Harmattan Winds, Disease and Gender Gaps in Human Capital Investment: Evidence from Niger's 1986 Meningitis Epidemic

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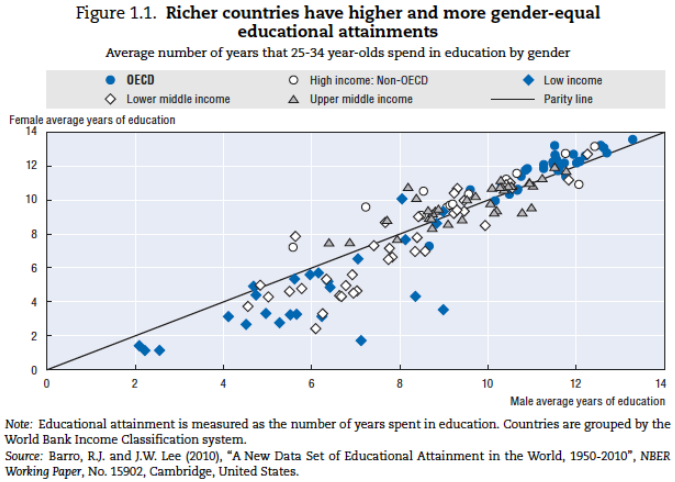
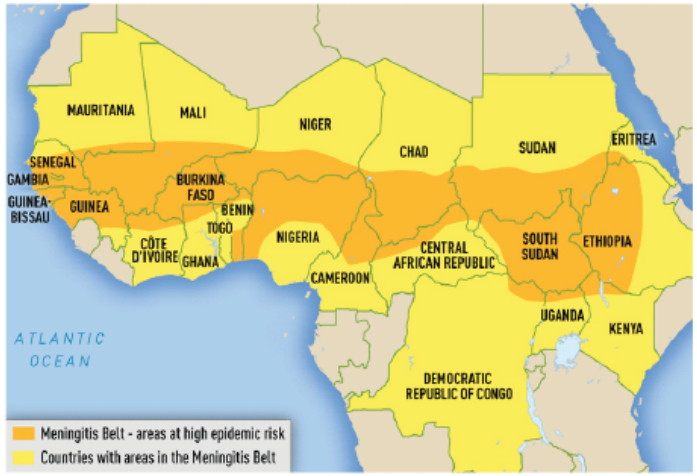
Despite Notable Investments, Gender Gap in Educational Attainment Remains High in Developing Countries- What is the Contribution of Climate-Induced Disease?





MAP 3-11. AREAS WITH FREQUENT EPIDEMICS OF MENINGOCOCCAL MENINGITIS[1]

[1] Disease data source: World Health Organization. International Travel and Health. Geneva, Switzerland: 2012.

Region (2010)	All	Males	Females
Niger	2.1	2.8	1.5
SSA	5.2	5.8	4.6
World	7.8	8.2	7.3

Figure: What is the contribution of climate-induced disease to persistent gender gap in educational attainment?

Preview of Results: Climate-Induced Epidemic Widened the Gender Gap in Education, Income Effects and Early Marriage of Girls a Primary Mechanism

- Evidence from 1986 meningitis epidemic in Niger
- Harmattan season strongly predicts meningitis epidemics
- Find higher meningitis exposure during the epidemic reduced years of education for school-going aged girls at the time of the epidemic (3-4%)

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- Evidence from 1986 meningitis epidemic in Niger
- Harmattan season strongly predicts meningitis epidemics
- Find higher meningitis exposure during the epidemic reduced years of education for school-going aged girls at the time of the epidemic (3-4%)
- Primary mechanism: Income effects and early marriage of girls (bride price)

Health Shocks, Probability of Marriage and Human Capital Investments

- Jayachandran and Lleras-Muney, 2009; Bjorkman-Nyqvist, 2013: unitary hh, parents maximize discounted (concave) EU, 2 periods
- Choose to invest in schooling for girls and boys (s_b and s_g.) Value girls' domestic production more $\eta_g > \eta_b \equiv 1$
- Equilibrium: "if both $s_b > 0$ and $s_g > 0$ reduction in parental income will, on the margin, only reduce investment in girl's education" (Bjorkman-Nyqvist, 2013)

$$max U_i = u(c_1^i) + \delta c_2^i \tag{1}$$

s.t.

$$c_1^i = y_1 - pe_b^i - pe_g^i + \eta_b(1 - s_b^i) + \eta_g(1 - s_g^i) \tag{2}$$

and

$$c_2^i = y_2 + \gamma_b y_b^{ai} + \gamma_g y_g^{ai} \tag{3}$$

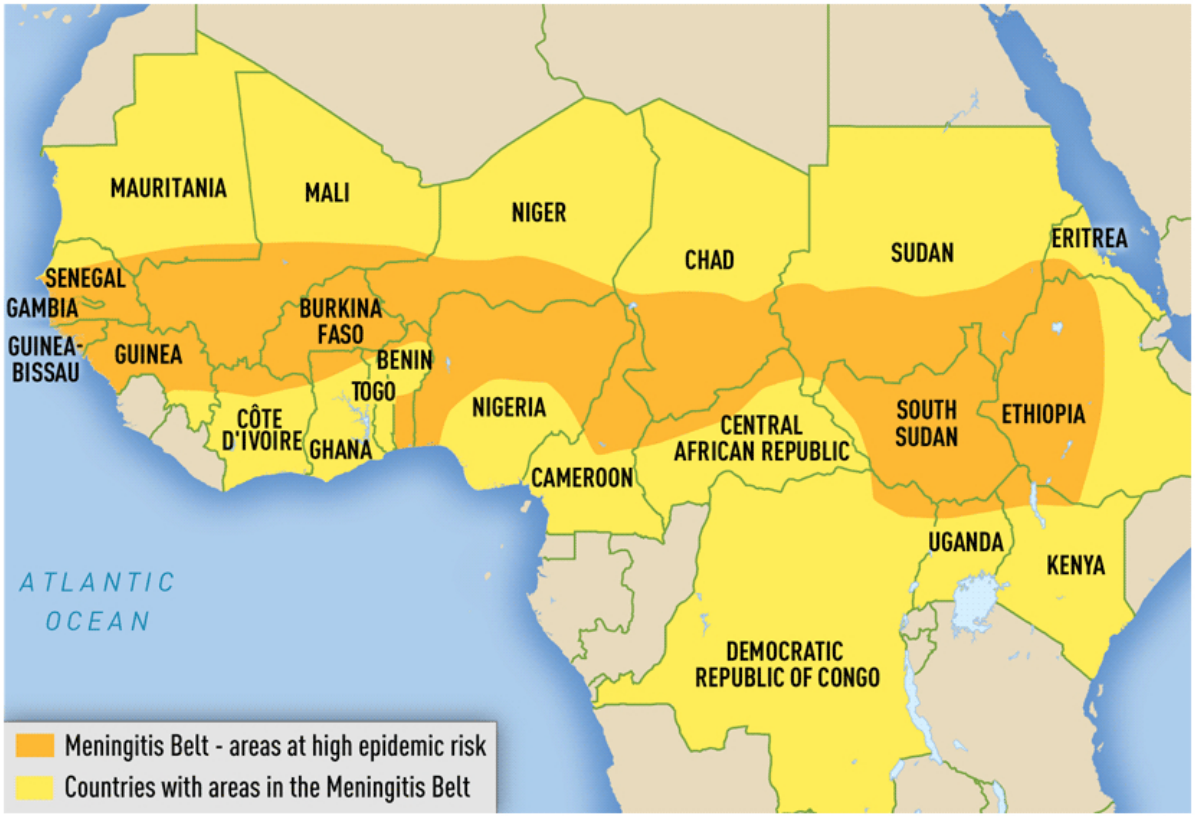
where $a_s^i = \alpha_s^i s_s^i$; $s_s^i \in [0,1]$; $y^{ai} = \omega_s a_s^i (\omega_b > \omega_g and \gamma_b > \gamma_g)$; $\theta_s = \delta\gamma_s\omega_s and \theta_g < \theta_b$

$$FOC : -u'(c_1)\eta_s + \alpha_s^i\theta_s^i \leq 0 \quad \text{for} \quad s_s \in [0,1] \tag{4}$$

Health Shocks, Probability of Marriage and Human Capital Investments

- Corno, Hilderbrandt and Voena (2016); Corno and Voena (2016)
- Patrilocal societies, women move and contribute to groom hh budget
- Shocks (negative income) increase early marriage in bride price societies
- Son's income as insurance, Δ marriage eq. q and bride's family response

95% of Niger's Population Resides in the Meningitis Belt



MAP 3-11. AREAS WITH FREQUENT EPIDEMICS OF MENINGOCOCCAL MENINGITIS[1]

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Figure: Areas with Frequent Epidemics of Meningococcal Meningitis ('Meningitis Belt')

1986 Meningitis Epidemic in Niger

- *Neisseria meningitidis* effects
- Complex epidemiology (Harmattan, 25-30% in Niger), Limited effectiveness of vaccines (since 1909, mutation, LaForce et al., 2009)
- 6 Epidemics between 1986-2008, 1986 particularly severe with 15,823 cases/100,000 pop and mortality rate of 4%
- Young children and teenagers particularly vulnerable to infection (median age 15 yrs over last decade, so major share of pop.)
- Limited interdistrict migration in Niger (.99 and .97 ($p < .001$) cor between 1986 to 1992 and 1998 resp.)
- Assess individual exposure to 1986 epidemic based on geographically based assignment at the district level, given low levels of interdistrict migration

Health Costs of Meningitis Epidemics

- Burkina Faso: HH spent $90 per meningitis case; 34% of per capita GDP; sequelae: $154 per case in affected hh (Colombini et al, 2009)
- DMC: $25.3; ICs: $49.20 per case, loss of caregiver income (9 days lost work, $28.50); loss of infected person income (21 days lost work; if attending school (12 days of missed school)
- DMC- "free" vaccines during epidemics but information asymmetry among health care workers and shortages

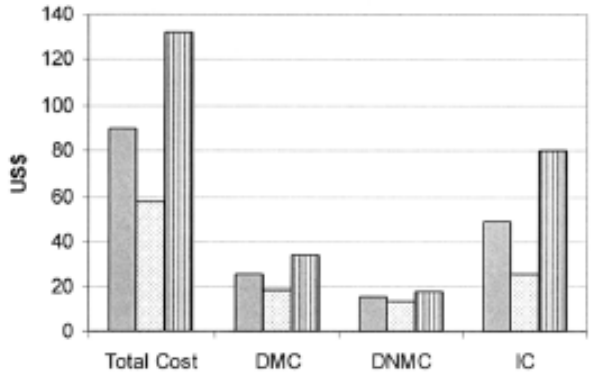


Figure 1. Average costs per meningitis case for rural and urban households, Burkina Faso, 2006–2007. The gray bars are for all households, the dotted bars are for rural households, and the striped bars are for urban households. DMC, direct medical cost; DNMC, direct nonmedical

Data and Cohorts

- WHO (meningitis cases) and DHS data (education, 1992 and 1998) across individuals in all 36 districts in country
- Education measures nos. of yrs of education individual completed
- Limit sample to cohort born bet. 1960-1992: includes school going age during the 1986 meningitis epidemic
- Niger- 20mn people, Homogeneity in religion, ethnic and income characteristics across individuals , 36 districts, capital at Niamey

Niger Meningitis Cases and Population in 1986 and 1990

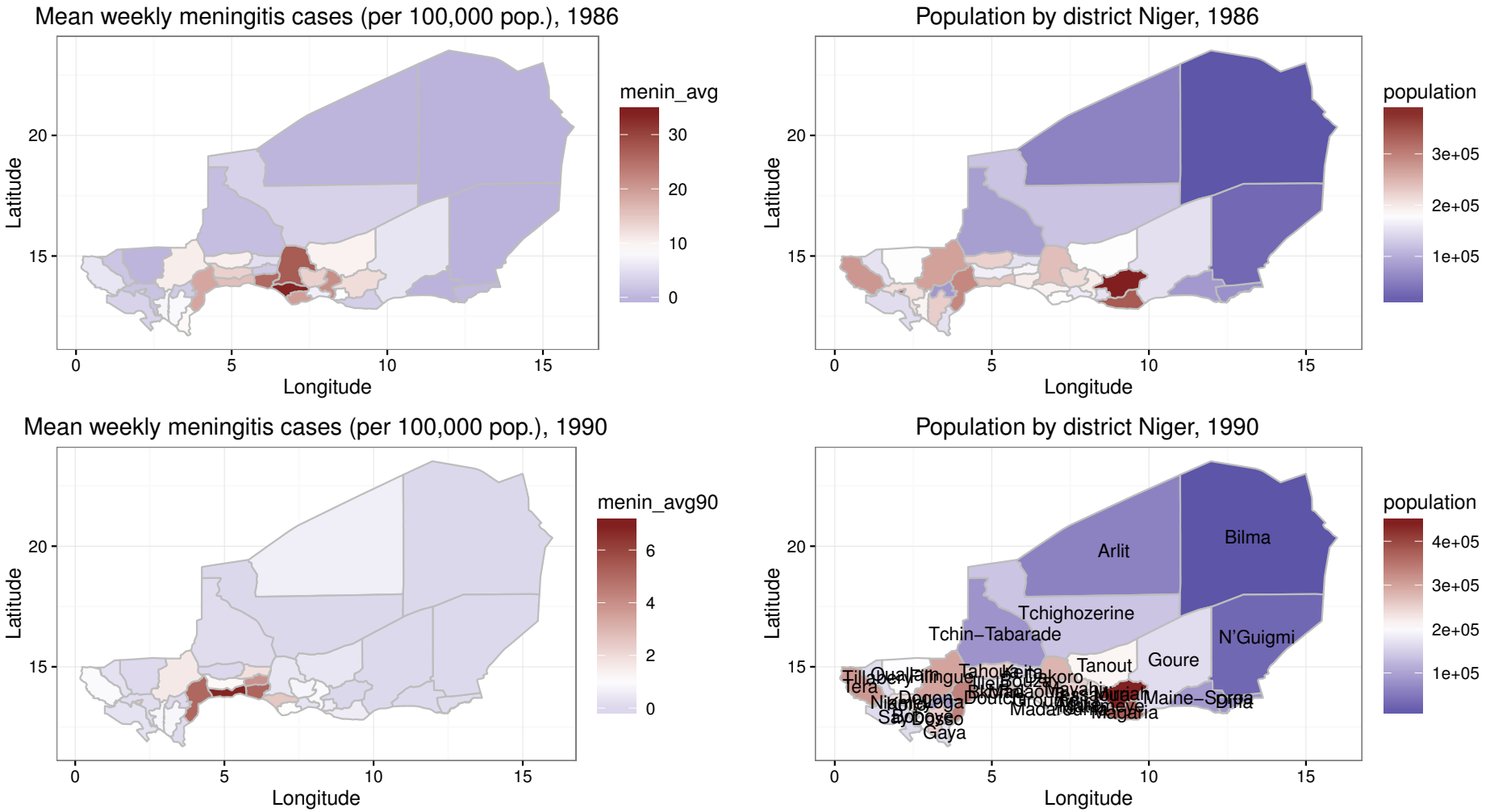
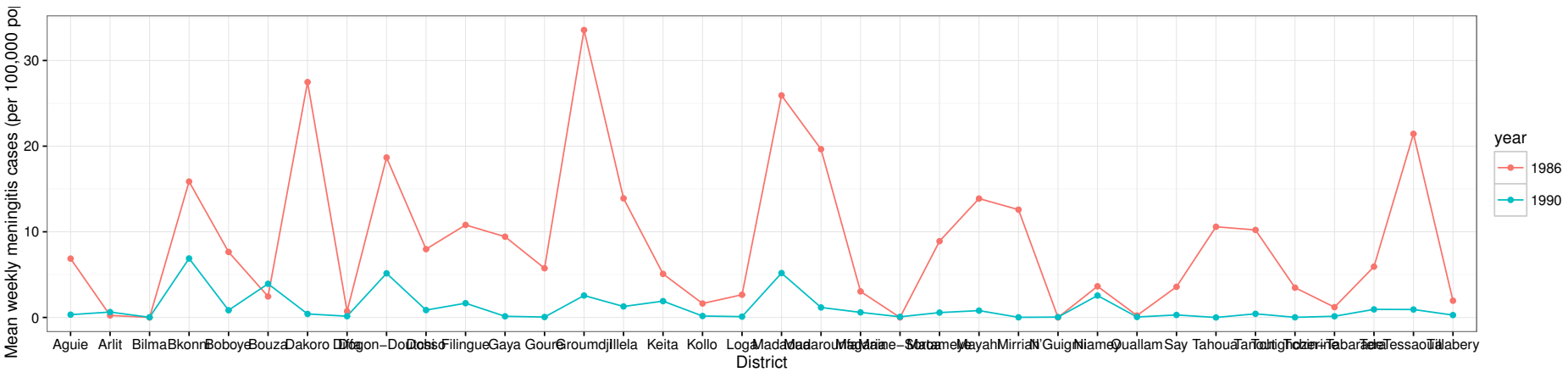


Figure: Niger Meningitis Cases and Population by District in Epidemic (1986) and Non-epidemic (1990) Years

Meningitis Exposure in Epidemic (1986) and Non-Epidemic (1990) Years



Construction of Cohorts

- 3 Categories defined: ages 0-5, 6-12, 13-20 with reference to 1986
- Age bands reference Niger school going context- 6-12 (primary); 13-20 (secondary); 0-5 (non-school going)
- FPE, Mandatory school going start age is 7, allow primary to start at 6 to control for early school going children
- Overall results insensitive to marginal changes in age cutoffs
- Should see no or little effect of meningitis exposure on yrs of education for non-school aged girls during epidemic yr

Empirical Framework

$$\text{education}_{iadrg} = \beta_g \text{female}_{ig} + \beta_a \text{MENIN}_{adt} + \gamma_{ag} \text{MENIN}_{adt} \times \text{female}_{ig} + \mu_d + \delta_r + \delta_t + \epsilon_{iadrg} \quad (5)$$

- MENIN is measured in two ways. In the first case, we calculate the mean weekly cases of meningitis per 100,000 population recorded in a district (MENIN Cases)
- The second case modifies the first measure by interacting it with the number of months for which meningitis incidence is strictly positive (MENIN Intensity)
- Implied key variable of interest (γ_{ag}) is constructed by interacting the MENIN measures with gender.
- Birth year, survey round, district FE. Clustered SE. Robustness checks and falsification tests conducted

Main Results: DD Estimates of the Differential Impact of of Meningitis Exposure on Education (1986 Epidemic Year), MENIN x Female

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

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1986 epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the 1986 meningitis epidemic year multiplied by number of months of exposure (with greater than zero cases). Mean level of education in the sample is 1.22, and the standard deviation is 2.7. Mean level of education for boys in the sample is 1.51 and the mean level

DD Estimates of the Differential Impact of Meningitis Exposure on Education (1986 Epidemic Year), Robustness Check

	Dependent Variable: Years of Education			
	MENIN Cases		MENIN Intensity	
	(3a)	(3b)	(3c)	(3d)
Female	−0.644***	−0.535***	−0.645***	−0.546***
	(0.049)	(0.067)	(0.049)	(0.064)
Meningitis exposure at ages 0-4	0.006	0.005*	0.001	0.0005*
	(0.004)	(0.003)	(0.0004)	(0.0003)
x Female		0.0005		0.0001
		(0.006)		(0.001)
Meningitis exposure at ages 7-12	−0.025	−0.003	−0.002*	−0.0004
	(0.016)	(0.020)	(0.001)	(0.002)
x Female		−0.042***		−0.004***
		(0.012)		(0.001)
Meningitis exposure at ages 14-21	−0.046	−0.028	−0.004	−0.002
	(0.030)	(0.029)	(0.003)	(0.002)
x Female		−0.031***		−0.003***
		(0.009)		(0.001)
Constant	1.038***	0.982***	1.018***	0.966***
	(0.199)	(0.210)	(0.187)	(0.195)
District fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Year of birth fixed effects	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697
R^2	0.208	0.210	0.208	0.209

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1986 epidemic year. MENIN intensity is

DD Estimates of the Differential Impact of Meningitis Exposure on Education (1990 Non-Epidemic Year), Robustness Check

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

Notes: Regressions estimated by OLS. Robust standard errors in parentheses clustered by district. Dependent variable is years of education across all specifications. MENIN cases is the meningitis exposure explanatory variable defined as average district level weekly case (per 100,000 population) exposure for cohort at specified ages during the 1990 non-epidemic year. MENIN intensity is the meningitis exposure explanatory variable measured as district level case exposure for cohort at specified ages during the

Meningitis Epidemics and Harmattan Intensity

- Data: MERRA 2- Harmattan wind, dust and meningitis response in Niger (Perez Garcia-Pando et al, 2014)
- Wind speed: m/s
- Surface dust concentration (kg/m3)
- Oct-December preceding dust and zonal wind partly predicts meningitis incidence/epidemic in Niger (Perez Garcia-Pando et al, 2014)
- IV (2SLS):

$$education_{iadrg} = \gamma_{ag} MENIN_{adt} \times female_{ig} + \mu_d + \delta_r + \delta_t + \epsilon_{iadrg} \quad (6)$$

$$MENIN_{dt} = \rho \boldsymbol{Harm}_{dt} + c_d + \nu_{dt} \quad (7)$$

IV First Stage: Harmattan and Meningitis Cases

VARIABLES	(1) Cases	(2) Cases	(3) Cases
1985 Avg dusts and winds	Yes	No	No
1985Q4 Avg dusts and winds	No	Yes	No
1985OND dusts and winds	No	No	Yes
Current weather controls	Yes	Yes	No
District fixed effects	Yes	Yes	No
Observations	231	231	33
1st-stage: F-statistic	4.8E21	9.20E20	3.27
1st-stage: P-value	<0.0001	<0.0001	0.0337

Notes: Table reports the results from regressions of meningitis cases on previous Harmattan season and current weather variables: temperature and precipitation at the district level. Columns (1)-(3) differ based on the included variables. Column (1) includes the average wind and dust concentration from 1985, column (2) includes the average wind and dust concentration in the last quarter of 1985 (Harmattan season), while column (3) includes the actual monthly observations from the last quarter of 1985 but excludes the district fixed effects. Errors are clustered at the district level. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

IV Estimates 1: Harmattan Induced Meningitis and Educational Gender Gaps

	Dependent Variable: Years of Education			
	MENIN Cases		MENIN Intensity	
	(1)	(2)	(3)	(4)
Female	−0.624***	−0.413***	−0.624***	−0.406***
	(0.0521)	(0.0864)	(0.0521)	(0.0861)
Meningitis exposure at ages 0-5	−0.00818	−0.00143	−0.000875	−0.000175
	(0.00549)	(0.00737)	(0.000564)	(0.000742)
x Female		−0.0129		−0.00129
		(0.00979)		(0.000972)
Meningitis exposure at ages 6-12	−0.0627*	−0.0308	−0.00638	−0.00324
	(0.0314)	(0.0347)	(0.003171)	(0.00350)
x Female		−0.0598***		−0.00591***
		(0.00927)		(0.000921)
Meningitis exposure at ages 13-20	−0.104*	−0.0726	−0.01051	−0.00733
	(0.0588)	(0.0577)	(0.005939)	(0.00580)
x Female		−0.0534***		−0.00538***
		(0.0127)		(0.00127)
Constant	1.305***	1.192***	1.302***	1.186***
	(0.342)	(0.367)	(0.339)	(0.364)
District fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Year of birth fixed effects	Yes	Yes	Yes	Yes
Instrument	1985 Avg Dust & Wind	1985 Avg Dust & Wind	1985 Avg Dust & Wind	1985 Avg Dust & Wind
Current weather controls	Yes	Yes	Yes	Yes
Observations	43,814	43,814	43,814	43,814
R^2	0.215	0.218	0.215	0.218

Notes: Second stage IV results. Table reports the results from regressions of educational attainment on Harmattan-instrumented meningitis exposure at the district level. Columns (1)-(4) differ based on how the exposure to meningitis is defined and its interaction with gender. Columns (2) and (4) include the interaction terms between cohort level meningitis exposure and gender, while columns (1) and (3) omit the interactions. Errors are clustered at the district level. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level

IV Estimates 2: Harmattan Induced Meningitis and Educational Gender Gaps

	Dependent Variable: Years of Education			
	MENIN Cases		MENIN Intensity	
	(1)	(2)	(3)	(4)
Female	−0.624***	−0.413***	−0.624***	−0.407***
	(0.0519)	(0.0868)	(0.0520)	(0.0864)
Meningitis exposure at ages 0-5	−0.00744	−0.000706	−0.000770	−0.000096
	(0.00562)	(0.00759)	(0.000577)	(0.000765)
x Female		−0.0129		−0.00129
		(0.00988)		(0.000982)
Meningitis exposure at ages 6-12	−0.0622*	−0.0301	−0.00634*	−0.00316
	(0.0329)	(0.0362)	(0.00333)	(0.00366)
x Female		−0.0602***		−0.00595***
		(0.00938)		0.000932)
Meningitis exposure at ages 13-20	−0.106*	−0.0737	−0.0107*	−0.00745
	(0.0606)	(0.0597)	(0.00613)	(0.00600)
x Female		−0.0540***		−0.00545***
		(0.0127)		(0.00127)
Constant	1.307***	1.194***	1.305***	1.189***
	(0.347)	(0.372)	(0.344)	(0.369)
District fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Year of birth fixed effects	Yes	Yes	Yes	Yes
Instrument	1985Q4 Avg Dust & Wind	1985Q4 Avg Dust & Wind	1985Q4 Avg Dust &Wind	1985Q4 Avg Dust &Wind
Current weather controls	Yes	Yes	Yes	Yes
Observations	43,814	43,814	43,814	43,814
R^2	0.215	0.218	0.215	0.218

Notes: Second stage IV results. Table reports the results from regressions of educational attainment on Harmattan-instrumented meningitis cases in 1986 at the district level. Columns (1)-(4) differ based on how the exposure to meningitis is defined and its interaction with gender. Columns (2) and (4) include the interaction terms between cohort level meningitis exposure and gender, while columns (1) and (3) omit the interactions. Errors are clustered at the district level.Errors are clustered at the district level. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level.

Potential Mechanisms

- Indirect channel: BF and 34% GDP/cap. Economic responses: early marriage of girls in bride price societies (Corno and Voena, 2016)
- Early marriage response: "women's families more price sensitive than men's families"
- Direct channel: Differential biological responses to meningitis? (Trotter and Greenwood, 2007), Treatment?

Early Marriage in Niger

Aichatou, who was married at 15 and widowed at 16, writes on the blackboard during French class. © UNFPA Niger/Souleymane Saddi Maâzou

- Niger: Highest rate of child marriage in world, 75% marry before 18
- Economic reasons: bride price, "costs of girls"
- Age gaps, Northern Nigeria

Risk of Early Marriage, DHS Subsamples: Men and Women's Sample Variable Means

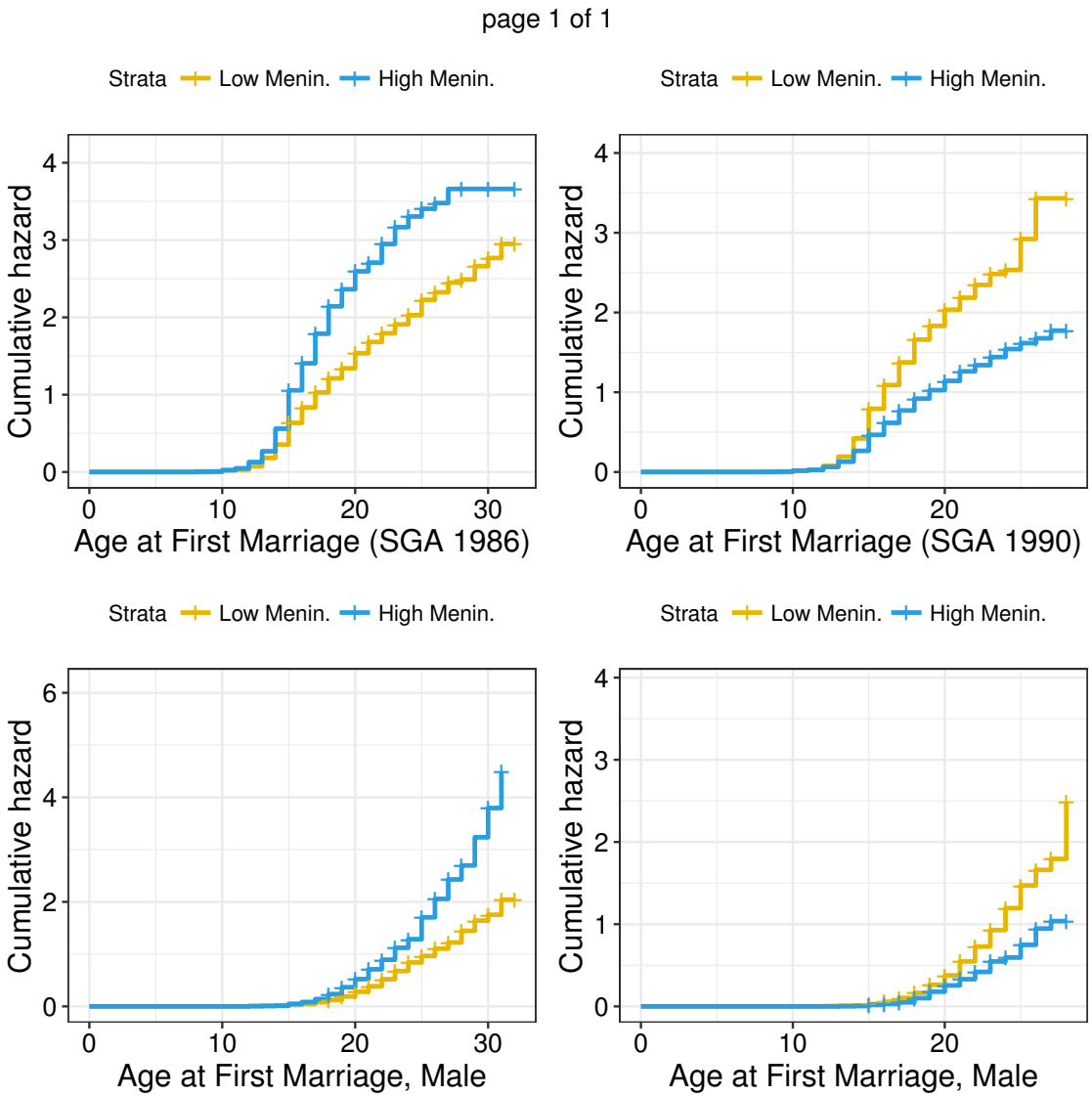
Statistic	N	Mean	St. Dev.	Min	Max
DHS Women's Sample, SGA 1986					
Age at First Marriage	5,898	15.061	2.533	8	31
Years of Education	7,255	1.557	3.064	0	16
Meningitis Cases 1986	7,255	9.634	7.951	0.000	31.231
Age	7,255	22.458	4.504	15	32
Nos. of Wives	5,573	0.354	0.594	0	7
Age at First Birth	5,280	17.250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

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

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

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

Early Marriage of Girls Increased Significantly during 1986 Epidemic Year



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

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

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

Robustness Check: Impact of Concurrent (Rainfall) Shocks on Education (1986 Epidemic Year)

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

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

Robustness Check: Impact of Concurrent (Rainfall) Shocks (Sd) on Education (1986 Epidemic Year)

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

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

Robustness Check: Wealth and Age at First Marriage (1986 Epidemic and 1990 Non-Epidemic Years)

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

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

Conclusions, Further Research and Policy Implications

1. Gender gap widened during the epidemic year
2. Harmattan and disease burden in tropics- climate change and worsening social inequality through widening gender gaps
3. A primary mechanism is early marriage of girls
4. Given intergeneration returns to female education and economic gains from closing gap, results highlight need for multi-pronged policy- climate, education and health
5. Further work: Bride price and economic impacts from meningitis belt

Summary statistics

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

1986 Meningitis Epidemic in Niger

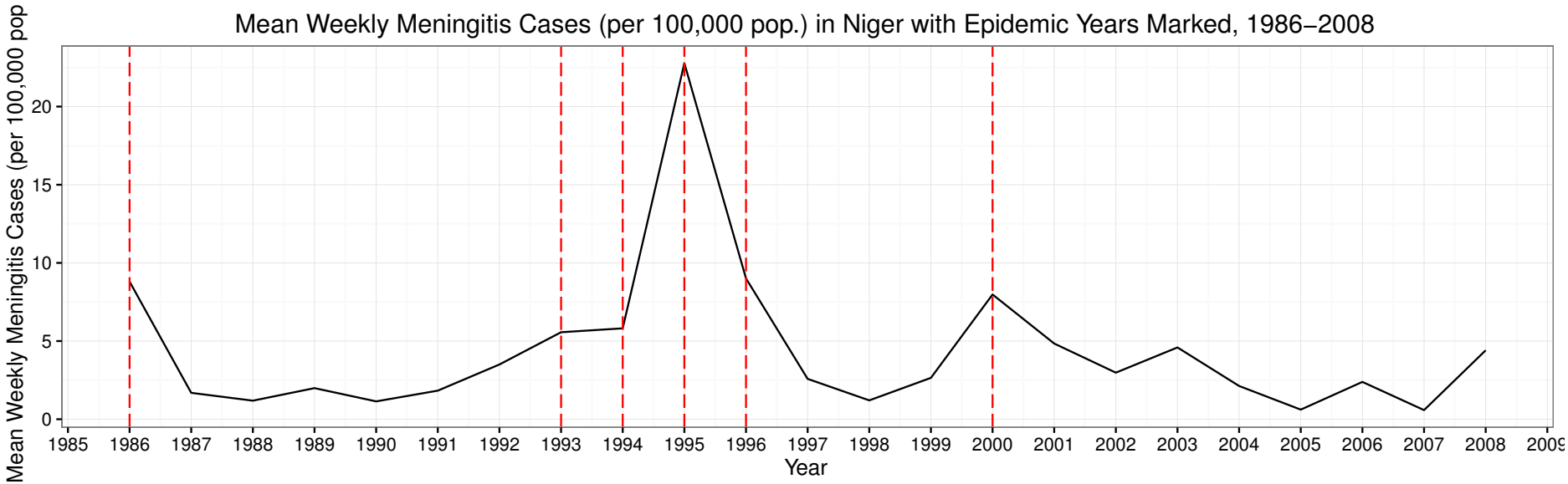
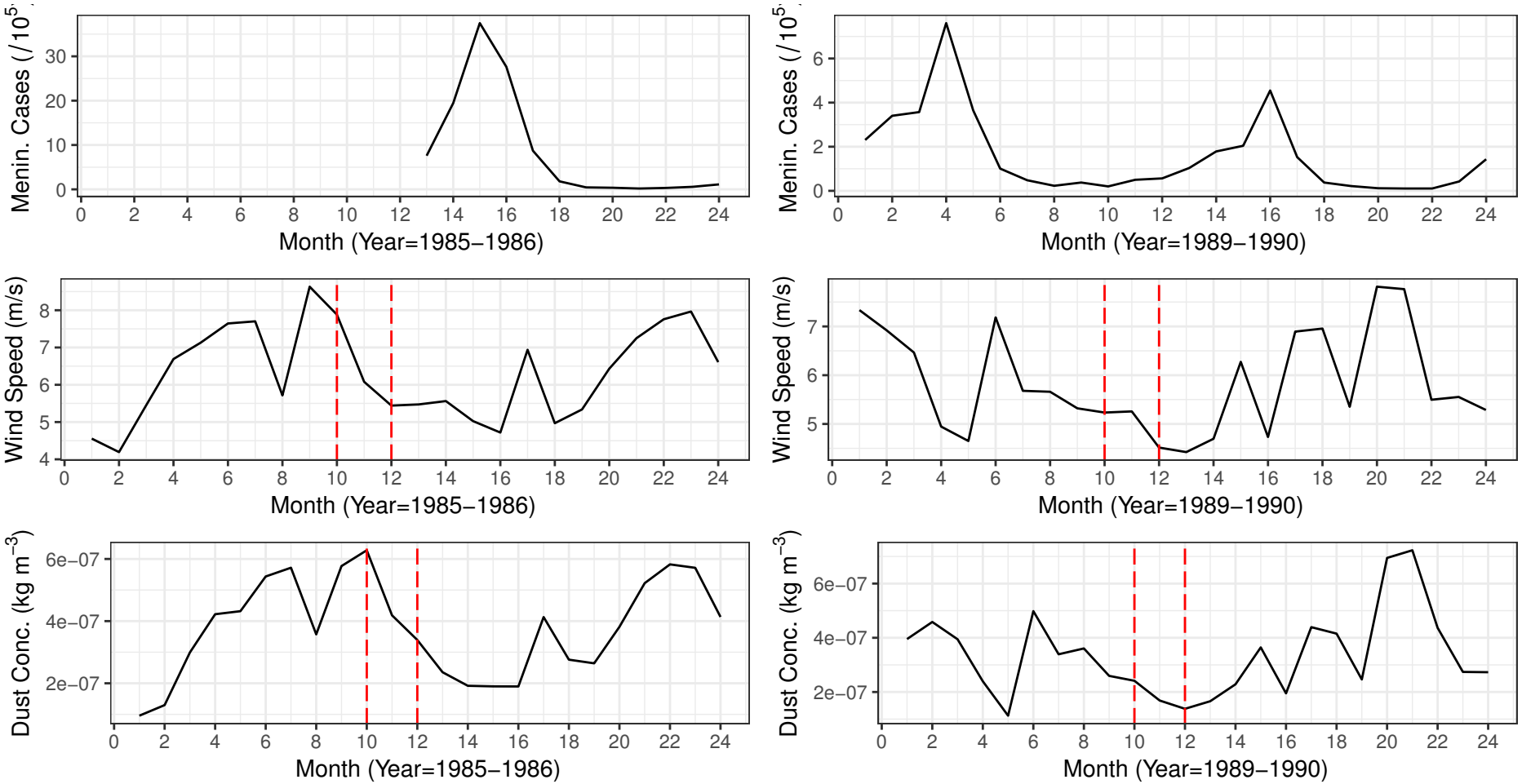
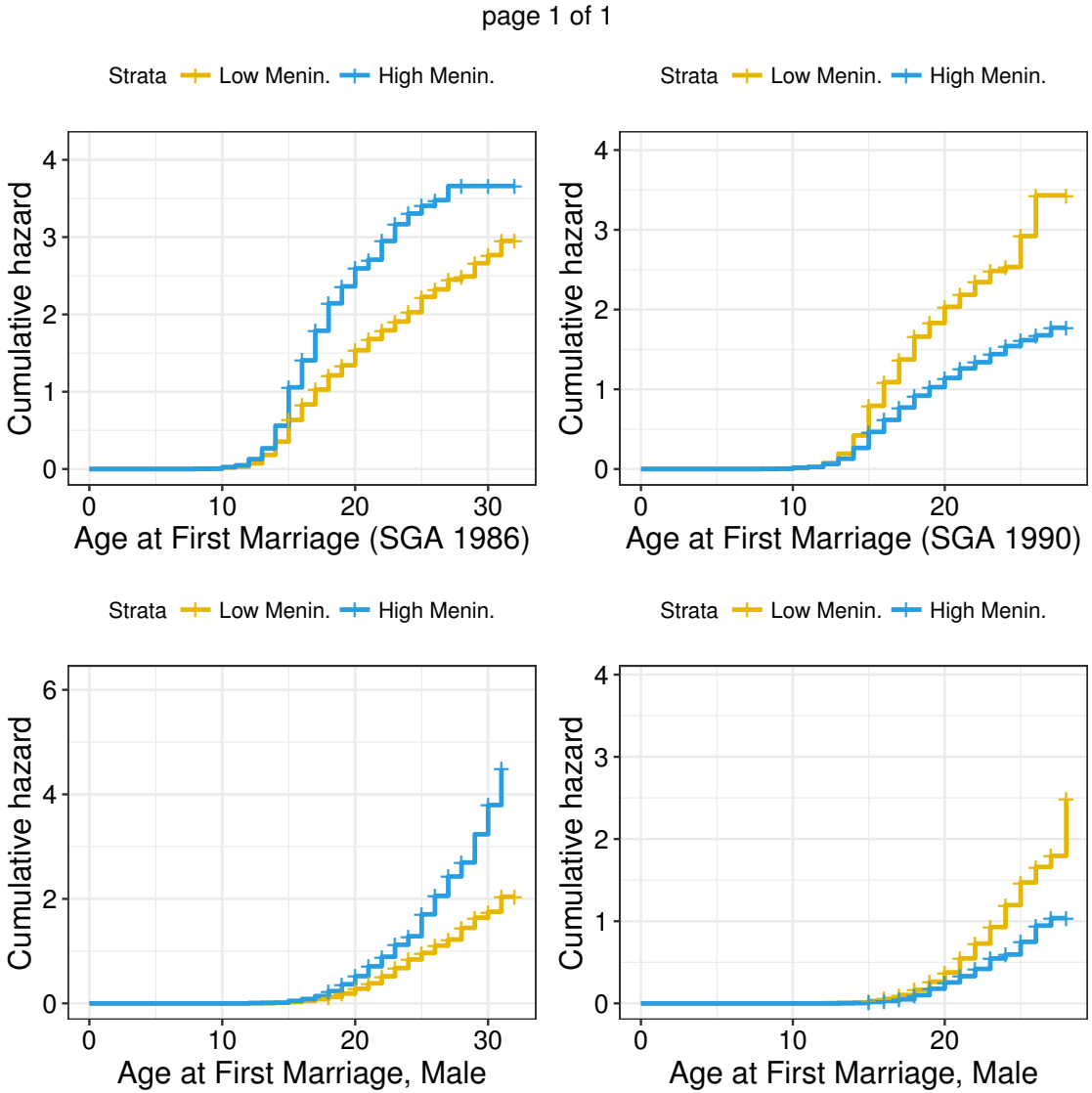


Figure: Niger Meningitis Cases by District in Epidemic (1986) and Non-epidemic (1990) Years

Harmattan and Meningitis Response



Testing Mechanisms: Risk of Early Marriage, Cumulative Hazard



Testing Mechanisms: Correlation Between District Mortality Rate During 1986 Epidemic and 1992-1998 District Level Share of Female Respondents

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

Summary statistics- Wind Speeds

Statistic	N	Mean	St. Dev.	Min	Max
Wind 85	33	6.468	0.638	5.243	7.482
Wind85 high	33	0.606	0.496	0	1
Wind 86	33	5.353	0.387	4.664	6.609
Wind86 high	33	0.515	0.508	0	1

Effect of Repeated High Exposure to Epidemics Post 1986 (1986-1996)

	Dependent Variable: Years of Education							
	Meningitis Exposure							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
female	−0.647***	−0.537***	−0.646***	−0.523***	−0.647***	−0.558***	−0.645***	−0.588***
	(0.051)	(0.066)	(0.050)	(0.073)	(0.051)	(0.062)	(0.051)	(0.050)
case86_05	−0.0001	0.0005						
	(0.001)	(0.002)						
female ∗case86_05		−0.001						
		(0.002)						
case86_612	−0.005	0.004						
	(0.005)	(0.007)						
female ∗case86_612		−0.017***						
		(0.004)						
case86_1320	−0.011	−0.005						
	(0.008)	(0.008)						
female ∗case86_1320		−0.011**						
		(0.004)						
case086_05			−0.002	0.001				
			(0.003)	(0.004)				
female ∗case086_05				−0.004				
				(0.006)				
case086_612			−0.022	−0.001				
			(0.015)	(0.019)				
female ∗case086_612				−0.041***				
				(0.011)				
case086_1320			−0.040	−0.024				
			(0.025)	(0.025)				
female ∗case086_1320				−0.028***				
				(0.010)				
case186_05					−0.001	0.001		
					(0.003)	(0.004)		
female ∗case186_05						−0.004		
						(0.005)		
case186_612					−0.015	0.005		
					(0.011)	(0.016)		
female ∗case186_612						−0.039***		
						(0.012)		
case186_1320					−0.026	−0.012		
					(0.016)	(0.017)		
female ∗case186_1320						−0.024**		
						(0.010)		
case286_05							0.005	0.002
							(0.004)	(0.006)
female ∗case286_05								0.006
								(0.007)
case286_612							0.016	0.047***
							(0.010)	(0.017)
female ∗case286_612								−0.059***
								(0.019)
case286_1320							0.006	0.029
							(0.016)	(0.024)
female ∗case286_1320								−0.039**
								(0.019)
Constant	1.062***	1.004***	1.041***	0.976***	1.061***	1.014***	1.043***	1.014***
	(0.204)	(0.215)	(0.201)	(0.213)	(0.204)	(0.213)	(0.203)	(0.203)
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of birth fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	47,697	47,697	47,697	47,697	47,697	47,697	47,697	47,697
R^2	0.206	0.208	0.207	0.209	0.206	0.208	0.205	0.207

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

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

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