks on fertility in the 1990 non-epidemic year.

An explanation for the trends shown in the early marriage results- where the rate of early marriage rises for women in meningitis shock districts but not for their male counterparts during the epidemic year, can be gleaned from Table 6. First, note that the median male respondent 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, another explanation is that there is an increase in one to many matches with relatively wealthier men marrying more than one wife during the epidemic year. To test this hypothesis, we examine the relationship between the number of wives and meningitis shocks during the epidemic and non-epidemic years.

The results reported in Table A9 show a positive and significant relationship between meningitis shocks and the number of wives reported by school going aged women during the 1986 epidemic year. There is no statistically significant relationship between meningitis shocks and the number of wives reported by their male counterparts during the epidemic or non-epidemic years. While the differences between the number of wives result for men and women in the same cohort appear puzzling on the surface, a useful 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 6, while the maximum number of wives reported by women who were school going aged during the 1986 epidemic is seven, the maximum number of wives reported by men in the same cohort is four. Given that Islamic law prohibits men from having more than four 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.

Our analysis provides suggestive evidence that one primary channel that may explain the differential gender impacts of meningitis epidemics on education is that girls are married off at earlier ages as a response to meningitis shocks. This would be especially true for liquidity-constrained households[39]. Using data on assets from the DHS we construct a wealth index based on principal components analysis (PCA) scores and define liquidity or asset-constrained households as those located in the lower parts of the asset distribution. In

[39]Ideally, to test the income effect more directly, we would be able to examine the effect of meningitis shocks on household level income for 1986, the epidemic year. Unfortunately, we do not have micro level data on income from the epidemic year to test this directly.

Appendix A.1.1, we examine the heterogeneity in the effects of meningitis epidemics on early marriage by current, at the time of the survey, wealth status of women's households to test the hypothesis that the effect of the shock is largely concentrated on asset-constrained households[40]. The results are reported in Table A11 and suggest that the early marriage effects are concentrated in the potentially liquidity constrained households, as hypothesized in the conceptual framework. These results are consistent with previous studies showing marriage responses to shocks in bride price settings (Corno, Hildebrandt, and Voena, 2020).

While we show results here that the likelihood of early marriage rises for women in meningitis shock districts during the epidemic and provide this as suggestive evidence that a primary mechanism that may explain the increased gender gaps results in Section 6 is the early marriage/bride price channel, it is possible that these are two linked, but plausibly independent responses of households to the epidemic. Lacking data on bride price, we are unable to conclusively rule out alternate explanations for the marriage and education results, and we explore other explanations in Section 7.2 and Section 7.3.

7.2 Direct Channels: Health and Gender Gaps

On the direct health channel, given the paucity of data on infection and fatality rates by gender, we refer to the epidemiology and health literature on the biology of meningitis infection. There is little documented evidence for differential infection and fatality rates from meningitis by gender (Trotter and Greenwood, 2007). 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, primarily in Indian contexts (Barcellos, Carvalho, and Lleras-Muney, 2014; Jayachandran and Pande, 2017). This might also lead to differential mortality

[40]The analysis assumes stationarity in the wealth status of women's households between the 1986 epidemic year and the 1992 and 1998 survey years and results should be interpreted with caution here.

by gender during the epidemic. 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[41].

To test the differential mortality channel, we estimate the effect of meningitis shocks on gender gaps in infant mortality for children born during the 1986 epidemic year and in more highly exposed districts. We assemble DHS data on infant mortality for children born between 1986, the epidemic year, and 1992, before the start of the next recorded epidemic in 1993. We run four falsification tests to answer the following questions: (i) First, for the sample of children born in 1986, are there gender gaps in infant mortality for children born in meningitis shock districts?; (ii) Second, for the sample of children born to the same mother between 1986 and 1992, are female children born in the 1986 epidemic year more likely to die within the year, than their non-epidemic year born siblings?; (iii) Third, for the sample of children born to the same mother between 1986 and 1992, are female children born in meningitis shock districts more likely to die within the year?; (iv) Fourth, for the sample of children born in 1986, are there gender gaps in infant mortality for children born in districts with high meningitis case fatality rates?

The results are in Table 9. Across all four tests [42], there are no significant gender gaps in infant mortality for children born during the epidemic year or in more highly exposed, meningitis shock districts[43].

[41]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. The effect is reversed in dowry societies like India, which may explain the gender bias in investments in health seen in those contexts (Corno, Hildebrandt, and Voena, 2020).

[42]For test (i), results are in Columns (1) and (2); test (ii) results are in Columns (3) and (4); test (iii) results are in Columns (5) and (6) and test (iv) results are in Column (7) of Table 9.

[43]The main effects are not significant, and results are shown in Table A10 in the Appendix. Unfortunately, we do not have routine vaccination rates for children born in 1986 to assess the differential treatment hypothesis, but other research has not found significant gender gaps in vaccination rates for children born in epidemic years in meningitis belt countries (Archibong, Annan, and Ekhator-Mobayode, 2020).

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 3 provides a test for such a biological channel, where this hypothesis is rejected. If this channel is meaningful, then one would expect the effect of the 1986 meningitis epidemic 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

Guided by the conceptual framework in Section 2, we have explored both indirect income and direct health channels, finding suggestive evidence for the income channels, possibly through early marriage in bride price societies. However, there are other possible channels through which epidemics may affect gender gaps in education. This section discusses two such alternative explanations of the results: 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 relatively idiosyncratic rainfall shocks, common in SSA, might explain the relationship between meningitis and the gender gap in education during the epidemic year. To test this, we re-estimate Equation 1 by interacting the various cohorts with precipitation shocks. Precipitation shocks are defined in two ways: (i) as the difference between district level rainfall and the district specific prior five year mean rainfall using available data from NASA's Modern Era Retrospective Analysis for Research and Applications (MERRA-2)[44], which starts in 1980; and (ii) as the average district-level precipitation differenced from the national mean during the 1986 epidemic year. The results

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

for method (i) are reported in Table 10, and the results from method (ii) are presented in Table A12 in the Appendix. Each column in the table denotes different model specifications, with and without controls for temperature[45]. The results in column (4) of Table A12 show no effect of concurrent precipitation shocks on gender gaps in education across all school-aged cohorts during the epidemic year, lending further support to the estimated effect of meningitis shocks during the epidemic[46]

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[47] (Alsan et al., 2017; Qureshi, 2018). We do not rule out this explanation for the gender gap in education results, and 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 (Ashraf et al., 2020).

[45] Following previous research showing correlations between temperature and precipitation (Schlenker and Roberts, 2009).

[46] There is a significant negative effect of precipitation shocks on education for female respondents in the non-school going aged 0-5 category. A discussion of this result is beyond the scope of this paper. See Maccini and Yang (2009) for further discussion of the effects of rainfall shocks on education.

[47] In their analysis of 38 low and middle income countries in the DHS, including Niger, Alsan et al. (2017) find that girls were 2.69 pp less likely to attend school if a household reported more than one recent illness episode among children under the age of 5 years.

8 Conclusions

Recent epidemics have had costly human capital impacts including: the Ebola epidemic in West Africa which resulted in an estimated 28,600 cases and 11,325 deaths, the 2016 dengue epidemic worldwide which resulted in 100 million cases and 38,000 deaths, and most recently, the, as of 2020 ongoing, coronavirus, COVID-19 pandemic, which has resulted in over 24 million cases and more than 800,000 deaths globally as of August 2020 (Bloom and Cadarette, 2019; Lai et al., 2020). A growing scientific literature has provided evidence that future warming and climate change have the potential to significantly increase the likelihood of aggregate shocks like epidemics and alter the geographic distribution of infectious disease (Wu et al., 2016). This will have potentially devastating consequences 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. 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 and health to target the gender gap in educational attainment.

We provide suggestive 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 increased probability of early marriage for girls during epidemic years and subsequent increased total fertility, which may partly explain the widened gender gap in education during the epidemic year. An important contribution of the paper is to show that aggregate shocks like epidemics can contribute significantly to worsening gender inequality with associated implications for development. Future work will examine the role of policy responses from domestic and international institutions in mitigating the negative effects of epidemic disease on economic outcomes (Archibong, Annan, and Ekhator-Mobayode, 2020).

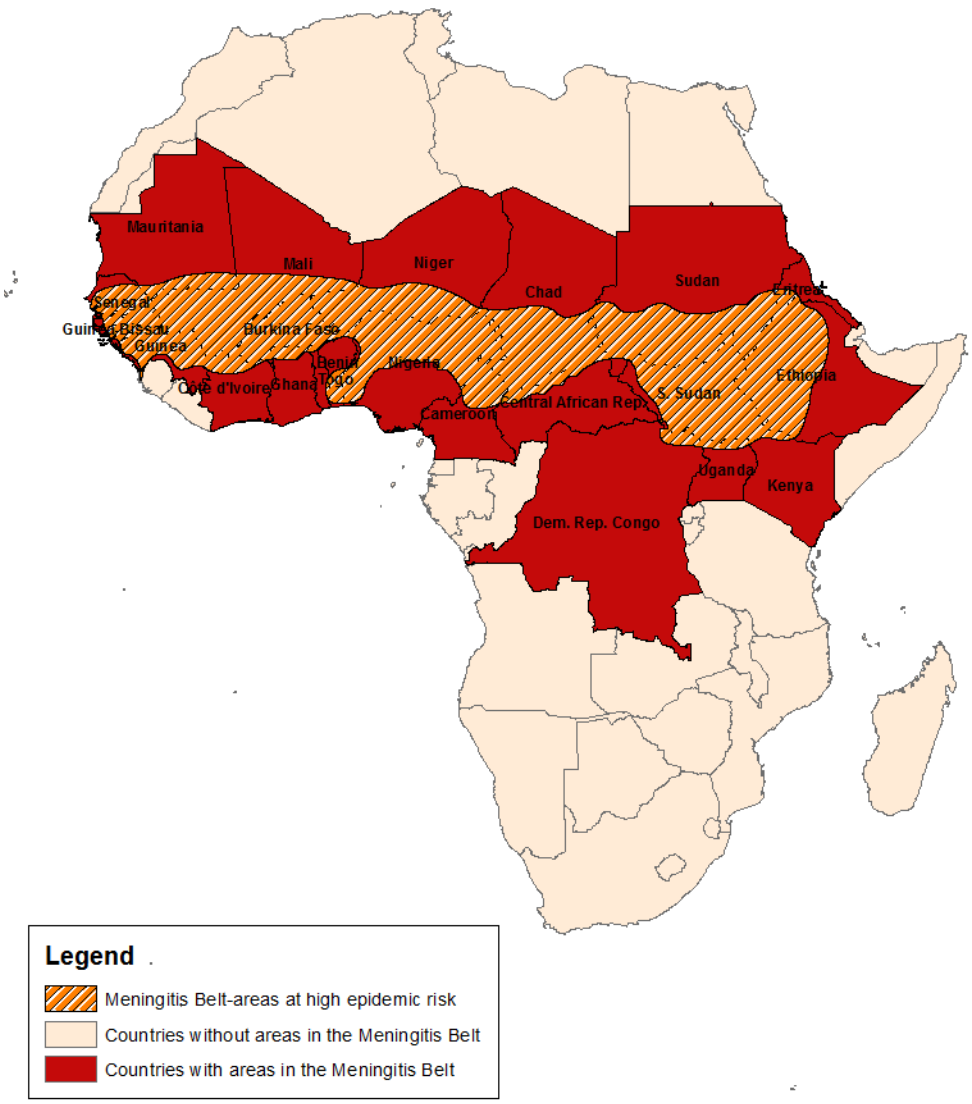


Figure 1: Areas with frequent epidemics of meningococcal meningitis (“Meningitis Belt”)

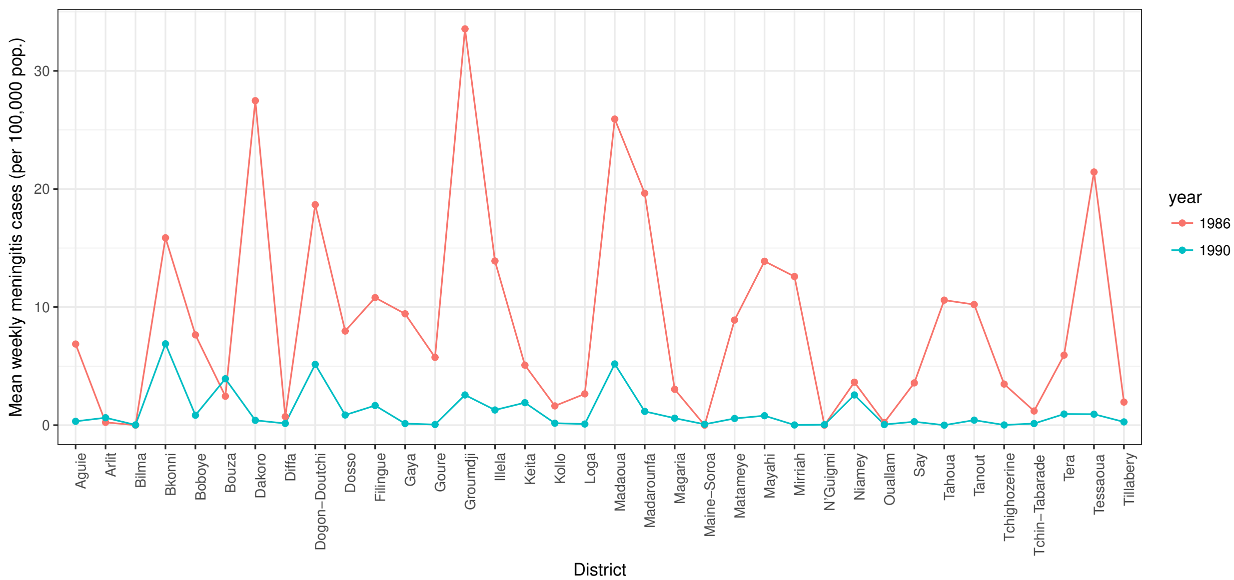


Figure 2: Niger meningitis cases by district in epidemic (1986) and non-epidemic (1990) years

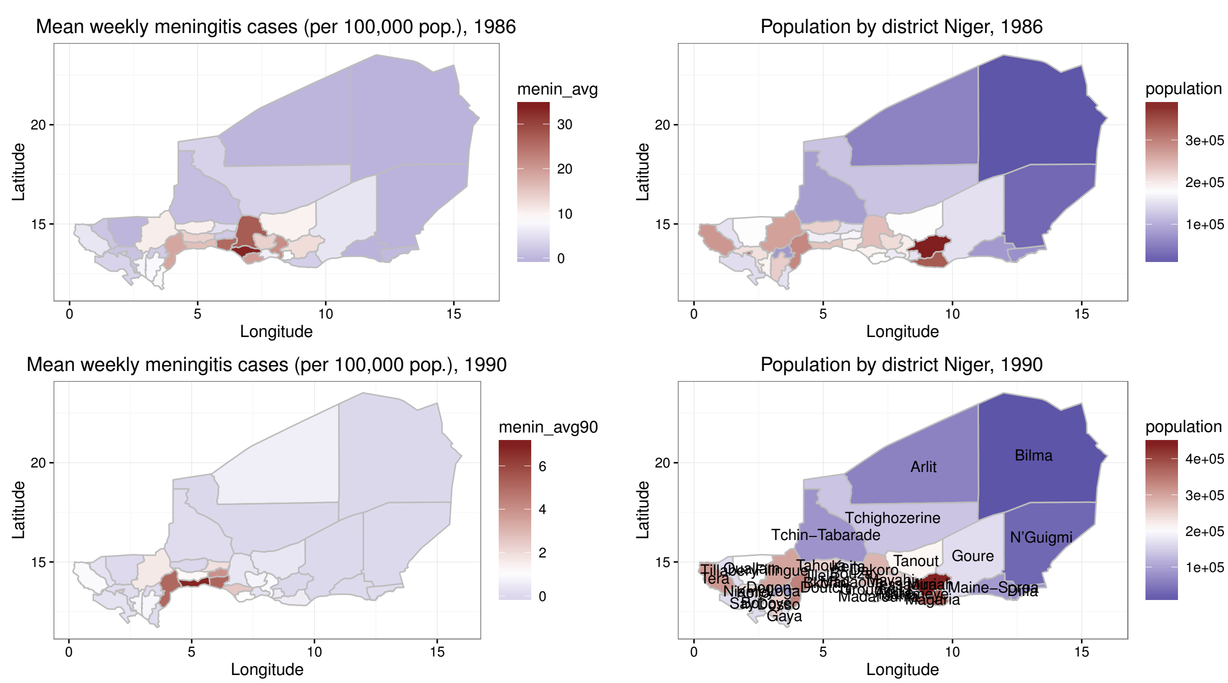
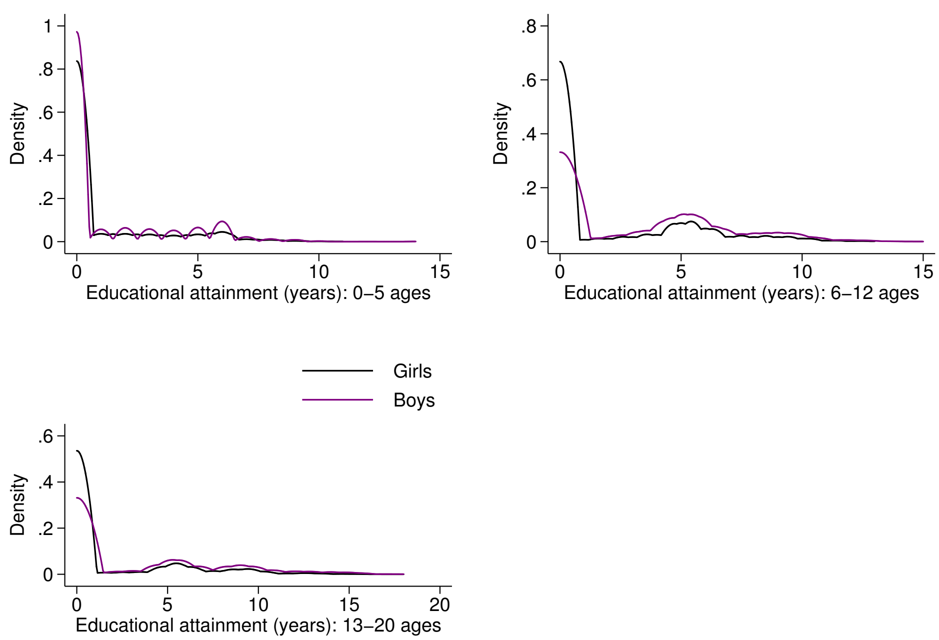


Figure 3: Niger meningitis cases and population by district in epidemic (1986) and non-epidemic (1990) years

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	0.20
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 shock cohort exposure									
age 0-5 in 1986	0.43	0.44	0.44	0.44	0.45	0.44	0.43	0.44	0.43
age 6-12 in 1986	0.40	0.41	0.40	0.42	0.40	0.41	0.38	0.42	0.40
age 13-20 in 1986	0.39	0.46	0.42	0.37	0.47	0.41	0.40	0.45	0.42
Meningitis cases cohort exposure									
age 0-5 in 1986	9.80	10.35	10.05	9.90	10.49	10.16	9.70	10.22	9.94
age 6-12 in 1986	9.33	9.98	9.60	9.70	9.76	9.73	8.97	10.15	9.49
age 13-20 in 1986	9.02	10.66	9.80	8.83	10.86	9.76	9.16	10.52	9.84
Years of education									
Control Cohorts: age 0-5 in 1986	0.40	1.95	1.09	0.46	2.33	1.30	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	1.38



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 (K-S test)

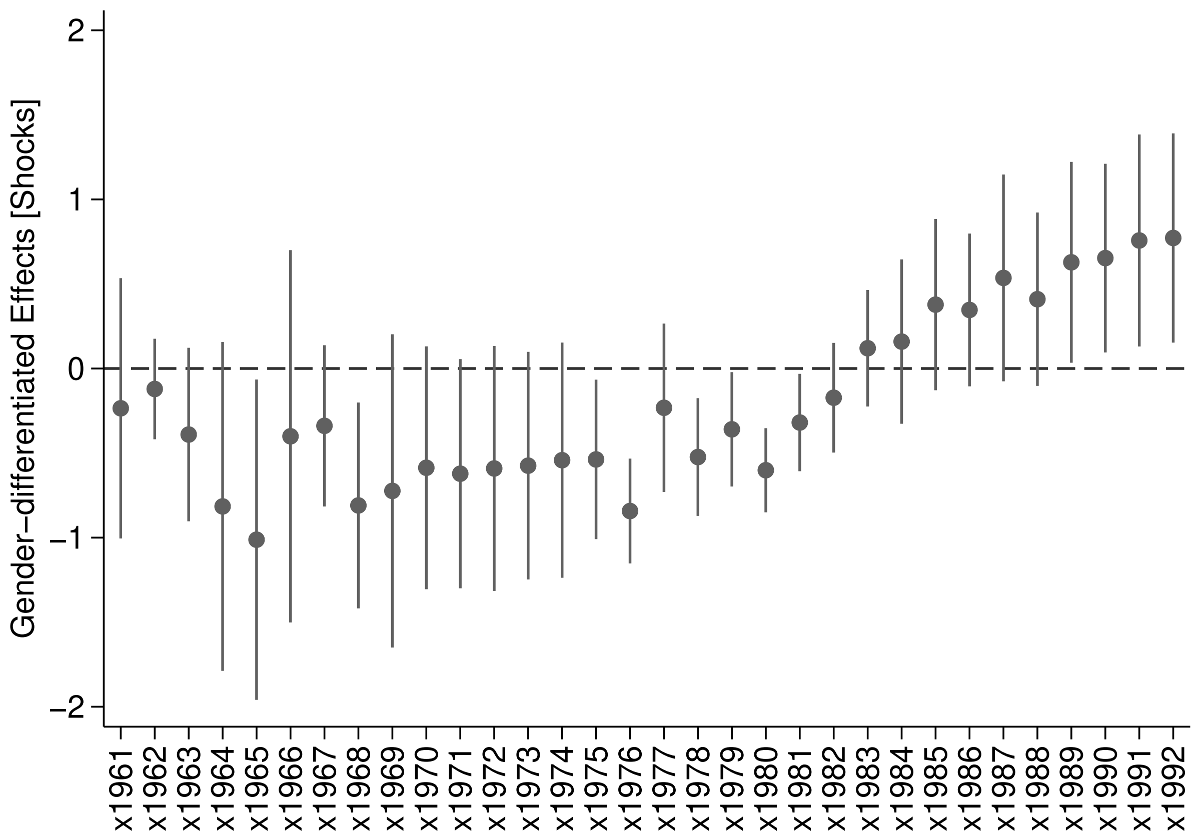


Figure 5: Coefficients of the interaction between year of birth [age] and gender-differentiated effects of meningitis shock (1986 epidemic year)

Table 2: Balance on geographic and institutional characteristics, pre-1986 outcomes

	Panel A: Weather Variables (1980-1985 Averages)				
	Precipitation	Temperature	Humidity	Dust	Wind
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	0.001	−0.098	0.0002	−0.00001	0.254
	(0.002)	(0.300)	(0.0004)	(0.00001)	(0.159)
Mean of outcome	0.011	300.575	0.007	0.0001	6.195
Observations	32	32	32	32	32
R^2	0.011	0.004	0.006	0.021	0.078
	Panel B: Geographic Characteristics				
	Elevation	Land Suitability	Malaria Stability	Distance to Capital	Uranium
	(1)	(2)	(3)	(4)	(5)
Meningitis shock	15.133	0.0013	3.075	−40.594	−0.043
	(34.511)	(0.022)	(2.715)	(121.972)	(0.061)
Mean of outcome	350.976	0.063	20.664	481.664	0.029
Observations	35	35	35	35	35
R^2	0.008	0.00000	0.032	0.003	0.015
	Panel C: Institutional Characteristics				
	Share Muslim	Centralization Index	Centralization Dummy	Pastoralism Dummy	
	(1)	(2)	(3)	(4)	
Meningitis shock	−0.004	0.031	−0.002	0.022	
	(0.004)	(0.206)	(0.092)	(0.131)	
Mean of outcome	0.993	1.771	0.896	0.250	
Observations	35	48	48	48	
R^2	0.030	0.0005	0.00001	0.001	

Notes: Regressions estimated by OLS. Observations at the district level in all specifications except Panel C for the centralization and pastoral outcomes, where observations are districts intersected with Murdock ethnicity regions. 'Meningitis shock' is an indicator that equals one if mean weekly meningitis cases for the district is above the national average in the 1986 epidemic year. Precipitation $(gm-2s-1)$., Dust (g/m^3), Wind (m/s), and Temperature (K) and Humidity are long-run averages from 1980 to 1985 from NASA-MERRA2 data. Land suitability is land suitability for agriculture from FAO data. Elevation is mean elevation in km from the Global Climate database. Malaria stability is from the malaria ecology index from Kiszewski et al. (2004). Share muslim is based on DHS data. Uranium is an indicator for the presence of active uranium mines; uranium is the major mineral export in Niger (Nunbogu, Kala, and Mensah, 2018). Distance to capital from district centroid in km. Centralization index is the level of precolonial centralization from Murdock ethnicity data (Murdock, 1967) and Centralization dummy is an indicator that equals 1 if the index is greater than 0 (following Archibong (2019)). Pastoralism dummy equals 1 if pastoralism was primary contributor to livelihood in precolonial ethnic region from Murdock data. We do not cluster the errors so as to reject the null hypothesis more often. Standard errors (not clustered) are in parentheses. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 3: Effect of meningitis shock on gender gaps in education (1986 epidemic year)

	Dependent Variable: Years of Education			
	(1)	(2)	(3)	(4)
Female	-0.661^{***}	-0.579^{***}	-0.646^{***}	-0.557^{***}
	(0.054)	(0.085)	(0.050)	(0.078)
Meningitis shock at ages 0-5	-0.461	-0.457	-0.044	-0.029
	(0.282)	(0.316)	(0.054)	(0.073)
x Female		-0.007		-0.028
		(0.099)		(0.095)
Meningitis shock at ages 6-12	-0.860	-0.493	-0.328	0.049
	(0.598)	(0.646)	(0.295)	(0.347)
x Female		-0.704^{***}		-0.720^{***}
		(0.176)		(0.172)
Meningitis shock at ages 13-20	-1.144	-0.921	-0.661	-0.417
	(0.832)	(0.898)	(0.545)	(0.610)
x Female		-0.388^{**}		-0.421^{**}
		(0.195)		(0.191)
Mean of outcome	1.216	1.216	1.216	1.216
District FE	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.127	0.128	0.207	0.209

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. 'Meningitis shock at ages x' is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters (35 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 4: Effect of meningitis shock on gender gaps in education (1986 epidemic year): Robustness check: marginal changes in age cohort cutoff

	Dependent Variable: Years of Education			
	(1)	(2)	(3)	(4)
Female	-0.659^{***}	-0.598^{***}	-0.644^{***}	-0.578^{***}
	(0.053)	(0.075)	(0.049)	(0.070)
Meningitis shock at ages 0-4	-0.384	-0.416	0.064	0.046
	(0.240)	(0.273)	(0.081)	(0.070)
x Female		0.065		0.036
		(0.089)		(0.087)
Meningitis shock at ages 7-12	-0.853	-0.505	-0.260	0.099
	(0.635)	(0.682)	(0.294)	(0.346)
x Female		-0.666^{***}		-0.686^{***}
		(0.195)		(0.193)
Meningitis shock at ages 14-21	-1.233	-1.013	-0.664	-0.429
	(0.856)	(0.914)	(0.526)	(0.582)
x Female		-0.383^{**}		-0.409^{**}
		(0.180)		(0.175)
Mean of outcome	1.216	1.216	1.216	1.216
District FE	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.126	0.127	0.207	0.208

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. 'Meningitis shock at ages x' is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters (35 clusters). ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 5: Effect of meningitis shock on gender gaps in education (1990 non-epidemic year), Robustness check

	Dependent Variable: Years of Education			
	(1)	(2)	(3)	(4)
Female	-0.654^{***}	-0.682^{***}	-0.640^{***}	-0.656^{***}
	(0.053)	(0.093)	(0.046)	(0.077)
Meningitis shock at ages 0-5	0.158	-0.118	-0.759	-0.977^{*}
	(0.169)	(0.095)	(0.504)	(0.571)
x Female		0.556^{***}		0.440^{***}
		(0.171)		(0.139)
Meningitis shock at ages 6-12	0.753	0.746	-0.248	-0.227
	(0.541)	(0.459)	(0.173)	(0.249)
x Female		0.014		-0.039
		(0.187)		(0.167)
Meningitis shock at ages 13-20	1.242	1.465^{*}	0.146	0.336
	(0.912)	(0.878)	(0.246)	(0.229)
x Female		-0.428^{***}		-0.361^{***}
		(0.102)		(0.076)
Mean of outcome	1.216	1.216	1.216	1.216
District FE	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.127	0.129	0.209	0.210

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. 'Meningitis shock at ages x' is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (1.6 cases/100,000 pop.) and cohorts at specified ages during the 1990 non-epidemic year. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters (35 clusters). ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

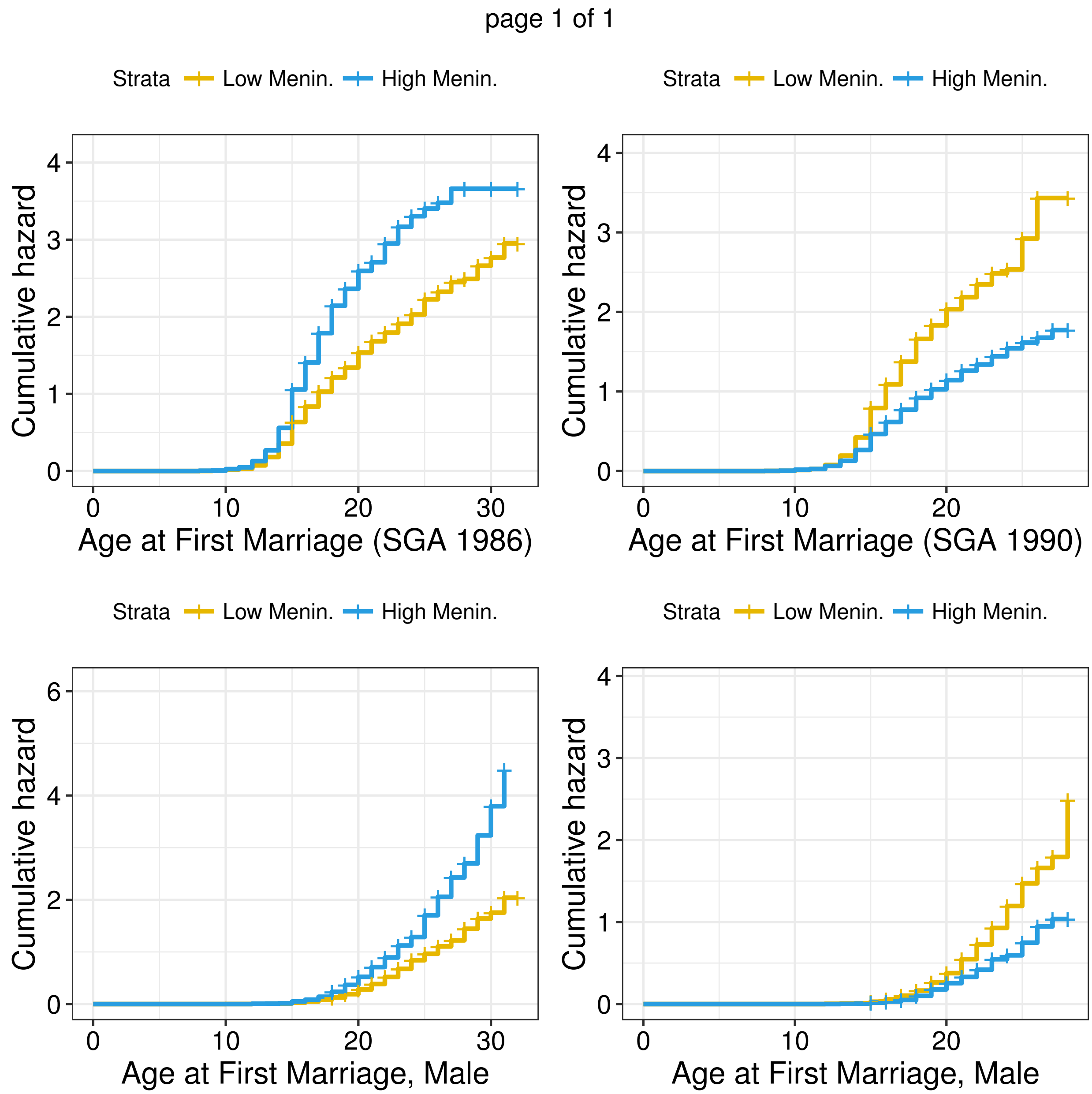


Figure 6: Age at first marriage cumulative hazard for school-going aged (SGA) populations by meningitis shock ('High Menin.') in epidemic (1986) and non-epidemic (1990) years

Table 6: DHS Subsamples: Men and Women's Sample Variable Means

Statistic	N	Mean	St. Dev.	Min	Max
DHS Women's Sample, SGA 1986 F					
Early Marriage	5,898	0.863	0.344	0.000	1.000
Age at First Marriage	5,898	15.061	2.533	8	31
Years of Education	7,255	1.557	3.064	0	16
Meningitis Shock	7,255	0.425	0.494	0	1
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 M					
Early Marriage	954	0.172	0.377	0.000	1.000
Age at First Marriage	954	20.755	3.557	10	31
Years of Education	1,657	1.750	2.413	0	13
Meningitis Shock	1,657	0.406	0.491	0	1
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 F					
Early Marriage	4,550	0.887	0.317	0.000	1.000
Age at First Marriage	4,550	14.989	2.257	8	27
Years of Education	6,447	1.680	3.071	0	16
Meningitis Shock	6,447	0.394	0.489	0	1
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 M					
Early Marriage	551	0.212	0.409	0.000	1.000
Age at First Marriage	551	19.920	3.003	12	28
Years of Education	1,728	1.799	2.366	0	10
Meningitis Shock	1,728	0.425	0.494	0	1
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

Table 7: Correlation between early marriage and years of education for school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	Dependent Variable: Years of Education							
Sample:	SGA 1986 F		SGA 1986 M		SGA 1990 F		SGA 1990 M	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Early Marriage	−2.471***	−2.086***	−0.337*	−0.182	−1.987***	−1.667***	−0.409	−0.238
	(0.679)	(0.477)	(0.190)	(0.203)	(0.561)	(0.389)	(0.254)	(0.273)
Mean of outcome	0.984	0.984	1.194	1.194	0.901	0.901	1.134	1.134
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
Observations	5,898	5,898	954	954	4,550	4,550	551	551
R^2	0.121	0.202	0.003	0.077	0.079	0.160	0.006	0.109

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. SGA is School going aged sample during the 1986 epidemic or 1990 non-epidemic years; F is the women's DHS sample, and M is the men's DHS sample. Early Marriage is an indicator that equals one if the age at first marriage is below 18 years. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 8: Effect of meningitis shock on early marriage for female and male school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	Panel A: DHS Women's Sample					
	Dependent Variable: Early Marriage					
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	0.092**	0.092**	0.048**	−0.062	−0.059	−0.012
	(0.040)	(0.039)	(0.021)	(0.044)	(0.041)	(0.021)
Mean of outcome	0.863	0.863	0.863	0.887	0.887	0.887
Sample	SGA 1986 F	SGA 1986 F	SGA 1986 F	SGA 1990 F	SGA 1990 F	SGA 1990 F
Observations	5,898	5,898	5,898	4,550	4,550	4,550
	Panel B: DHS Men's Sample					
	Dependent Variable: Early Marriage					
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	0.034	0.017	0.015	−0.067**	−0.074***	−0.069**
	(0.031)	(0.027)	(0.031)	(0.031)	(0.027)	(0.029)
Mean of outcome	0.172	0.172	0.172	0.212	0.212	0.212
Sample	SGA 1986 M	SGA 1986 M	SGA 1986 M	SGA 1990 M	SGA 1990 M	SGA 1990 M
Observations	954	954	954	551	551	551
District 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 early marriage or an indicator that equals 1 if the respondent was married before the age of 18. SGA is School going aged sample during the 1986 epidemic or 1990 non-epidemic years. 'Meningitis shock' is an indicator that equals 1 if mean weekly meningitis cases (per 100,000 pop.) for the district is above the national average in the 1986 and 1990 epidemic and non-epidemic years respectively. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 9: Effect of meningitis shock on gender gaps in infant mortality

	Dependent Variable: Infant Mortality						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Female	−0.028	−0.024	−0.051*	−0.051*	−0.036	−0.035	−0.010
	(0.039)	(0.038)	(0.027)	(0.027)	(0.026)	(0.026)	(0.045)
Meningitis shock	−0.014	−0.024			0.050	0.050	
	(0.040)	(0.041)			(0.034)	(0.034)	
x Female	0.023	0.019			−0.073	−0.075	
	(0.061)	(0.060)			(0.051)	(0.051)	
Born epidemic year			0.084*	0.085*			
			(0.045)	(0.045)			
x Female			−0.061	−0.061			
			(0.057)	(0.057)			
High meningitis mortality							0.022
							(0.041)
x Female							−0.008
							(0.062)
Mean of outcome	0.295	0.295	0.316	0.316	0.316	0.316	0.295
Mother's controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE*	No	Yes	No	Yes	No	Yes	Yes
Mother FE	No	No	Yes	Yes	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth FE	No	No	No*	No*	Yes	Yes	No
Observations	952	952	5,084	5,084	5,084	5,084	949
R^2	0.009	0.011	0.744	0.744	0.745	0.745	0.011

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is infant mortality across all specifications. The infant mortality measure is an indicator that equals one if a child born in a given year died within the year. 'Meningitis shock' is indicator that equals 1 if mean weekly meningitis cases (per 100,000 pop.) for the district is above the national average in the 1986 epidemic year. 'Born epidemic year' is an indicator that equals one if the child was born in the 1986 epidemic year. 'High meningitis mortality' is an indicator that equals one if the case mortality rate for the district is above the national average. The sample for the models in Column (1), (2) and (7) is children born to mothers in the 1986 epidemic year. The sample in Columns (3) to (6) is children born to mothers between 1986 and 1992 (i.e., before the next epidemic year in 1993). Mother's controls include mother's age at birth and level of education at time of survey. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. Mother FE, year FE and year of birth FE are fixed effects for mother, year of survey and year of birth respectively. *Child age, in years, is included as a control in models in Column (3) and (4). Main effects are not significant and results provided in the Appendix. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table 10: Effect of precipitation shock on gender gaps in 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 shock 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 shock 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 shock 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)
Mean of outcome	1.299	1.299	1.299	1.299
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 shock explanatory variable is precipitation deviation, 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. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

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A Appendix (For Online Publication)

Contents

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A.1 Effects of Meningitis Epidemic on Gender Inequality, Robustness Checks

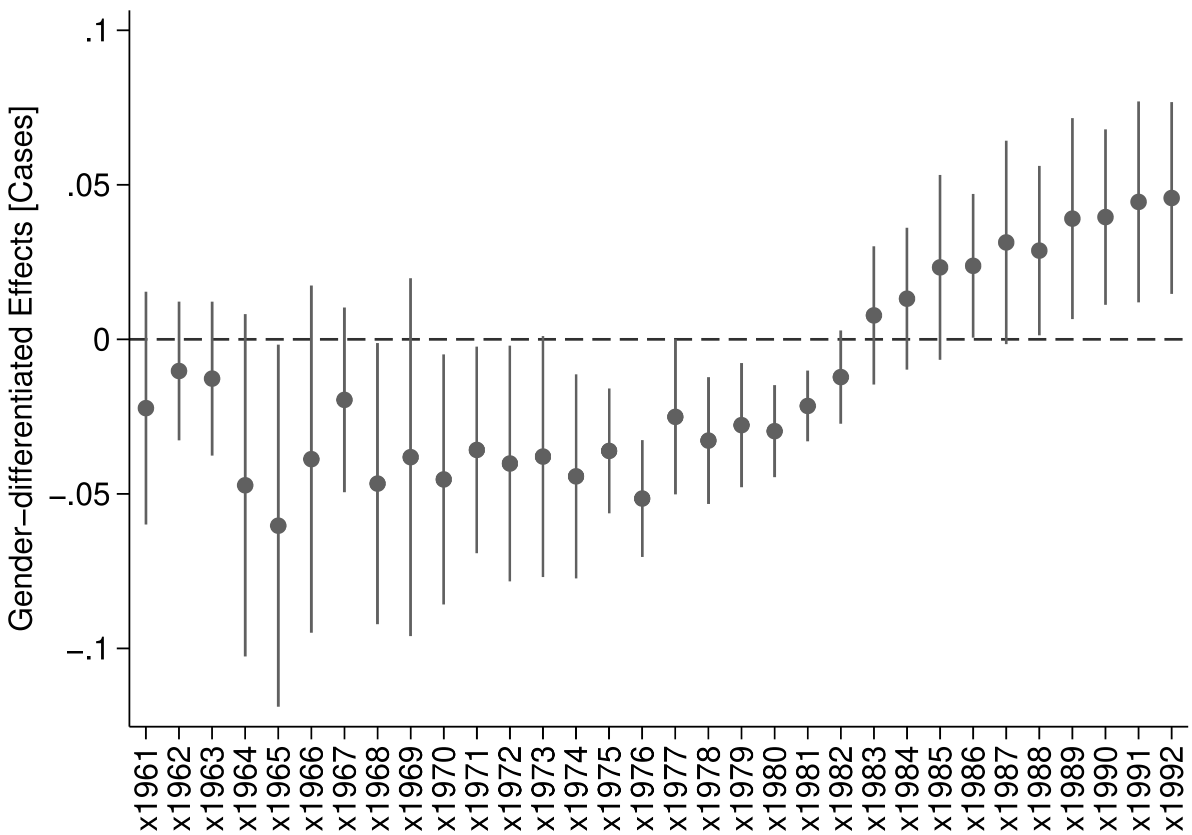

Figure A1: Coefficients of the interaction between year of birth [age] and gender-differentiated effects of meningitis cases (1986 epidemic year)

Table A1: Effect of meningitis exposure (shock and cases) on gender gaps in education (1986 epidemic year). Robustness check: wild cluster bootstrap p-values

	Dependent Variable: Years of Education			
	Meningitis Cases		Meningitis Shock	
	(1)	(2)	(3)	(4)
Female	-0.646^{***}	-0.498^{***}	-0.646^{***}	-0.557^{***}
	(0.050)	(0.076)	(0.050)	(0.078)
	[<.001]	[<.001]	[<.001]	[<.001]
Meningitis exposure at ages 0-5	-0.002	0.001	-0.044	-0.029
	(0.003)	(0.004)	(0.054)	(0.073)
	[0.599]	[0.718]	[0.409]	[0.723]
x Female		-0.006		-0.028
		(0.006)		(0.095)
		[0.410]		[0.811]
Meningitis exposure at ages 6-12	-0.027	-0.004	-0.328	0.049
	(0.017)	(0.021)	(0.295)	(0.347)
	[0.222]	[0.891]	[0.528]	[0.928]
x Female		-0.044^{***}		-0.720^{***}
		(0.012)		(0.172)
		[<.001]		[0.001]
Meningitis exposure at ages 13-20	-0.047	-0.029	-0.661	-0.417
	(0.031)	(0.030)	(0.545)	(0.610)
	[0.276]	[0.596]	[0.557]	[0.821]
x Female		-0.032^{***}		-0.421^{**}
		(0.011)		(0.191)
		[<.001]		[0.079]
Mean of outcome	1.216	1.216	1.216	1.216
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.208	0.210	0.207	0.209

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. Meningitis 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. Meningitis Shock is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A2: Effect of meningitis exposure (shock and cases) on gender gaps in education (1986 epidemic year). Robustness check: marginal changes in age cutoff

	Dependent Variable: Years of Education			
	Meningitis Cases		Meningitis Shock	
	(1)	(2)	(3)	(4)
Female	-0.644^{***}	-0.535^{***}	-0.578^{***}	-0.644^{***}
	(0.049)	(0.067)	(0.070)	(0.049)
Meningitis exposure at ages 0-4	0.006	0.005^{*}	0.046	0.064
	(0.004)	(0.003)	(0.070)	(0.081)
x Female		0.0005		0.036
		(0.006)		(0.087)
Meningitis exposure at ages 7-12	-0.025	-0.003	0.099	-0.260
	(0.016)	(0.020)	(0.346)	(0.294)
x Female		-0.042^{***}		-0.686^{***}
		(0.012)		(0.193)
Meningitis exposure at ages 14-21	-0.046	-0.028	-0.429	-0.664
	(0.030)	(0.029)	(0.582)	(0.526)
x Female		-0.031^{***}		-0.409^{**}
		(0.009)		(0.175)
Mean of outcome	1.216	1.216	1.216	1.216
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.208	0.210	0.208	0.207

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. Meningitis 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. Meningitis Shock is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A3: Effect of meningitis exposure (shock and cases) on gender gaps in education (1990 non-Epidemic year). Robustness check: non-epidemic year

	Dependent Variable: Years of Education			
	Meningitis Cases		Meningitis Shock	
	(1)	(2)	(3)	(4)
Female	-0.644^{***}	-0.652^{***}	-0.640^{***}	-0.656^{***}
	(0.050)	(0.076)	(0.046)	(0.077)
Meningitis exposure at ages 0-5	-0.070	-0.129	-0.759	-0.977^{*}
	(0.096)	(0.118)	(0.504)	(0.571)
x Female		0.117^{**}		0.440^{***}
		(0.047)		(0.139)
Meningitis exposure at ages 6-12	-0.006	0.011	-0.248	-0.227
	(0.042)	(0.057)	(0.173)	(0.249)
x Female		-0.032		-0.039
		(0.041)		(0.167)
Meningitis exposure at ages 13-20	0.011	0.072	0.146	0.336
	(0.050)	(0.061)	(0.246)	(0.229)
x Female		-0.111^{***}		-0.361^{***}
		(0.038)		(0.076)
Mean of outcome	1.216	1.216	1.216	1.216
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.205	0.207	0.209	0.210

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. Meningitis 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. Meningitis Shock is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1990 non-epidemic year. Results remain unchanged when we use wild bootstrap-t inference to account for potentially few clusters. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A4: Effect of 1986 meningitis shock on gender gaps in education for 1986 and 1990 cohorts, Robustness check

	Dependent Variable: Years of Education			
	1986 Cohort		1990 Cohort	
	(1)	(2)	(3)	(4)
Female	−0.646***	−0.557***	−0.645***	−0.617***
	(0.050)	(0.078)	(0.049)	(0.066)
Meningitis shock at ages 0-5	−0.044	−0.029	0.492	0.304
	(0.054)	(0.073)	(0.398)	(0.378)
x Female		−0.028		0.385***
		(0.095)		(0.086)
Meningitis shock at ages 6-12	−0.328	0.049	0.145	0.339**
	(0.295)	(0.347)	(0.151)	(0.145)
x Female		−0.720***		−0.372***
		(0.172)		(0.098)
Meningitis shock at ages 13-20	−0.661	−0.417	−0.188	0.085
	(0.545)	(0.610)	(0.219)	(0.263)
x Female		−0.421**		−0.506***
		(0.191)		(0.131)
Mean of outcome	1.216	1.216	1.216	1.216
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	0.207	0.209	0.207	0.209

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. Meningitis shock at ages x is measured as the the interaction between an indicator that equals 1 if the average district level weekly case is greater than the national mean for cohorts at specified ages during the 1986 epidemic year and 1990 non-epidemic years. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A5: Effect of meningitis shock on gender gap in education in non-epidemic years, Robustness check

	Dependent Variable: Years of Education					
	Meningitis Shock 1990		Meningitis Shock 1991		Meningitis Shock 1992	
	(1)	(2)	(3)	(4)	(5)	(6)
Female	−0.640***	−0.656***	−0.666***	−0.641***	−0.643***	−0.653***
	(0.046)	(0.077)	(0.094)	(0.046)	(0.048)	(0.061)
Meningitis shock at ages 0-5, 1990	−0.759	−0.977*				
	(0.504)	(0.571)				
Meningitis shock at ages 6-12, 1990	−0.248	−0.227				
	(0.173)	(0.249)				
Meningitis shock at ages 13-20, 1990	0.146	0.336				
	(0.246)	(0.229)				
Meningitis shock at ages 0-5 x Female, 1990		0.440***				
		(0.139)				
Meningitis shock at ages 6-12 x Female, 1990		−0.039				
		(0.167)				
Meningitis shock at ages 13-20 x Female, 1990		−0.361***				
		(0.076)				
Meningitis shock at ages 0-5, 1991			−0.966	−0.744		
			(0.654)	(0.602)		
Meningitis shock at ages 6-12, 1991			−0.445	−0.440		
			(0.443)	(0.346)		
Meningitis shock at ages 13-20, 1991			0.181	−0.013		
			(0.165)	(0.111)		
Meningitis shock at ages 0-5 x Female, 1991			0.455***			
			(0.118)			
Meningitis shock at ages 6-12 x Female, 1991			0.011			
			(0.207)			
Meningitis shock at ages 13-20 x Female, 1991			−0.370**			
			(0.187)			
Meningitis shock at ages 0-5, 1992					0.818	0.540
					(0.642)	(0.626)
Meningitis shock at ages 6-12, 1992					0.499	0.559
					(0.469)	(0.454)
Meningitis shock at ages 13-20, 1992					0.142	0.457**
					(0.179)	(0.196)
Meningitis shock at ages 0-5 x Female, 1992						0.571***
						(0.072)
Meningitis shock at ages 6-12 x Female, 1992						−0.119
						(0.089)
Meningitis shock at ages 13-20 x Female, 1992						−0.568***
						(0.135)
Mean of outcome	1.216	1.216	1.216	1.216	1.216	1.216
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697	47,697	47,697
R^2	0.209	0.210	0.210	0.208	0.208	0.210

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education. 'Meningitis shock' is the meningitis shock explanatory variable measured as the the interaction between an indicator that equal 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean for cohorts at specified ages during the specified non-epidemic years in 1990, 1991 and 1992. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A6: Reduced form relationship between epidemic year and health expenditures for meningitis belt countries, 1995-2008

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

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

Table A7: Effect of meningitis shock on early marriage for female and male school-going aged respondents during epidemic (1986) year by cohort

	Dependent Variable: Early Marriage			
Sample:	SGA 1986 F		SGA 1986 M	
	(1)	(2)	(3)	(4)
Meningitis shock at ages 0-5	0.000***	−0.033	0.000	0.008
	(0.000)	(0.026)	(0.314)	(0.314)
Meningitis shock at ages 6-12	0.060**	0.009	0.020	−0.031
	(0.027)	(0.027)	(0.050)	(0.057)
Meningitis shock at ages 13-20	0.101**	0.028*	0.016	−0.044
	(0.048)	(0.016)	(0.027)	(0.038)
Mean of outcome	0.870	0.870	0.162	0.162
District FE	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	8,887	8,887	1,714	1,714
R^2	0.033	0.096	0.068	0.113

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is early marriage or an indicator that equals 1 if the respondent was married before the age of 18. SGA is School going aged sample during the 1986 epidemic or 1990 non-epidemic years; F is the women's DHS sample, and M is the men's DHS sample. 'Meningitis shock' is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equal 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A8: Effect of meningitis shock on fertility for school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	Dependent Variable: Nos. of Children					
Sample:	SGA 1986 F			SGA 1990 F		
	(1)	(2)	(3)	(4)	(5)	(6)
Meningitis shock	0.290**	0.337***	0.220***	−0.141	−0.139	0.044
	(0.129)	(0.111)	(0.072)	(0.142)	(0.158)	(0.106)
Mean of outcome	2.640	2.640	2.640	2.272	2.272	2.272
District 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
Observations	4,911	4,911	4,911	3,351	3,351	3,351
R^2	0.010	0.462	0.473	0.003	0.448	0.463

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is the total number of children born after 1985, through the 1992 and 1998 survey years for women who were school going aged (between 6 and 20 years old) during the 1986 epidemic and 1990 non-epidemic years. SGA is School going aged sample.'Meningitis shock' is an indicator that equals 1 if mean weekly meningitis cases (per 100,000 pop.) for the district is above the national average in the 1986 and 1990 epidemic and non-epidemic years respectively. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A9: Effect of meningitis shock on number of wives for school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	Dependent Variable: Nos. of Wives			
Sample:	SGA 1986 F	SGA 1986 M	SGA 1990 F	SGA 1990 M
	(1)	(2)	(3)	(4)
Meningitis shock	0.088**	0.036	−0.023	0.012
	(0.036)	(0.022)	(0.035)	(0.034)
Mean of outcome	0.354	1.086	0.303	1.070
District FE*	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	5,573	906	4,322	515
R^2	0.030	0.045	0.023	0.051

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. 'Meningitis shock' is an indicator that equals 1 if mean weekly meningitis cases (per 100,000 pop.) for the district is above the national average in the 1986 and 1990 epidemic and non-epidemic years respectively. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A10: Effect of meningitis shock on infant mortality

	Dependent Variable: Infant Mortality			
	(1)	(2)	(3)	(4)
Meningitis shock	−0.016		0.013	
	(0.027)		(0.017)	
Born epidemic year		0.055		
		(0.035)		
High meningitis mortality				0.019
				(0.027)
Mean of outcome	0.295	0.316	0.316	0.295
Mother's controls	Yes	Yes	Yes	Yes
District FE*	Yes	Yes	Yes	Yes
Mother FE	No	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	No	No*	Yes	No
Observations	952	5,084	5,084	949
R^2	0.011	0.742	0.744	0.011

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is infant mortality across all specifications. The infant mortality measure is an indicator that equals one if a child born in a given year died within the year. 'High meningitis exposure' as indicator that equals one if mean weekly meningitis cases for the district is above the national average. 'Born epidemic year' is an indicator that equals one if the child was born in the 1986 epidemic year. 'High meningitis mortality' is an indicator that equals one if the case mortality rate for the district is above the national average. The sample for the models in Column (1) and (4) is children born to mothers in the 1986 epidemic year. The sample in Columns (2) and (3) is children born to mothers between 1986 and 1992 (i.e., before the next epidemic year in 1993). Mother's controls include mother's age at birth and level of education at time of survey. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. Mother FE, year FE and year of birth FE are fixed effects for mother, year of survey and year of birth respectively. *Child age, in years, is included as a control in models in Column (3) and (4). Main effects are not significant and results provided in the Appendix. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

A.1.1 Meningitis, Wealth and Age at First Marriage

In Section 7.1.1, we show that one primary channel that may explain 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[48]. We reaffirm this by estimating a model that links age at first marriage with liquidity. Using data on assets from the DHS[49], we construct a wealth index based on principal components analysis (PCA) scores and define liquidity or asset-constrained households as those located in the lower parts of the asset distribution. The distribution of the wealth score underlying the index is shown in Figure A2; a majority of households are concentrated in the lower parts of the wealth distribution.

The results are reported in Table A11. 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 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 effect 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,

[48]Ideally, to test the income effect more directly, we would be able to examine the effect of meningitis exposure on household level income for 1986, the epidemic year. Unfortunately, we do not have micro level data on income from the epidemic year to test this directly.

[49]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). Since there is no 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.

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.

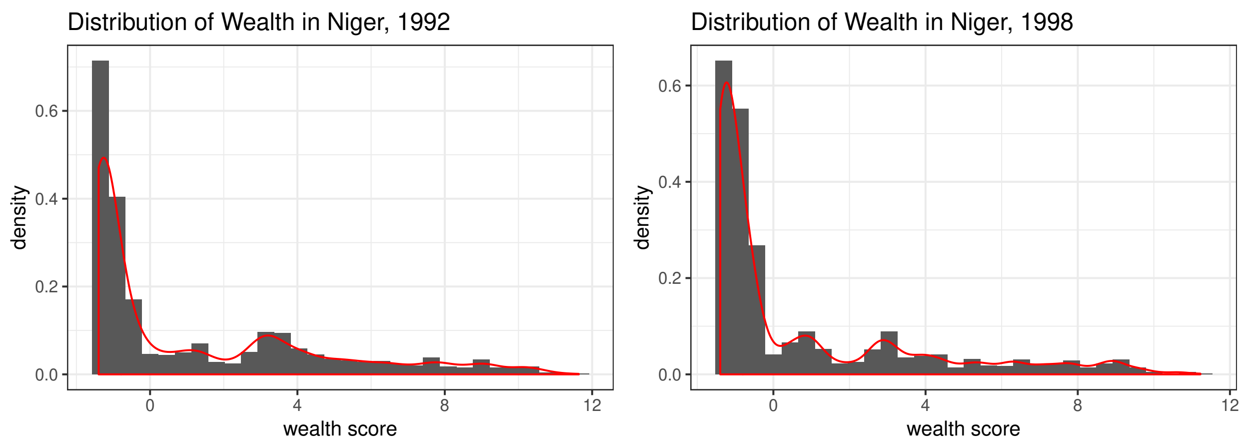

Figure A2: Distribution of wealth among households in Niger

Table A11: Effect of meningitis shock on early marriage by wealth quintile for female school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	Dependent Variable: Early Marriage			
Sample:	SGA 1986 F			
	(1)	(2)	(3)	(4)
Meningitis shock	0.049**	0.051**	0.029	0.033
	(0.021)	(0.020)	(0.023)	(0.021)
Wealth Quintile 2 (WQ2)	−0.027	0.008	−0.058**	−0.019
	(0.017)	(0.015)	(0.025)	(0.026)
Wealth Quintile 3 (WQ3)	−0.012	−0.007	−0.018	−0.013
	(0.014)	(0.013)	(0.023)	(0.022)
Wealth Quintile 4 (WQ4)	−0.047***	−0.039**	−0.067***	−0.058**
	(0.015)	(0.016)	(0.024)	(0.024)
Wealth Quintile 5 (WQ5)	−0.122***	−0.133***	−0.142***	−0.150***
	(0.018)	(0.017)	(0.029)	(0.027)
Meningitis shock x WQ2			0.060**	0.052*
			(0.030)	(0.030)
Meningitis shock x WQ3			0.009	0.011
			(0.026)	(0.025)
Meningitis shock x WQ4			0.040	0.036
			(0.029)	(0.031)
Meningitis shock x WQ5			0.037	0.031
			(0.036)	(0.034)
Mean of outcome	0.863	0.863	0.863	0.863
District FE*	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	5,838	5,838	5,838	5,838
R^2	0.062	0.088	0.063	0.089

Notes: OLS regressions. Robust standard errors in parentheses clustered by district. Dependent variable is early marriage or an indicator that equals 1 if the respondent was married before the age of 18. SGA is School going aged sample during the 1986 epidemic year. 'Meningitis shock' is an indicator that equals one if mean weekly meningitis cases for the district is above the national average in the 1986 epidemic year. Wealth quintiles are estimated from wealth scores from principal components analysis. WQ1 is dropped as the comparison group. District FE are capital district Niamey fixed effects here as meningitis shock only varies at the district level. In alternate specifications, we control for district level geographical characteristics including distance to the capital district, mean elevation, malaria suitability, land suitability for agriculture and a uranium indicator with results largely unchanged. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

A.2 Effects of precipitation shocks on education, Robustness check

Table A12: Effect of precipitation shocks on education (1986 epidemic year), Alternate specification

	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 FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	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.

A.3 Selective Migration

There is little information on internal migration over the full sample from 1986 to 1998 in Niger. We provide estimates on internal migration based on the ACMI (aggregate crude migration index) and net internal migration rate (NIMR) values calculated from 1988 to 1992 in Bocquier and Traoré (1998). The ACMI is a widely-used measure of internal migration in the demography literature and represents the share of the population that has changed address averaged over a specified time period. Specifically, the ACMI is a global average based on the following specification: $CMI_n = \sum_i \sum_{j \neq i} M_{ij} / \sum_i P_i$ where M_{ij} is the total number of migrants or migrations between origin area $i = 1, n$ and destination area $j = 1, n$; and P_i is the population of each area i at risk of migrating (Bell et al., 2015; Bernard and Bell, 2018). The population assessed here is the population over the age of 15 (Bocquier and Traoré, 1998; Bell et al., 2015; Bernard and Bell, 2018).

The NIMR measures the difference between incoming and outgoing migrants in a particular locality. Table A13 shows the ACMI and NIMR values for Niger and peer countries in the meningitis belt. Internal migration is extremely low in Niger, with just 6% of the population reporting changing their place of residence within the country over the four-year interval from 1988 to 1992. Compared to fellow meningitis belt countries, Niger has some of the 'least mobile populations' internally in the region (Bocquier and Traoré, 1998). The net internal migration rate for Niger was also very low over this period. The NIMR for rural areas, where over 80% of the population reside[50] was -0.04% or near zero. Among the set of seven meningitis belt countries measured, Niger was the only country where the net migration rate in the capital city, Niamey, was almost zero at -0.06%.

The main results in Section 6 assume that internal migration is very minimal, based on the empirical data presented in Section 5.3. Here, we relax this assumption and instead

[50] Source: World Bank estimates from 1986 to 2018.

explore selective migration as a potential channel of interest explaining our results. Selective migration between the 1986 epidemic year and 1992 to 1998 surveys years would be a plausible channel for our estimated gender differences if high ability individuals (specifically, all the high ability school going-aged boys) left the high meningitis epidemic exposed districts to non-exposed districts over the period. Detail micro-level data on migration rates does not exist for our study area over this period; however, we carry out a trimming exercise to examine how likely selective migration (i.e., differential rates of migration) could explain our results. With estimated internal migration rate of 6% and net internal migration rate of -0.04% between 1988-1992 in Niger (Bocquier and Traoré, 1998), we conservatively trim the educational attainment outcome using a migration rate of 3%. First, we drop the top 3% of respondents with the highest education levels-reflecting the highest ability individuals- in high meningitis exposed districts during the 1986 epidemic year and re-estimate our baseline model. Second, we omit the top 3% of male respondents with the highest education levels-reflecting the highest ability school going-aged boys in in high meningitis exposed districts during the epidemic and repeat the re-estimation exercise.

Tables A14 and Table A15 contain the results and show that estimates of gender gaps in education attainment following the sudden exposure to the 1986 epidemic remain similar in magnitude and statistical significance. Our trimming exercise and results suggest that migration between 1986 and the survey years is not the main channel underlying the estimated gender gaps. This evidence is consistent with the fact that most of Niger is rural where (selective) migration may be difficult to achieve, and also consistent with other papers showing a lack of selective migration in developing country settings (Bazzi et al., 2016).

Table A13: Internal migration statistics for selected countries in the meningitis belt, 1988-1992, Source: Bocquier and Traore (1998)

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

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

Table A14: Selective migration test: Effect of meningitis shock on gender gaps in education (1986 Epidemic Year) with trimming of top 3% of highest educated respondents in high meningitis exposed districts

	Dependent Variable: Years of Education			
	Meningitis Cases		Meningitis Shock	
	(1)	(2)	(3)	(4)
Female	−0.597***	−0.477***	−0.597***	−0.537***
	(0.057)	(0.087)	(0.057)	(0.087)
Meningitis exposure at ages 0-5	0.002	−0.006	0.028	0.047
	(0.003)	(0.006)	(0.055)	(0.076)
x Female		−0.006		−0.037
		(0.006)		(0.099)
Meningitis exposure at ages 6-12	−0.031*	−0.010	−0.417	−0.094
	(0.017)	(0.021)	(0.297)	(0.354)
x Female		−0.039***		−0.613***
		(0.012)		(0.172)
Meningitis exposure at ages 13-20	−0.057*	−0.045	−0.884	−0.812
	(0.032)	(0.031)	(0.551)	(0.609)
x Female		−0.020**		−0.123
		(0.008)		(0.147)
Mean of outcome	1.163	1.163	1.163	1.163
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,453	47,453	47,453	47,453
R^2	0.218	0.220	0.217	0.218

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Observations with trimming of the top 3% of most educated population in high meningitis exposed districts. Dependent variable is years of education across all specifications. Meningitis 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. Meningitis Shock is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Table A15: Selective migration test: Effect of meningitis shock on gender gaps in education (1986 Epidemic Year) with trimming of Top 3% of highest educated male respondents in high meningitis exposed districts

	Dependent Variable: Years of Education			
	Meningitis Cases		Meningitis Shock	
	(1)	(2)	(3)	(4)
Female	−0.715***	−0.515***	−0.715***	−0.571***
	(0.049)	(0.070)	(0.049)	(0.078)
Meningitis exposure at ages 0-5	−0.002	0.002	−0.053	−0.003
	(0.003)	(0.004)	(0.052)	(0.0723)
x Female		−0.008		−0.095
		(0.005)		(0.094)
Meningitis exposure at ages 6-12	−0.032*	−0.003	−0.457	0.077
	(0.017)	(0.022)	(0.297)	(0.354)
x Female		−0.056***		−1.038***
		(0.014)		(0.161)
Meningitis exposure at ages 13-20	−0.054*	−0.028	−0.844	−0.392
	(0.032)	(0.031)	(0.550)	(0.619)
x Female		−0.047***		−0.793***
		(0.013)		(0.211)
Mean of outcome	1.179	1.179	1.179	1.179
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Observations	47,469	47,469	47,469	47,469
R^2	0.217	0.221	0.216	0.220

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Observations with trimming of the top 3% of most educated male population in high meningitis exposed districts. Dependent variable is years of education across all specifications. Meningitis 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. Meningitis Shock is the meningitis exposure explanatory variable measured as the the interaction between an indicator that equals 1 if the average district level weekly case (per 100,000 pop.) is greater than the national mean (10 cases/100,000 pop.) and cohorts at specified ages during the 1986 epidemic year. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.