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Climate Change, Fertility and Sahelian Demographics

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Abstract

Climate change, especially in Africa's central Sahel region, is occurring in the context of exponential population rise with countries like Chad and Niger still in the "early expanding phase" of demographic growth. While many experts predict a mid-century climate and demographic 'mega crisis' for the region; our paper looks at the effect of the rising temperature, through the medium of increased temperature and precipitation variability upon fertility and hence demographic trends as we advance into the 21st century. The paper uses climate data and DHS (Demographic and Health Survey) data from Chad, which has demonstrated significant warming since the late 1960's. We create a weather shock variable that is defined as a t>2 departure from the post-1960 mean of temperature and precipitation by month, year, and GIS location. We regress the following years' human fertility outcomes by month and GIS location upon these shocks when occurring in the growing months of June, July, and August. We find that the effect is highly negatively significant with a one-year lag. Then we go on to look for the mechanism behind this significance; the literature suggesting that climate effects fertility through biological or food security related channels. We then regress the male/female sex ratio on the same weather shocks to see if there is a rise in miscarriages among male fetuses due to either the direct effect of heat or as an effect of increased female malnutrition. By running both these models with weather shocks from Chad's dry season months of December, January, and February, we discern whether the significance is driven by pure temperature or by some sort of food security/household income channel. Though we see some dry season effect, most of the significance is driven by the shocks in the growing season and with the significant effect of these shocks on the sex ratio, we can assume that increased female malnutrition is a key driver of both the rise in miscarriages and the drop-in fertility. We then run these models within each of the three Chadian climate zones: the Sahara, the Sahel, and the Sudan. Seeing that the Sahel zone is the major driver for the significance of our models, we discuss if this can have implications for the wider African Sahel.

Keywords: climate change, Africa, fertility, demographics, the Sahel, Chad

1. Introduction

Climate change disproportionately affects Sub-Saharan Africa. The more devastating effects of rising temperature and reduced precipitation are particularly salient in the Sahel—the semi-arid region that separates the Sahara zone from green Soudanese Africa. In this region, the decrease in precipitation and rise in temperature since the early sixties is among of the most significant in recorded climatological history (IPCC, 2001).

In this paper we examine the relationship between fertility and temperature and precipitation shocks in the country of Chad. Chad contains three distinct ecological climate zones. In addition to the central semi-arid Sahel, the country has a desert Saharan region and the greener Soudanese region. In areas highly dependent on rainfed agriculture, weather shocks can hold significant consequences for household well-being. Climate change has hit Chad particularly hard with temperatures rising 2.64 degrees centigrade between 1960 and 2010 (Abidoye and Odusola, 2015). One major effect of a changing climate is increased weather variability and as climate change continues, we can expect temperature and precipitation shocks to increase in both frequency and intensity (Potts 2015).

The effects of climate change and associated shocks are well documented and wide ranging (Abidoye and Odusola 2015). Increased weather variability can influence fertility through behavioral, biological, and socio-economic channels. Numerous studies point to households' child preferences and their behavioral response to weather shocks as a channel for climate's influence on fertility. These studies demonstrate that households may increase their fertility as a response to the increases in risk and mortality caused by climate shocks (Salas 2017; Gemenne 2011;

Das Gupta et al. 2009; Lackzo, Aghazarm 2009). Much of this literature focuses primarily on major environmental and/or weather events and the associated rise in child mortality (Portner 2018; Brauner-Otto & Axina 2017; J.Davis 2017; Owoo, AgyeiMensah & Onusha 2015). As a result, households may exhibit child hoarding behaviors. This response may be exacerbated in developing countries where children are often an important source of family labor in agricultural areas (Cain 1981). Increasing fertility may also simply be an insurance mechanism where in the face of greater climate uncertainty parents decide to have more children to provide for a more uncertain future (Rozensweig & Schultz 1983; Cain 1981). However, these behavioral responses relate to the mortality events caused by major weather shocks. In this paper we are more concerned with weather shocks that are not necessarily associated with higher child mortality but still affect individual and household well-being and, in turn, their subsequent fertility.

Specifically, we examine the effect of growing season temperature and precipitation shocks on cluster level birth rates using data from the 2014-2015 wave of the Demographic and Health Survey in Chad. We find that growing season weather shocks reduce cluster-level birth rates with this effect being largely driven by the semi-arid region of the Sahel. We further explore the possibility that these effects are due to weather's effect on food security by comparing the effects of growing season shocks with dry season shocks. We also explore the potential of weather biologically affecting reproductive health and subsequently miscarriage rates by looking at its effect on cluster-level male-to-female sex ratios—given evidence that male fetuses are more likely to miscarry than female fetuses due to population stressors (Fukuda et al 2014; Catalano 2003; Byrne et al, 1987).

2. Climate Change and Fertility

In this paper, we are concerned with the effect of temperature and precipitation shocks on fertility. These shocks can affect household fertility decisions both through biological and socio-economic channels. Temperature and precipitation can biologically affect fertility through a direct effect on reproductive ability. Evidence demonstrates that extreme heat reduces human fertility (Atiqul Haq et al 2021; Nielson 2016; Lam, Miron 1996; Becker, Chowdhury, Leridon 1986; Richards 1983). There are also papers on the negative effect of rising heat on baby weight, as well as general mortality (Bakhtsiyarava et al 2018; Chapman et al 2017; Grace et al 2015). Gregory Casey et al's paper demonstrates that the effect of heat on fertility depends on global position, where Eissler et al shows that the effect of heat on fertility is mitigated by urban/rural status, education, and parity (Casey et al 2019; Eissler et al 2019; Grace 2015).

However, the mechanism by which this happens is not clear. Moreover, while this effect of heat on fertility has been observed in the United States and the numerous developing countries, researchers have been largely unable to replicate it in Europe (Kestenbaum 1987; Richards 1983; Warren, Tyler 1979; Chaudhury 1972; Pasaminick, Dinitz, Knobloch 1960). Therefore, the biological process by which heat affects fertility continues to be a source of debate.

Some argue that the effect of heat on human fertility may augmented by seasonal photoperiodic effects on individual hormone levels (Levine 1994).[1] However, changes in the length of day versus night cannot explain the fertility effects of within season climate shocks. Generally, the effect of heat on human fertility theorized to be the result of two physiological processes; increased temperature can reduce male spermatogenesis as well as restrict female ovulatory function (Scholte, Van den Berg, Lindeboom 2015; Lam, Miron 1996; Boserup 1985).

Higher temperature can also lead to increased incidence of stillbirth (Basu, Sarovar & Malig 2016; Strand, Barnett & Tony 2012), however increased stillbirths maybe also due to poor maternal nutrition (Bhutta et al 2013; Snigal & Doyle 2008; Nalumbamba -Phiri & Goldberg 2006). Climate shocks can affect a region's disease environment as well as food security through its effect on crop yields (Tiwari et al., 2017; Porter et al 2014; Ray et al 2012). This, in turn can affect maternal malnutrition during pregnancy, which can affect both fertility and the ability to carry a child to term (Alan & Portner 2018; Kim & Prskawetz 2010). Maternal malnutrition can then reduce fertility through several processes. For example, biological evidence establishes that there exists a level of malnutrition beyond which short-term ovulatory function shuts down. Additionally, evidence indicates that childhood and in-utero female malnutrition can affect adult sterility (Song 2013; Lumey and Stein 1997; Gluckman et al. 2005; Gardner et al. 2009). Carico et al shows that weather shocks can lead to a greater prevalence of child marriage, which can increase fertility (Carico et al 2020). Finally, maternal malnutrition is also associated with increased rates of infant mortality and adverse birth outcomes (Bhutta et al 2013; Snigal & Doyle 2008; Nalubamba-Phiri & Goldberg 2006).

In regions dependent on rainfed agriculture, climate's effect on crop yields means that climate shocks can result in economic shocks, have significant implications for households' socio-economic status and can influence fertility

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[1] Photoperiodism is defined as the physiological response of plants and animals to the length of day or night.

decisions beyond the biological processes discussed above. Much has been written on the effect of scarcity on fertility (Alan & Portner 2018; de Sherbinan et al 2007), with scarcity changing the parameters of the child quality/quantity trade-off (Becker & Lewis 1973). Climate shocks can therefore result in a tightening of resource constraints that then influences a household's fertility decisions and may cause reduced or delayed fertility (Mckelvey Thomas & Frankenberg 2012; Mckenzie 2003; Eloundou-Enyegue, Stokes & Cornwell 2000). A changing climate (i.e. long term change in weather patterns) may also affect expectations on future returns to child labor in agricultural households.

Conversely, households could respond to income shocks by deciding to have more children. This may be due to households viewing children as a source of less expensive labor where labor markets are incomplete (Cain 1981). Others find evidence that households exhibit a 'family-bonding response' to income or environmental shocks, which leads to a rise in fertility (Cohan & Cole 2012; Love, Rhodes et al 2012; Kesler et al 2006; D. Henry, Tolan & Gorman-Smith 2004).

3. Data and Chadian Context

Chad is situated on the convergence of three distinct climatological/geographical zones; the northern Saharan desert zone, the central arid steppes of the Sahelian zone and the southern green Soudanese zone. There is also a small part of the Guinean zone in the far south that is typified by a lot more rainfall than even the Soudanese zone. The Sahara is typified by low population growth, low rainfall, lack of agriculture and extreme heat. The Sahel, the largest of the three major zones, is semi-arid and perceived as extremely vulnerable to any change in weather variability (Potts et al 2012). Finally, the Soudan includes the more agriculturally fertile areas of Chad and is more susceptible to flooding because of a positive precipitation shock.

Climate change since the early 1960's has been typified (in Africa's Sahel region) by rising temperatures and reduced precipitation. The Sahel, the semi-arid region that separates the desert Sahara zone and the green Soudanese zone, has especially witnessed extreme temperature rises and reductions in precipitation.

Consequently, Chad has experienced a dramatic rise in the frequency of temperature and precipitation shocks (defined below) in the last several decades. Figure 1 plots the average number of growing season weather shocks across observed clusters. Here we see an increasing frequency of weather shocks during the period since 1960 when warming has been detected in Chad. The frequency of shocks has especially grown since the mid 1990's as the pace of Sahelian climate change has moved exponentially. From figure 1 we can see the increasing intensity of extreme weather variability caused by the advance of global climate change.

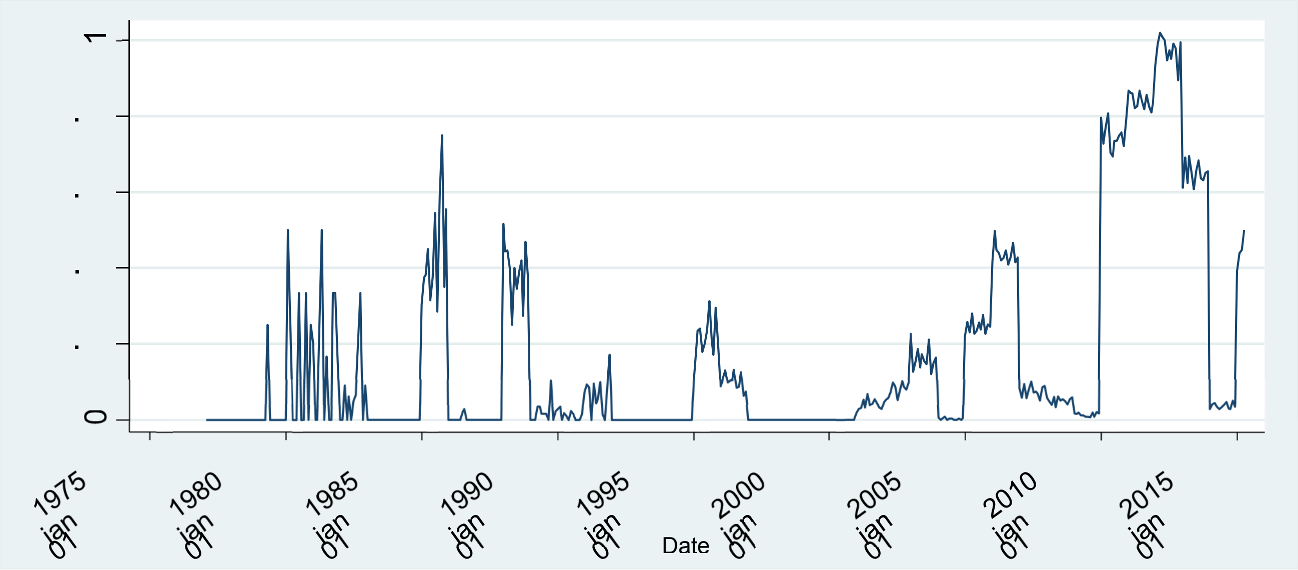

Figure 1. Growing season temperature and precipitation shocks since 1970

We examine the effect of temperature and precipitation shocks on community-level fertility rates in Chad. To do so, we employ climate data from the University of East Anglia's Climate Research Unit (CRU) that provides high-resolution gridded data drawn from weather satellites. The CRU data provide monthly mean, minimum, maximum and standard deviation for both temperature and precipitation at a 5-degree spatial resolution. We use monthly averages for all the 5-degree grids within Chad. When generating our weather shock variables, it is important that we purge them of spatial patterns that may be correlated with fertility. Geographic variation may be correlated with other important regional characteristics. For example, high rainfall areas may be wealthier or warmer areas may be more reliant on agriculture. If this is the case, then regressing fertility on observed weather conditions may result in a spurious association rather than a causal effect. To address this concern, we create temperature and precipitation z-scores by standardizing monthly averages based on month- and grid-specific average and standard deviation over the period of 1960 to 2015. This grid- and month-specific standardization will be orthogonal to the long-run means themselves as well as to expected seasonality in climate. Finally, we define temperature and precipitation shocks as z-scores that are either 2 standard deviations above or below what is expected for that grid in that month. In other words, we generate weather shock dummy variables equal to one if the z-score is less than -2 or greater than 2.

We combine this weather information with household and fertility data from the 2014-2015 wave of the Demographic and Health Survey (DHS) in Chad commissioned by the U.S. Agency for International Development (USAID). The DHS contain rich information on female well-being and fertility making it an ideal vehicle for exploring the link between increased weather variability and human fertility. While four DHS surveys have been conducted in Chad, the 2014-15 survey is the only that includes GIS locations for surveyed households. We therefore restrict our analysis to this wave as it allows us to link our household data with our geocoded weather data. The data include 17, 719 women surveyed across 626 location clusters.

We measure cluster-level fertility as the cluster-level birth rate. The DHS surveys ask sample women about each birth they experienced. From this we know the month and year of each birth for each woman. Using this information, we construct a variable capturing the month- and year-specific number of sampled births that happened in each cluster over our sample period. From this we construct a month- and year-specific birth rate for each cluster as the number of births divided by the cluster's 2014-15 population. While we realize this variable fails to capture all births in each cluster, it should nonetheless capture variations in the birthrate across clusters and across time. Finally, we want to be sure that we are accurately capturing a representative sample of births for each year. We therefore exclude births that occurred prior to 1995. Women who gave birth prior to 1995 are more likely to be dead or past their reproductive years making them less likely to be sampled or have their birth histories taken. We then take the natural log of our constructed birth rate and use that as our main dependent variable of interest.

In addition to numerous controls at the socio-economic controls, in our later analysis we also control for violence intensity and proximity. Chad, since independence, has known a significant degree of armed conflict. Since this conflict may create 'noise' in our analysis, we use data from the Uppsala Conflict Data Program maintained by the University of Uppsala, Sweden. We create a 'Violence Index' for each GIS cluster by dividing the number of deaths resulting from each conflict by the conflict's distance from each of our sample clusters. We then use this variable as a control in our later analysis. After accounting for missing observations, we are left with 27,494 cluster-month-year observations for 435 clusters.

Table 1. Cluster-level summary statistics across Chad's ecological zones

	Full Sample	Sahara	Sahel	Soudan
	N=27,494	N=1,779	N=12,377	N=13,388
Male-to-Female Sex Ratio	1.29	1.33	1.29	1.29
	(0.83)	(0.81)	(0.83)	(0.83)
Negative temperature shock	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Positive temperature shock	0.07	0.02	0.07	0.08
	(0.26)	(0.16)	(0.26)	(0.26)
Negative precipitation shock	0.03	0.00	0.03	0.04
	(0.18)	(0.00)	(0.18)	(0.18)
Positive precipitation shock	0.05	0.06	0.04	0.06
	(0.23)	(0.23)	(0.21)	(0.24)
Average female education	3.44	3.66	3.38	3.47
	(0.91)	(1.20)	(1.07)	(0.67)
Average female BMI	21.42	20.9	20.96	21.91
	(1.88)	(2.34)	(2.06)	(1.46)
Rural	0.71	0.54	0.58	0.84
	(0.46)	(0.50)	(0.49)	(0.36)
Average male out migration	0.37	0.59	0.48	0.24
	(0.38)	(0.41)	(0.39)	(0.31)
Violence Index	0.05	0.05	0.06	0.04
	(0.11)	(0.04)	(0.15)	(0.04)
Birthrate: sample births per 1000	1.05	3.54	0.76	0.18

Table 1 reports summary statistics for our full sample, as well as for each of the Chadian main three ecological zones. On average, we observe less than one sample birth per 1000 in each cluster-month-year. The striking exception to this is the Sahara region, which experiences an average of 20.14 sample births per 1000 per month in each cluster over the sample period. Most of our sample (71%) is rural and this is intensified as most of our households reside in the more agricultural Soudan where over 80% of the sample is rural.

Clusters were much more likely to experience a positive growing season temperature or precipitation shock than a negative one, with approximately 7% and 5% of our cluster-month-year observations experiencing a positive growing season temperature and precipitation shock, respectively. Only 3% of these observations experienced a negative growing season precipitation shock. The proportion experiencing a negative growing season temperature shock is negligible. In fact, since 1994 none of our sample cluster-month-year observations experienced a negative temperature shock. This highlights the extreme rise in temperature the country has experienced in recent decades.

Cluster-level average female education is low at approximately 3.5 years indicating that the women in our sample likely left school at a young age on average, However, average female BMI is relatively healthy at around 22.[2] That said, we also see greater variation in average female BMI in Saharan and Sahelian clusters indicating pockets of deprivation in these zones. Sample households in the Sahara report much higher levels of male out migration than the other two zones. Cluster averages of the proportion of households reporting male out migration is 59% in the Sahara, 48% in the Sahel, and only 24% in the Soudan.

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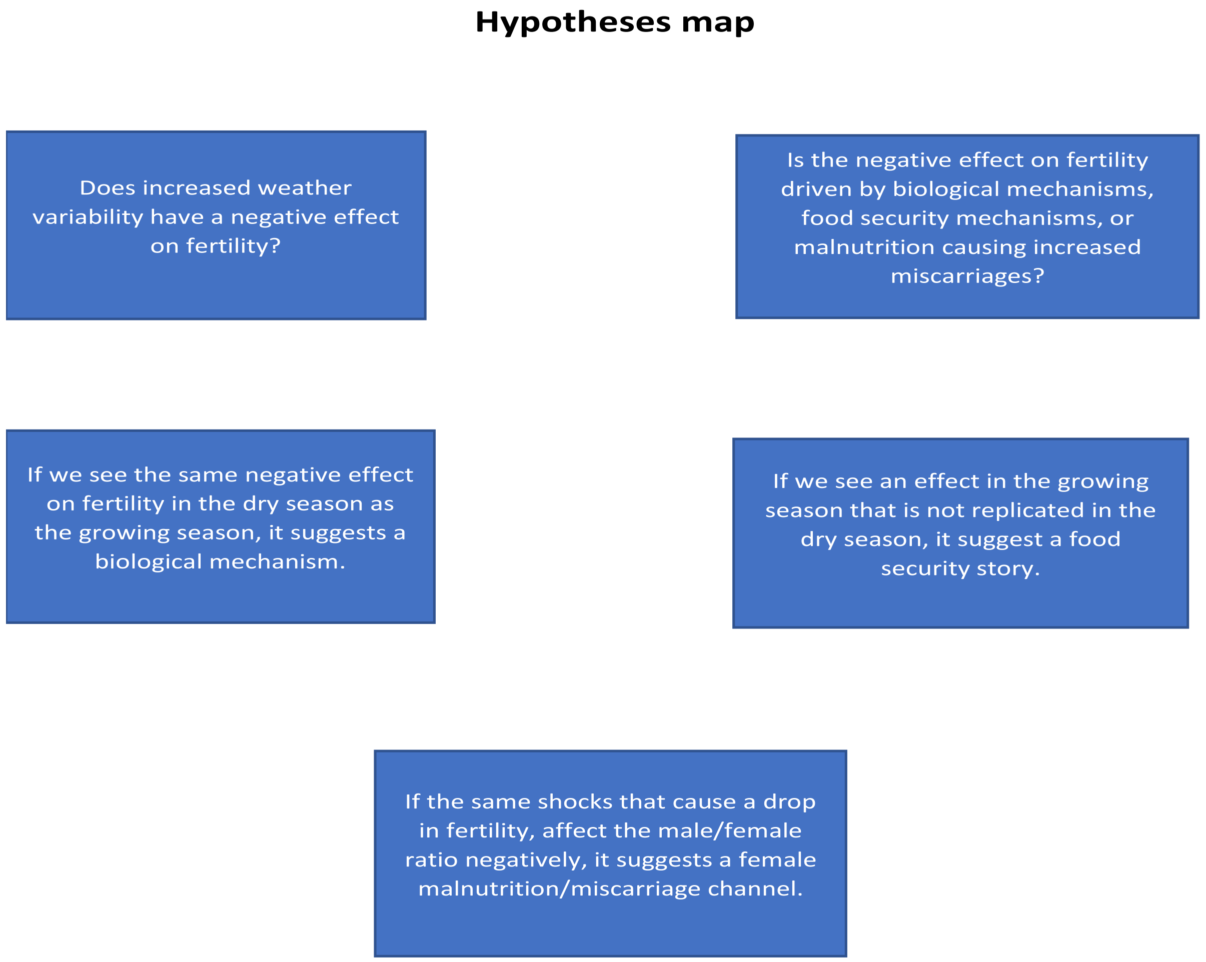
[2] An individual is considered underweight if BMI is less than 18.5 and overweight if BMI is more than 24.

4. Empirical Strategy

Table 2. Hypotheses Map



Hypotheses map

Does increased weather variability have a negative effect on fertility?

Is the negative effect on fertility driven by biological mechanisms, food security mechanisms, or malnutrition causing increased miscarriages?

If we see the same negative effect on fertility in the dry season as the growing season, it suggests a biological mechanism.

If we see an effect in the growing season that is not replicated in the dry season, it suggest a food security story.

If the same shocks that cause a drop in fertility, affect the male/female ratio negatively, it suggests a female malnutrition/miscarriage channel.

To test these hypotheses, we develop four empirical models that utilize similar right hand side variables. One model with the natural log of the birth rate as the dependent variable, and the second with the male/female ratio as the dependent variable. We run these two models in the growing season and the dry season.

In the following analysis we examine the effect of growing season temperature and precipitation shocks on cluster-level birthrates. In doing so, we distinguish between positive and negative shocks as they might hold different implications for fertility. We model the natural log of sample births per 1000 in cluster i, month m, and year y as follows:

$$lnbirthrate_{imy} = \beta_0 + \beta_1 Pneg_{imy} + \beta_2 Ppos_{imy} + \beta_3 Tpos_{imy} + \beta_4 X_i + z_i + m_m + y_y + \epsilon_{imy} \qquad (1)$$

Where $Pneg_{imy}$ and $Ppos_{imy}$ are equal to one if cluster i in month m and year y experienced a negative and positive precipitation shock, respectively, in the most recent growing season and zero otherwise. The primary growing season in Chad occurs during the months of June, July, and August. Similarly, $Tpos_{imy}$ equals one if cluster i in month m and year y experienced a positive temperature shock in the most recent growing season and zero otherwise. We exclude negative growing season temperature shocks because none were experienced in our sample clusters during our sample period. X_i is a matrix of cluster-level controls and includes a rural indicator, average female education, average female BMI, average wealth strata, proportion of reported male out migration, and the violence index. z_i, m_m, and y_y are vectors of climate zone, month, and year fixed effects, respectively. We also include a vector of zone fixed effects to control for systematic differences across zones.

After establishing a relationship between our weather shocks and cluster-level sample birthrates we then turn to exploring the mechanisms that may underlie this relationship. We first check to see if the relationship is due to the variation in fetal miscarriages due to weather shocks. Evidence points to a physiological process by which pregnant women are more likely to miscarry male fetuses than female (Catalano 2003; Byrne et al, 1987). While we do not observe miscarriage rates, we do know the sex of each birth. If climate shocks result in increased rates of miscarriage, then we would expect this to affect the ratio of males to females being born. To explore this possibility, we estimate equation (1) with percentage male as the dependent variable.

$$\text{percmale}_{imy} = \beta_0 + \beta_1 P\text{neg}_{imy} + \beta_2 P\text{pos}_{imy} + \beta_3 T\text{pos}_{imy} + \beta_4 X_i + z_i + m_m + y_y + \epsilon_{imy} \qquad (2)$$

Where percmale_{imy} is the number of male births divided by to total births in *i,* month m, and year y. If we find that temperature and precipitation shocks affect the percentage of males, then this is at least suggestive that these shocks may be operating through a biological process. However, we would not know if that is due to shocks affecting spermatogenesis and ovulatory function or through affecting food security and in turn the nutritional status of women during pregnancy. One way to distinguish between these two mechanisms at least partly is to examine if temperature and precipitation shocks exert a similar effect on fertility and sex ratios if they are experienced during the dry season. We therefore model birth rate and sex ratio as a function of temperature and precipitation shocks experienced in the most recent dry seasons as follows:

$$lnbirthrateimy = \beta 0 + \beta 1 P\text{neg}dryimy + \beta 2 P\text{pos}dryimy + \beta 3 T\text{pos}dryimy + \beta 4 Xi + zi + mm + yy + \epsilon imy \qquad (3)$$

$$sexratio = \beta 0 + \beta 1 \text{Pneg}dry\text{imy} + \beta 2 \text{Ppos}dryimy + \beta 3 T\text{pos}dryimy + \beta 4 Xi + zi + mm + yy + \epsilon imy \qquad (4)$$

Where $Pdryimyneg$ and $\text{Ppos}dryimy$ are equal to one if a negative or positive precipitation shock was experienced in cluster *i,* month m, and year *y, in* the most recent dry season and $T\text{pos}dryimy$ is equal to one if a positive temperature shock as experienced in the most recent dry season. Chad's dry season occurs during the months of December, January, and February. All other right-hand-side variables are the same as in equation (1).

If weather shocks exert a similar effect on fertility and sex ratio during the dry season as they do during the growing season, then it is likely that the relationship is due to the direct biological effect of weather on fertility and reproduction. However, if we find that the weather shocks do not exert an effect during the dry season, then it is likely that they are operating through the mechanisms of food security and socioeconomic factors.

Finally, we further explore how these weather shocks may be operating on fertility by estimating equations (1)—(4) for each climate zone separately: the Sahara (desert) zone, the Sahel (semi-arid) zone, and the Soudan (greener) zone. This will not only help us to better understand the mechanisms driving our results but also allow us to extrapolate what these findings might mean for other regions across the continent with similar climates.

5. Results

Table 3 reports the estimated effect of growing season weather shocks on cluster-level sample birth rates. Specifically, we estimate the effect of a positive temperature shock or a positive or negative precipitation shock as there were no negative temperature shocks experiences over our sample area and period. Column 1 of Table 2 reports results from simply regressing the log birth rate on the three shock variables as well as zone, month, and year fixed effects. Columns 2 and 3 iteratively add cluster-level controls. Experiencing any of the three specified weather shocks reduces the log of our sample birth rate by 0.29 to 0.51. Thus, in the face of a shock, households appear to be having less children. However, it is unclear if this is the result of households choosing to reduce fertility or households experiencing increased miscarriages due to these shocks.

Table 3. Effect of growing season temperature and precipitation shocks on sample birth rate

	ln(Birth Rate)	ln(Birth Rate)	ln(Birth Rate)
	(1)	(2)	(3)
Positive temperature shock	-0.5084***	-0.3096***	-0.2947***
	(0.047)	(0.040)	(0.040)
Negative precipitation shock	-0.5020***	-0.1225***	-0.1262***
	(0.052)	(0.045)	(0.044)
Positive precipitation shock	-0.3699***	-0.1231***	-0.1630***
	(0.05)	(0.04)	(0.04)
Cluster average wealth strata		-0.7886***	-0.7238***
		(0.010)	(0.010)
Cluster average female education		-0.1205***	-0.1028***
		(0.008)	(0.008)
Rural		-0.4988***	-0.6152***
		(0.024)	(0.024)
lnviolindex			-0.0734***
			(0.016)
Average female BMI			-0.1166***
			(0.005)
Proportion of male out migration			0.0761***
			(0.020)
Sahel Ecological Zone	-3.0673***	-3.1028***	-3.0642***
	(0.036)	(0.031)	(0.031)
Soudan Ecological Zone	-3.4496***	-3.9314***	-3.7099***
	(0.036)	(0.031)	(0.032)
Constant	0.5706***	4.0262***	5.8878***
	(0.072)	(0.079)	(0.141)
Birth Year Fixed Effects	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	27,494	27,494	27,494
R-squared	0.269	0.467	0.48

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

To explore whether the relationship between weather shocks and birth rate reported in Table 3 is the result of increased miscarriages, we then regress the month- and year-specific male-to-female sample sex ratio for each cluster on our growing season climate shocks. Evidence indicates that male fetuses are more likely to miscarry than female. Therefore, if the findings of Table 2 are due to increased miscarriages, then we should see this reflected in a reduced sex ratio. These findings are reported in Table 4.

Table 4. Effect of growing season temperature and precipitation shocks on male to female sex ratio

	Sex Ratio	Sex Ratio	Sex Ratio
	(1)	(2)	(3)
Positive temperature shock	-0.0606**	-0.0612**	-0.0602**
	(0.03)	(0.03)	(0.03)
Negative precipitation shock	0.0266	0.0272	0.0279
	(0.03)	(0.03)	(0.03)
Positive precipitation shock	-0.0123	-0.0134	-0.0113
	(0.03)	(0.03)	(0.03)
Cluster average wealth strata		0.01	0.0077
		(0.01)	(0.01)
Cluster average female education		-0.0082	-0.0086
		(0.01)	(0.01)
Rural		0.0359**	0.0403**
		(0.02)	(0.02)
lnviolindex			0.0067
			(0.01)
Average female BMI			0.0041
			(0.00)
Average male out migration			0.0037
			(0.01)
Sahel Ecological Zone	-0.0379*	-0.0414**	-0.0429**
	(0.02)	(0.02)	(0.02)
Soudan Ecological Zone	-0.0362*	-0.0411*	-0.0464**
	(0.02)	(0.02)	(0.02)
Constant	1.3947***	1.3710***	1.3191***
	(0.04)	(0.06)	(0.10)
Birth Year Fixed Effects	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	27,494	27,494	27,494
R-squared	0.003	0.003	0.003

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

According to the results reported in Table 4, neither positive nor negative precipitation shocks statistically significantly affect the percentage of males. However, experiencing a positive temperature shock in the most recent growing season reduces the percentage male by approximately 0.06. This is indicative that positive temperature shocks may increase the number of miscarriages in our sample. This suggests that at least part of the influence of weather shocks on fertility operates through a biological effect. This is consistent with evidence pointing to extreme heat as an increased risk factor for miscarriage (Catalino 2003; Byrne et al, 1987).

To further explore what may be driving these findings, we exploit climate differences across Chad's three distinct ecological zones: the Sahara, the Sahel, and the Soudan. Tables 5 and 6 report the effect of growing season temperature and precipitation shocks on the sample birth rate and sex ratio of each of these three zones, respectively.

Table 5. Effect of growing season temperature and precipitation shocks on sample birth rate across ecological zones

	Sahara	Sahel	Soudan
	(1)	(2)	(3)
Positive temperature shock	-0.4685	-0.3791***	-0.0117
	(0.316)	(0.056)	(0.062)
Negative precipitation shock	-	-0.1856***	0.1464***
	-	(0.068)	(0.045)
Positive precipitation shock	0.2985	-0.2160***	-0.0157
	(0.259)	(0.065)	(0.038)
Cluster average wealth strata	-1.1255***	-0.9166***	-0.7224***
	(0.058)	(0.014)	(0.015)
Cluster average female education	0.2885***	-0.1056***	-0.1521***
	(0.043)	(0.011)	(0.013)
Rural	1.3886***	-0.6801***	-1.5947***
	(0.100)	(0.033)	(0.036)
lnviolindex	-1.0349***	-0.1351***	0.1288**
	(0.244)	(0.021)	(0.053)
Average female BMI	0.0192	-0.1320***	-0.0940***
	(0.024)	(0.007)	(0.006)
Average male out migration	-0.8177***	0.2242***	-0.0522**
	(0.120)	(0.028)	(0.025)
Constant	-3.1905**	3.4850***	3.6178***
	(1.543)	(0.199)	(0.260)
Birth Year Fixed Effects	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	1,779	12,377	13,338
R-squared	0.297	0.463	0.247

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

What is immediately striking in Table 5 is that much of our reported effect of weather shocks on the sample birth rate is driven by clusters found in the Sahel. The measured weather shocks exert a robust and highly significant negative effect on cluster sample birth rates in the Sahel.

Additionally, looking at the R-squared, the Sahelian model explains 55% and almost 90% more of sample birth rate variation than it does for the Sahara and Soudan, respectively. The increased unpredictability of weather in this region-in addition to reliance on rainfed agriculture-likely results in a more marked sensitivity to weather variability. Table 6 reports the effect of weather shocks on zone-specific male-to-female sex ratios. The Sahel is also the only region where percentage male is sensitive to weather shocks. Consistently, a positive temperature shock reduces the percentage male, suggesting an increase in miscarriage rates. A negative precipitation shock, on the other hand, increases the percentage male suggesting a reduction in miscarriages. It is possible that a negative rainfall shock is associated with reduced flooding and an improved disease environment. However, we must be cautious in this interpretation as we cannot test for it.

Table 6. Effect of growing season temperature and precipitation shocks on male to female sex ratio across ecological zones

	Sahara	Sahel	Soudan
	(1)	(2)	(3)
Positive temperature shock	0.1181	-0.0930**	-0.0587
	(0.134)	(0.039)	(0.059)
Negative precipitation shock		0.0840*	-0.0153
		(0.047)	(0.043)
Positive precipitation shock	0.0057	-0.009	-0.0294
	(0.110)	(0.045)	(0.036)
(mean) wealthstrata	0.0428*	0.0026	0.007
	(0.024)	(0.009)	(0.014)
Average female education	-0.0288	-0.0122*	0.0107
	(0.018)	(0.007)	(0.012)
Rural	0.0309	0.0189	0.0593*
	(0.042)	(0.023)	(0.034)
lnviolindex	-0.0101	-0.0002	-0.0226
	(0.104)	(0.014)	(0.051)
Average female BMI	0.0001	0.0036	0.0033
	(0.010)	(0.005)	(0.006)
Average male out migration	0.0332	0.0198	-0.0165
	(0.051)	(0.019)	(0.024)
Constant	1.0551	1.2768***	1.1221***
	(0.653)	(0.138)	(0.246)
Birth Year Fixed Effecs	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	1,779	12,377	13,338
R-squared	0.027	0.005	0.004

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

In Tables 5 and 6, we see no statistically significant effect of positive temperature or precipitation shocks on the birth rate or percentage male in the desert region of the Sahara. The Sahara did not experience a negative precipitation shock during the sample period. Similarly, the weather shocks do not statistically, significantly affect the percentage male in the Soudan. Interestingly, a negative growing season precipitation shock in the Soudan exerts a statistically significant positive effect on cluster sample birth rates. The Soudan is a greener, agriculturally rich environment and is more prone to flooding than other areas of Chad. Therefore, a negative growing season precipitation shock may affect agricultural labor and/or output and in this way affect fertility decisions. Yet, again, we cannot test for this explanation, so we must be cautious.

Having established that the growing season weather shocks have a significant negative effect on fertility—an effect that appears to be particularly salient in the Sahel region of Chad, we are now interested in the extent that this effect is the result of weahter's effect on reproductive function versus food security/socio-economic well-being. We, therefore, regress sample birth rates and sex ratio on dry season climate shocks rather than growing season climate shocks. We do not have enough dry season variation in precipitation shock and therefore focus only on dry season temperature shocks. If the effect of weather on fertility and sex ratio is due to its direct effect on reproductive function, then we should expect to see similar effects in the dry season as we do in the growing season. If it is primarily due to an effect on food security, we would not expect to observe the same effects in the dry season.

Table 7. Effect of dry season temperature shocks on sample birth rate across ecological zones

	Sahara	Sahel	Soudan
	(1)	(2)	(3)
Positive Dry Season Temperature Shock	0.1818	0.0884	-0.069
	(0.224)	(0.056)	(0.051)
Negative Dry Season Temperature Shock	-1.6708	-0.3807***	0.2744***
	(1.383)	(0.126)	(0.073)
Cluster average wealth strata	-1.1316***	-0.9251***	-0.7178***
	(0.058)	(0.014)	(0.015)
Cluster average female education	0.2942***	-0.1033***	-0.1501***
	(0.043)	(0.011)	(0.013)
Rural	1.3682***	-0.6844***	-1.5833***
	(0.099)	(0.033)	(0.036)
lnviolindex	-1.1104***	-0.0821***	0.1191**
	(0.239)	(0.020)	(0.051)
Average female BMI	0.0187	-0.1360***	-0.0944***
	(0.024)	(0.007)	(0.006)
Average male out migration	-0.8121***	0.2268***	-0.0526**
	(0.121)	(0.028)	(0.025)
Constant	-3.6034**	3.7898***	3.5572***
	(1.519)	(0.196)	(0.252)
Birth Year Fixed Effecs	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	1,779	12,377	13,338
R-squared	0.297	0.461	0.246

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Tables 7 and 8 report the effect of dry season temperature shocks on sample birth rates and sex ratio, respectively, for each of the individual ecological zones. Temperature shocks in the Sahara do not exert a statistically significant effect on the birth rate. Negative dry season temperature shocks reduce sample birth rates in the Sahel but increases them in the Soudan. However, these effects are likely due to behavioral responses as the dry season temperature shock do not exert a statistically significant effect on the sex ratio in any of the regions. There are opposite effects on the sample birth rates of the Sahel and Soudan. The estimated weather shock effects for the dry season appear to substantively differ from those for the growing season. This indicates the robust negative effects of growing season temperature and precipitation shocks on fertility in the Sahel is likely in part due to their effect on food security and/or socio-economic factors.

Table 8. Effect of dry season temperature shocks on male to female sex ratio across ecological zones

	Sahara	Sahel	Soudan
	(1)	(2)	(3)
Positive Dry Season Temperature Shock	-0.1496	-0.0419	-0.0447
	(0.095)	(0.038)	(0.049)
Negative Dry Season Temperature Shock	0.5488	0.1205	-0.0266
	(0.585)	(0.087)	(0.069)
Cluster average wealth strata	0.0472*	0.0014	0.0046
	(0.024)	(0.009)	(0.014)
Cluster average female education	-0.0287	-0.0113	0.0091
	(0.018)	(0.007)	(0.012)
Rural	0.0358	0.018	0.0544
	(0.042)	(0.023)	(0.034)
lnviolindex	-0.0212	0.007	-0.0011
	(0.101)	(0.014)	(0.049)
Average female BMI	-0.0013	0.003	0.0039
	(0.010)	(0.005)	(0.006)
Average male out migration	0.0206	0.019	-0.0197
	(0.051)	(0.019)	(0.024)
Constant	1.0103	1.3242***	1.2121***
	(0.643)	(0.135)	(0.239)
Birth Year Fixed Effecs	Y	Y	Y
Birth Month Fixed Effects	Y	Y	Y
Observations	1,779	12,377	13,338
R-squared	0.029	0.004	0.004

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

To return to our hypotheses map. Our weather shocks have a generally negative significant effect on the fertility rate in the Chadian growing season that is not replicated in the dry season. Furthermore, the positive temperature shocks have a negative effect on the male/female ratio that confirms that the significant negative effect is being driven by some sort of food security channel. Clearly, female miscarriages are a biological channel, but in this case, we think it is driven by increased female malnutrition.

6. Conclusion

In this paper we examine the effect of precipitation and temperature shocks on fertility in Chad. We find a significant negative effect of these shocks on cluster-level birth rates. This effect is particularly salient in the semi-arid Sahel region and appears to be partially explained by the effect of weather variability on food security and reproductive health.

Much of the literature shows that fertility responds to weather disasters by way of a significant rise. However, this assumes a level of mortality related to the weather disaster which fits in with the ‘children as an insurance mechanism’ hypothesis for the response to mortality shocks in the developing world. This negative response to the extreme weather variability caused by climate change is a new strand in attempting to understand the non-mortality related effects of climate change on fertility.

This proposed negative effect on fertility through climate change would cause there to be a reevaluation of mid-21st century demographic projections in areas of the developing world that are significantly affected by climate change. The population of Chad in 2017 is 14, 900, 000 and is projected to rise to 33, 636, 000 by 2050 (UN WPP

2017). These projections assume a population growth rate of 3.04% or a total fertility rate of 6.3 children per women (UN estimate) or 6.4 (DHS 2014-15 estimate).

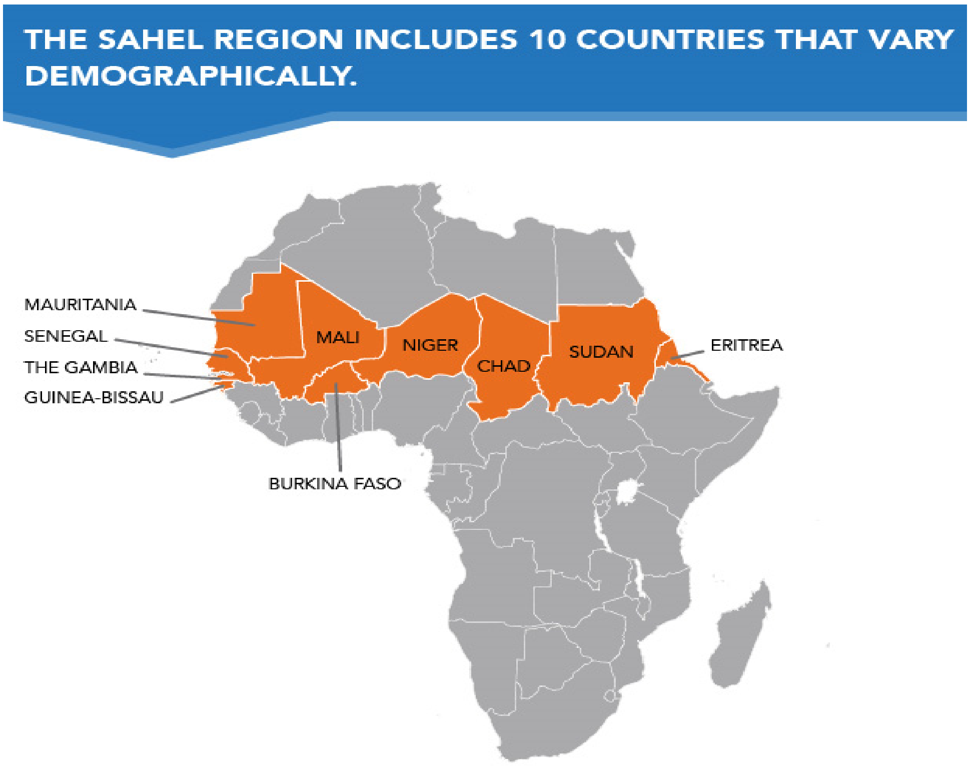


Figure 2. The African Sahel Region: Population Reference Bureau

The population of the G5 of Sahelian nations (Burkina Faso, Mali, Mauritania, Chad, and Niger) is projected to double between 2020 and 2040, a rise from a population of eighty million to one hundred and sixty million people (Pradelle 2019). This assumption of the future growth rate does not consider the effects of climate change in the Sahel region of Africa, but more particularly in the Sahelian regions of each of these countries.

We are not able to extrapolate from our results to the projected drop-in total fertility rate as that would need demographic expertise that is beyond the scope of this paper. However, the fact that the extreme weather shocks created by advancing climate change lead to decreases in fertility, suggests that any assumptions about the Chadian population growth rate must consider this 'climate effect'. We must assume that this 'climate effect' will intensify with the increasing trajectory of Chadian and wider Sahelian climate change.

Finally, though some may see the revision of Sahelian demographic predictions as a good thing, the harsh mechanisms by which this may happen are a categorically negative. This suggests that the Sahel requires greater input in its struggle to adapt to the effects of a global climate change that it did little to create.

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