Climate Change, Epidemics and Inequality*

Belinda Archibong[†]
Barnard College

Francis Annan
University of California, Berkeley

November 7, 2022

Abstract

What are the links between climate change, epidemics and socioeconomic inequality? While recent epidemics have focused attention on the effects of epidemics on economic outcomes, and a separate literature in climate science and environmental health has linked global environmental change to increased incidence of epidemics of infectious disease, there's relatively little work connecting these two literatures. We explore the links between climate change, epidemics and group-based inequality by first reviewing the scientific literature modeling the effects of global warming on epidemics of infectious disease. We highlight the ways in which climate variables like temperature, precipitation and wind speeds, and adaptive human behavior like migration may more easily facilitate the spread of infectious disease. We then examine the effects of climate-induced epidemics on gender inequality using evidence from the African meningitis belt. The results show that epidemics can worsen outcomes for groups in already relatively economically precarious circumstances, thereby widening group-based socioeconomic inequality. Effective polices to combat the negative effects of epidemics must be mindful not to increase existing group-based inequalities, and aim to reduce these inequalities by minimizing damage for members of the most marginalized groups in societies.

JEL classification: I12, I14, I24, J16, J24, O12, O15, Q54

Keywords: Climate Change, Epidemic, Disease, Economic, Pandemic, Inequality

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[*] We are grateful to Carlos Perez, Madeleine Thomson, Nita Bharti, and World Health Organization (WHO) for the data on meningitis used in this study. Thanks to Mary Evans and anonymous referees for helpful comments and suggestions. Thanks to Shristi Bashista for excellent research assistance. Errors are our own.

[†] Corresponding author. Barnard College, Columbia University. 3009 Broadway, New York, NY 10027, USA. ba2207@columbia.edu.

1 Introduction

What are the links between climate change, epidemics and socioeconomic inequality? While recent epidemics have focused attention on the effects of epidemics on economic outcomes, and a separate literature in climate science and environmental health has linked global environmental change to increased incidence of epidemics of infectious disease, there's relatively little work connecting these two literatures. Recent evidence from the COVID-19 pandemic has highlighted the very unequal way the pandemic and past epidemics have affected individuals and groups, with the most recent COVID-19 pandemic referred to as the "great unequalizer" (Alsan, Chandra, and Simon, 2021). There is a robust literature on the negative consequences of increased group-based or intergroup inequality for human welfare, with increased inequality associated with a host of negative outcomes from conflict (Huber and Mayoral, 2019) to decreased welfare (Klasen, 2002). To the extent that models of environmental health have linked climate change and global warming to the increased risk of epidemics of infectious disease, we explore the links between climate change, epidemics and group-based, socioeconomic inequality in this paper.

We explore these links in three steps. First, we review the scientific literature modeling the connections between anthropogenic climate change and epidemics. The models point to the role of both direct effects, where climate change and associated global warming may cause epidemics through changes in climate variables like temperature, precipitation and wind speeds, and indirect effects, where adaptive behavior to these direct effects by human populations through strategies like migration may more easily facilitate the spread of disease. We provide examples of these modeled effects from airborne diseases like meningococcal meningitis and vector-borne diseases like malaria and dengue fever. Second, we examine the effects of these climate-induced epidemics on group-based inequality using new evidence from the African meningitis belt. We provide a simple conceptual framework highlighting how aggregate health shocks like epidemics can have differential effects on individual outcomes based on group membership. We then present evidence from a 1986 meningitis epidemic to test predictions from the framework and examine the effects on gender inequality. The results show that epidemics can worsen outcomes for groups in already relatively economically precarious circumstances, like women around the world, thereby widening group-based, socioeconomic inequality.

Finally, we conclude with an exploration of the ways effective policies may be designed to mitigate the inequitable effects of climate-induced epidemics on group-based inequality, highlighting the role of fiscal responses like health aid, cash grants and targeted stimulus to groups and households, following evidence from a recent literature. We highlight that effective polices to combat the negative effects of epidemics must be mindful not to increase existing group-based inequalities, and in fact, aim to reduce these inequalities by minimizing damage for members of the most marginalized groups in societies.

2 Modeling the Links Between Climate Change and Epidemics

The Intergovernmental Panel on Climate Change (IPCC) predicted an average increase in temperatures by 1.5 to 5.8 degrees celsius around the world over the 21st century, with predicted corresponding increases in extreme weather events including heat waves, floods and droughts (Wu et al., 2016; Carleton and Hsiang, 2016). A growing literature has linked these changes in climate to human health, and particularly the spread of infectious diseases (Epstein, 1999; Carleton and Hsiang, 2016; Wu et al., 2016; Tol, 2020). Particularly worrying is the spread of epidemics and pandemics of infectious diseases, where an epidemic is defined by the World Health Organization (WHO) as "the occurrence in a community or region of cases of an illness clearly in excess of normal expectancy", and a pandemic is defined as exponential growth in the spread of infectious diseases cutting across international boundaries (WHO, 2020).

The links between climate change, and particularly, anthropogenic climate change caused by human activities, global warming, ecosystems and epidemics of infectious disease are complex, with feedbacks throughout the system as shown in the simplified schematic in Figure 1. Figure 1 also includes a definition of key terms associated with epidemics. Although the links between climate change and epidemics of infectious disease are complex, we can model the relationship broadly into pathways: (1) direct effects where climate change and associated global warming may cause epidemics through changes in climate variables like temperature, precipitation, and wind speeds and (2) indirect effects where adaptive behavior to these direct effects by human populations through strategies like migration may more easily facilitate the spread of disease.

2.1 Direct Effects: Temperature, Precipitation, Wind Speeds and Changing Environment

Airborne and vector-borne infectious diseases are among the top categories expected to be most affected by global warming (Kurane, 2010; García-Pando et al., 2014). These include vector-borne diseases like malaria and dengue fever, which are linked to the expansion of infested areas of mosquitoes, which are the primary vector of transmission. The distribution of these vector mosquitoes has been linked to inter-annual variability in temperature, rainfall and precipitation in affected regions within Africa and Asia (Kurane, 2010; Carleton and Hsiang, 2016). Both malaria and dengue fever are endemic[1] in many regions around the world, infecting an estimated 200 million and 50 million people globally every year (Carleton and Hsiang, 2016). Previous research has shown that temperature and the presence of open water, which is itself constrained by rainfall, are two key climatic factors that affect the intensity of infection in regions where malaria and dengue are endemic (Zhou et al., 2004; Bhatt et al., 2013). Hence changes in temperature and rainfall predicted by climate change

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[1] A disease outbreak is endemic when it is “consistently present but limited to a particular region” Source: CDC: https://www.cdc.gov/csels/dsepd/ss1978/lesson1/section11.html

models may change both the severity and distribution of malaria and dengue epidemics around the world, with significant consequences for human health.

Similarly, for airborne infectious diseases like meningococcal meningitis, changes in climate are associated with changes in the severity and distribution of epidemics of the disease (García-Pando et al., 2014). Meningococcal meningitis is a disease that is endemic in sub-Saharan Africa (SSA), with an entire region of 23 countries from Senegal to Ethiopia, making up over 700 million individuals, termed the 'meningitis belt' due to frequent exposure to meningitis epidemics[2] (Archibong and Annan, 2020). The epidemic form of the disease is caused by the bacterium *Neisseria meningitidis* and is characterized by an infection of the meninges or the thin lining covering the brain and spinal cord. Infection, similarly to malaria and dengue fever, is associated with fevers, pain, reduced cognitive function, and in the worst cases, permanent disability and death (Archibong and Annan, 2020). While the epidemiology of the disease is complex, scientists have linked higher wind speeds and dust concentrations and lower humidity and temperatures that come with the onset of the dry season in sub-Saharan Africa with higher incidence of meningitis epidemics (Perez Garcia Pando et al., 2014; Sultan et al., 2005; Yaka et al., 2008). The disease hence has a strongly seasonal quality, with cases increasing during the dry harmattan season from October to March and declining with the onset of the rainy season in June. The disease is spread through contact with respiratory droplets or throat secretions from infected individuals, and one proposed mode of transmission has been that hot, dry northeasterly trade winds blowing from the Sahara through West Africa carry dust particles that irritate the inner linings of the noses of the region's inhabitants, and hence increase the risk of meningitis infection during more intense dry seasons (Yaka et al., 2008). This pattern of transmission, particularly with airborne diseases like meningitis make adaptive human responses to climate change, like migration that might increase population density, an important way that epidemic disease can spread

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[2] The meningitis belt is shown in Figure 3 in the Appendix.

in response to global warming.

2.2 Indirect Effects: Migration

To what extent do adaptive human responses to climate change like migration increase the risk of epidemics of infectious disease? A recent literature has identified two countervailing effects of global warming on migration. First, increases in temperature associated with global warming may worsen economic conditions, particularly through their effects on decreasing crop yields that decrease incomes for, particularly, agricultural workers. This may then lead workers to either increase migration away from rural areas to more urban areas if they are not liquidity constrained and are able to access resources to move, or on the other hand, they may not move if they are unable to access resources to finance a move (Carleton and Hsiang, 2016; Cattaneo and Peri, 2016). While the evidence on the effects of climate change on migration is both sparse and mixed, recent evidence finds that in middle income economies, higher temperatures increased migration rates to urban areas and other countries (Cattaneo and Peri, 2016). As economies become wealthier and more countries achieve middle income status, one prediction is that we may see more migration to urban areas in response to climate pressures. Increased rural to urban migration and the associated higher population density has been linked to increased risk of infectious disease spread in existing epidemiological models (Archibong and Metcalf, 2021). Other works have linked high density, mass gatherings of people for cultural events like the Islamic Hajj to meningitis epidemics outbreaks in religious centers (Archibong, Annan, and Ekhator-Mobayode, 2021). The combination of these empirical facts point to the potential role that migration, as an adaptive strategy to climate change, may play in further increasing the risks of epidemic disease spread.

3 The Effects of Epidemics on Inequality: Evidence From the Meningitis Belt

3.1 On Group-Based Inequality

Given the links between climate change and epidemics outlined in Section 2, how then might these climate-induced epidemics affect socioeconomic, and particularly group-based inequality? Group-based inequality in socioeconomic outcomes refers to disparities in social and economic outcomes along the lines of social group identity markers like race, ethnicity, gender, class, and other social identifiers. This inequality can be present within countries or across countries, and we focus on the case of within country group-based inequality here[3]. Previous research has shown that group-based inequality can be persistent, and has well-documented negative consequences for development outcomes (Archibong, 2018). How do these group-based inequalities originate and persist over time? A growing body of work in stratification economics has highlighted how formal and informal institutions within societies can shape differential outcomes across groups through public policy, and the inequitable application of social, economic and political power[4] (Darity Jr, 2022; Chelwa, Hamilton, and Stewart, 2022; Archibong, 2018). These institutions can then maintain group-based inequality, further entrenching social hierarchies where members of some groups are more "subaltern" or marginalized relative to other groups (Darity Jr, 2022). This marginalization is reflected in lowered access to valuable goods like health, education, income, wealth and environmental quality, that makes members of these groups even more vulnerable to increased damage in the aftermath of health shocks like epidemics, in ways that are fundamentally inequitable.

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[3] There is a large literature that has examined the origins and drivers of between country group inequality, but a much sparser literature on intergroup inequality within countries, which motivates our study focus here (Corak, 2013).

[4] Apartheid and Jim Crow era policies that legally discriminated against Black South Africans and Black-Americans, respectively, over the 19th and 20th centuries are two infamous examples (Darity Jr, 2022).

A growing body of evidence shows that epidemics increase inequality by worsening outcomes among vulnerable or marginalized groups like women (Archibong and Annan, 2017, 2020; Bandiera et al., 2020) and Black-Americans in the United States (Alsan, Chandra, and Simon, 2021). To explore the channels through which epidemics can increase group-based inequality, we first present a simple framework in Section 3.2, then test predictions of the framework using evidence from meningitis epidemics in Section 3.3 and Section 3.4.

3.2 Conceptual Framework

Aggregate health shocks like epidemics can have differential effects on individual outcomes based on group membership like, for example, gender. Epidemics have both direct and indirect costs to individuals and households. Direct health costs come through costs associated with treatment of the illness itself which can have consequences for shifting in individual and household budget constraints or if diseases infect individuals differentially by group membership[5]. Indirect costs come through the opportunity cost of missed work or missed school and forgone income, along with the increased costs associated with taking care of sick household members. These costs can be particularly difficult to manage because, unlike idiosyncratic health shocks like illnesses in the household, epidemics will affect large numbers of people at the same time over a large geographic area, such that individuals cannot smooth consumption easily or manage the increase in individual and household costs, by simply borrowing from neighboring social networks (e.g. friends and family), especially in the absence of easy access to formal credit markets.

This may also lead households to attempt to smooth consumption by engaging in behaviors (e.g. marrying daughters off at earlier ages in environments where institutions of bride price exist that allow transfers of wealth from the groom's family to the bride's family upon marriage) that are detrimental in the medium to long run to members of already

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[5] For example, women are primarily affected by gynecological illnesses like uterine cancer.

marginalized groups (like women, in the case of the bride-price example). This means that, to the extent that groups are co-located, epidemics will have vastly differential outcomes based on group membership- worsening outcomes for groups in already economically precarious circumstances, with relatively lower income, wealth, educational attainment and human capital outcomes more generally.

We test the predictions of this framework by examining the effects of epidemics on gender inequality and the educational outcomes of girls using new evidence from meningitis epidemics and the meningitis belt in Africa.

3.3 The Meningitis Belt

As discussed in Section 2, meningococcal meningitis is a disease that is endemic in sub-Saharan Africa. 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)[6].

Young children and adolescents are particularly at risk of infection (Basta et al., 2018). 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

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

epidemics since 1986, with the longest lag occurring between the 1986 and 1993 epidemics[7] (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% (Archibong and Annan, 2017). The difference in the case load of meningitis between epidemic and non-epidemic years is stark, with caseloads much higher during epidemic years. 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[8]. While there is no concrete evidence of a causal link between climate change and the severity of the 1986 epidemic, there are strong associations between climate change and fluctuations in the climate variables described in Section 2.1 and the severity of the 1986 epidemic (Archibong and Annan, 2020; García-Pando et al., 2014).

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[9] 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

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[7] 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).

[8] Source: UNICEF statistics.

[9] 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).

shock to households in the belt. Using data from one of the largest meningitis epidemics in Niger's history, the 1986 epidemic, we can assess the effects of the epidemic on gender gaps in education (Archibong and Annan, 2017). Reviewing the impacts of this past epidemic may shed light on the effects of future climate-driven epidemics on gender inequality.

3.4 Niger's 1986 Meningitis Epidemic and Gender Inequality

The results on the effects of Niger's 1986 epidemic on gender gaps in education have been documented in previous research (Archibong and Annan, 2017). The findings show that sudden unexpected exposure to meningitis or meningitis shocks, increased the gender gap in educational attainment during the epidemic. The effect sizes are economically large with meningitis shocks during the epidemic year significantly decreasing years of education for girls relative to their male counterparts, by 0.7 years and 0.4 years for primary school (6-12 years old) and secondary school (13-20 years) 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 (Archibong and Annan, 2017).

These results suggest that these 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.

One way that parents might respond to rising costs is by marrying off female children-to reduce consumption burdens and accrue income from bride price transfers from grooms' families to brides' families. This is particularly salient within a context like Niger which has the highest rates of early marriage in the world, with 75% of girls married before the age of eighteen (Archibong and Annan, 2020). While detailed data on marriage payments in the form of bride price are not available, with per capita income at $250 in 1986 by World Bank estimates[10], 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 (Boye et al., 1991). 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, with results shown using cumulative hazard curves in Figure 2, and further evidence provided in Appendix A.1.[11] Women who were school going aged during the 1986 epidemic year were almost two times more likely to marry earlier, before the age of eighteen, in highly exposed meningitis shock districts than in less exposed areas. We do not observe the same trends during a non-epidemic year like 1990. The evidence from this research shows that epidemics can worsen outcomes for groups in already relatively economically precarious circumstances, like women around the world, widening group-based socioeconomic inequality.

4 Concluding Remarks and Designing Effective Policies to Mitigate the Effects of Climate-Induced Epidemics on Inequality

Climate change increases the likelihood that we will see an increase in more severe epidemics, like the 1986 meningitis epidemic in Niger, in the future. While the effects of climate-induced epidemics on group-based inequality, and particularly their role in worsening economic out-

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[10] In nominal prices.

[11] Figure 2 shows the trends in the raw data, and the effects are only robust for women, not men, as discussed in Appendix A.1.

comes of already marginalized populations, are worrying, there are important policy responses around adaptation and mitigation that can be pursued. A recent literature has highlighted the importance of fiscal responses, health aid and stimulus in mitigating the negative effects of epidemics, and assisting households with consumption smoothing during epidemics (Archibong, Annan, and Ekhator-Mobayode, 2021; Gyimah-Brempong, 2015). Particularly in light of how historical institutions have entrenched group-based inequalities in ways that make members of marginalized groups more vulnerable to the negative consequences of epidemics, targeted policies, like targeted health aid and cash grants to members of marginalized groups[12] during epidemics , can play an important role in mitigating these negative consequences and enhance societal welfare in the short to medium run.

As a further, more long-term policy, changes in institutions that may make members of marginalized groups more vulnerable during epidemics (like regulating bride price institutions that may disadvantage women or extending labor regulation protections to service sector workers like home health aides where Black women are more heavily represented in the US), are needed to reduce inequitable and unequal exposure to the negative effects of epidemics. Effective polices to combat the negative effects of epidemics must anticipate how epidemics are likely to widen existing group-based inequalities, and work to eliminate the sources of those inequalities before, during, and after epidemics occur, and should focus on minimizing damage for members of the most marginalized groups.

Further research needs to be done to evaluate the effectiveness of these policies, understand the role of migration and migratory pressures in response to climate change in increasing the risk of epidemics and think carefully about targeted prevention strategies that address the contribution of human activities to global warming and infectious disease spread. Without research-informed policy implementation, there is a real, present and grow-

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[12] For example, cash grants to households headed by women or low-income households with school-aged girls in the Niger example.

ing risk of detrimental increases in socioeconomic inequality from climate-induced epidemics, with the according negative consequences for human welfare.

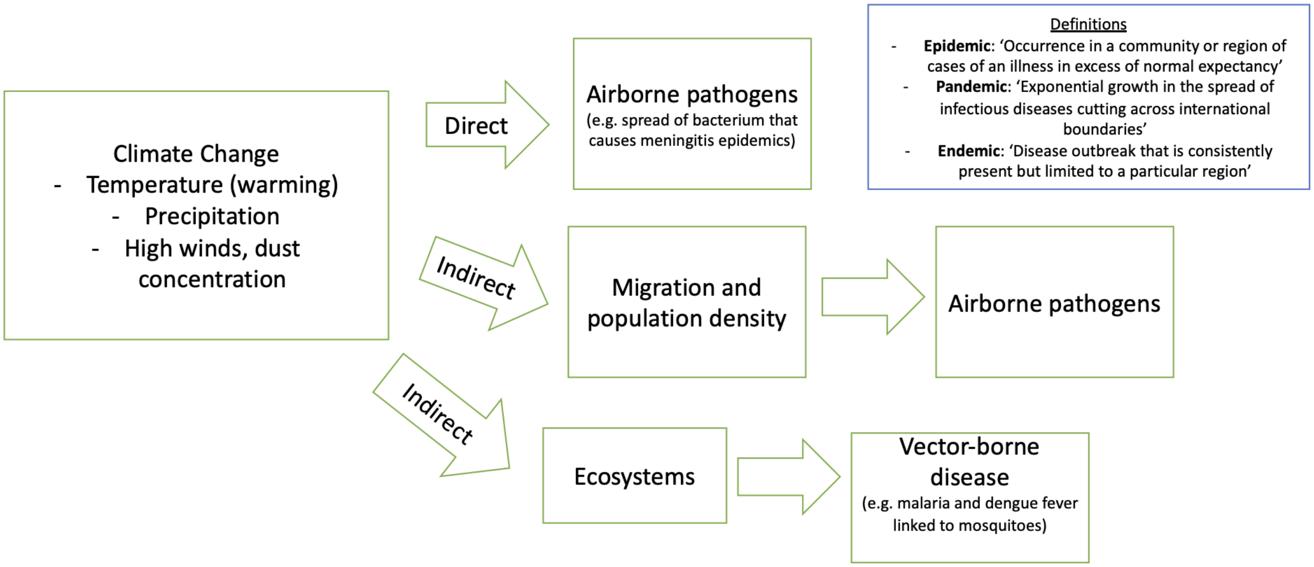

Figure 1: Modeling the links between climate change and epidemics

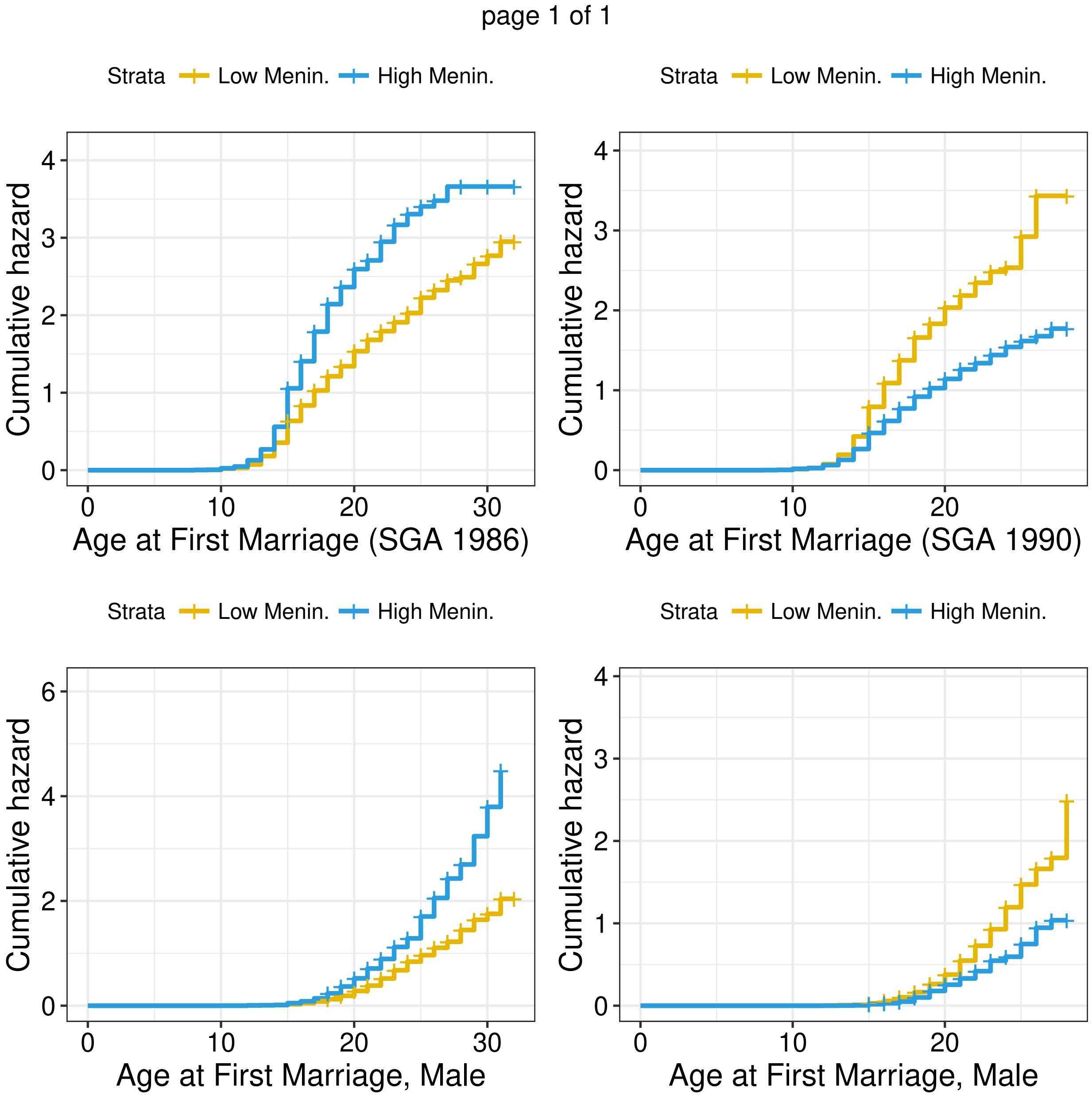

Figure 2: Age at first marriage cumulative hazard for school-going aged (SGA) populations in high meningitis areas (‘High Menin.’) in epidemic (1986) and non-epidemic (1990) years for female (top panel) and male (bottom panel) populations

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A Appendix (For Online Publication)

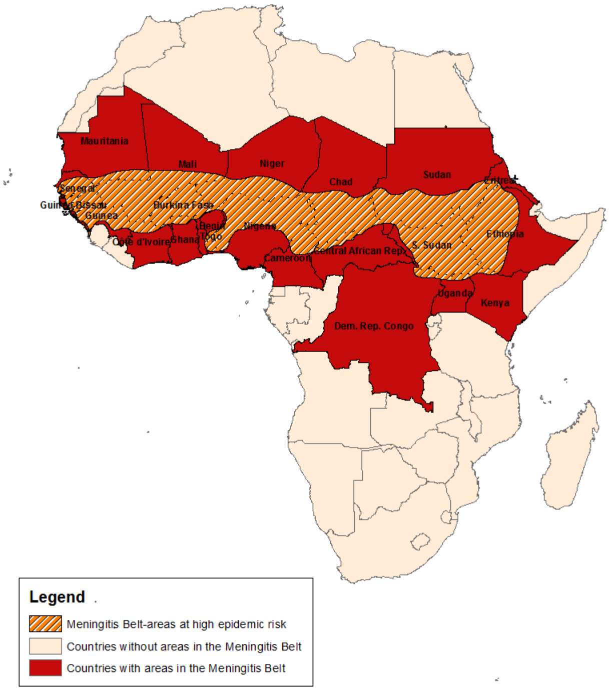

Figure 3: Areas with frequent epidemics of meningococcal meningitis ("Meningitis Belt")

A.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. Under Nigerien law, the legal age of marriage is 15 years for girls and 18 years for boys (Archibong and Annan, 2020). 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. 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 "status symbol demonstrating wealth and social prestige" (Boye et al., 1991). Previous studies have documented increases in the likelihood of early marriage following negative income shocks to households.[13] 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 (Archibong and Annan, 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[14], 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 predictions from the conceptual framework and the predictions of the literature on the marriage effects of economic shocks in bride price societies.

A.1.1 Empirical Strategy

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:

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[13] See Archibong and Annan (2020) for a summary.

[14] In nominal prices.

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

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. '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.

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, marriage outcomes and demographics from the Nigerien Demographic and Health Surveys (DHS). The geocoded, district-level DHS data are available for only 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 4 shows the distribution of meningitis cases by district for the epidemic year, 1986, versus a non-epidemic year, 1990, as a comparison[15]. There is significant variation in exposure to the meningitis epidemic across districts, with a mean of around 10 weekly cases per 100,000 population during the 1986 epidemic year versus 1.6 weekly cases per 100,000 population during the 1990 non-epidemic year. District level data on fatality rates from meningitis are available in aggregate form only, and not available by gender.

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 unable to cleanly replicate the cohort level analysis in Equation 1 for the marriage outcomes; 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[16].

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

[16] 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 4. Although results from Table 4 should be interpreted with caution due to the unbalanced nature of the sample.

A.1.2 Results

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 provided in Table 1. In line with the assumptions in the conceptual framework, 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 (Klasen, 2002) 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 2. 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 2. The results suggest that the association between early marriage and years of education is especially salient for women in the study region.

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 2. Figure 2 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 3. 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 3. 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 3.

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 3. 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 3. Interestingly, in line with the data distribution in Figure 2, 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 the predictions from the conceptual framework and provide suggestive evidence for the indirect channel, 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 5; 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 1. 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 6 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 1, 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[17]. 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. 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[18]. The results are reported in Table 7 and suggest that the early marriage effects are concentrated in the potentially liquidity constrained households, as hypothesized in the conceptual framework.

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[17] 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.

[18] 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.

Table 1: 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

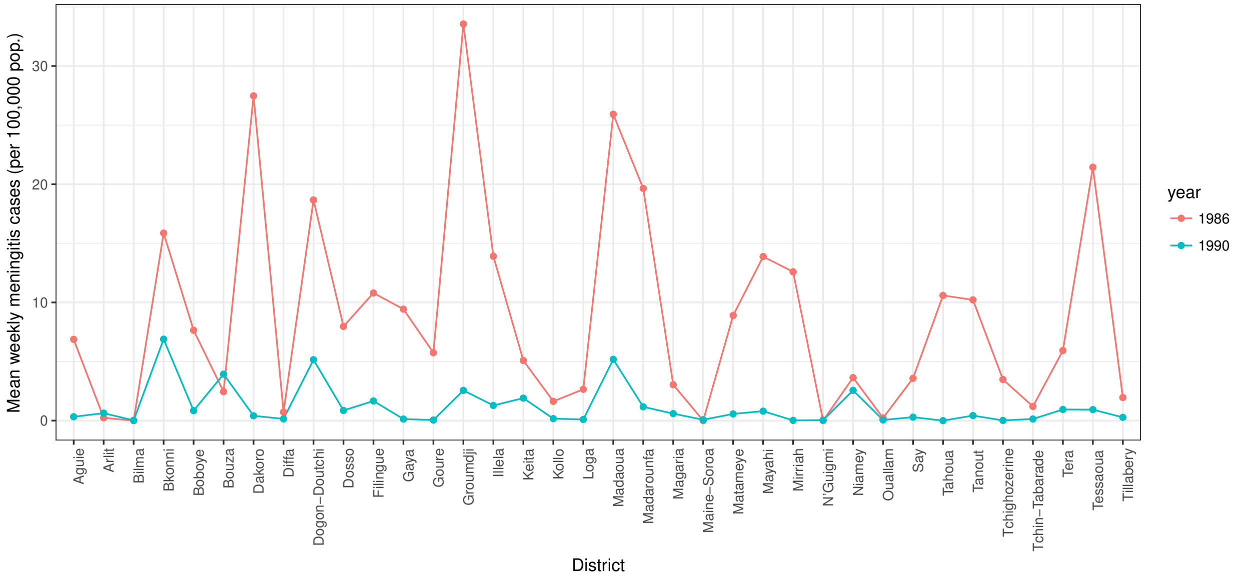

Figure 4: Niger meningitis cases by district in epidemic (1986) and non-epidemic (1990) years

Table 2: 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 3: Effect of meningitis shock on early marriage for female and male school-going aged respondents during epidemic (1986) and non-epidemic (1990) years

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: DHS Women's Sample						
Dependent Variable: Early Marriage						
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 4: 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 5: 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 6: 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 7: 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.