Chad: Human Fertility, Crop Production and Changing Weather Patterns

Jake Organ
Colorado College

This paper investigates the effect of changing weather patterns on human fertility in Chad. There is literature on the effect of mortality inducing extreme weather events and fertility. However, there is less literature on the effects of less extreme changing weather patterns on fertility. We adapt Becker's model of demand for children to a rural Chadian context and test the model with Chadian data and explore whether any effect is through biological or agricultural mechanisms. Using GIS-coded fertility and weather data, we look for correlations between the birth rate and the number of monthly high temperature days, while partitioning data by climatic zone and staple crop intensity. Running the same models with sorghum yield as the dependent variable, we find a pattern that the same planting season high temperature days that have a negative effect on the birth rate, also have a negative effect on sorghum yields, especially in the Sahel region. This accords with our model and provides tentative evidence of an agricultural mechanism by which heat affects fertility.

Keywords: climate change, the Sahel, Chad, fertility, GIS

INTRODUCTION AND CHAD BACKGROUND

Chad is at the forefront of global climate change, because of the mixture of Saharan, Sahelian, and Soudanian savanna climate zones that dominate the country, as well as its position in the center of landlocked Africa. It also has one of the fastest growing populations globally-9th in world in 2020, with a population growth rate of 3.12%. Many observers analyze the environmental damage, and infrastructure overload caused by the effects of climate change and population growth stemming from what they perceive as the multiplicative relationship between the two phenomena. However, it is not clear from the literature that there is any such multiplicative relationship between these two effects, and though there is a positive effect on human fertility caused by climate related disaster, the effect of rising temperature on human fertility is less clear.

Out interest in Chad comes from our desire to study the effects of the drastic rise in temperature on other variables in the context of the climate-sensitive African Sahel region. Chad has seen significant temperature rise since the late 1960s and Chad is a very under-researched country, which is a shame as it is at the forefront of the effects of global temperature rise. Chad is also interesting, in that it stretches across three of Africa's distinct climatic zones: the Saharan zone, the Sahelian zone, and the Soudanese (savanna) zone.

This paper (adapted from my PhD dissertation) came from a desire to look at the links between population growth and climate change in Sahelian Africa, due to seeing the deadly effects of the attempts of people from the Sahel to reach Southern Spain. We wanted to challenge the simple Malthusian understanding of the ‘Sahel crisis’. We eventually settled on looking at the micro relationship between rising heat and human fertility and adapted Becker’s model (Becker 1991) of demand for children to fit with a rural, Chadian context. The results showed that the Sahel climatic area of Chad demonstrates Becker’s (Becker 1991) hypothesis of ‘children as normal goods’. However, this result is only robust to Chadian Sahel-or Sahel-dominated-models.

Chad is a landlocked country bordered by Sudan, Central African Republic, Cameroon, Nigeria, Niger and Libya. Chad had a history of war and a legacy of slavery before the arrival of the French, a violent and exploitative colonial period, and an unstable and conflict-ridden post-independence history. It stands in the center of two of Africa’s traditional fault lines; the Islamic/non-Islamic and the Arab/non-Arab. These factors have led to a battle to develop a stable and sustainable state and society, leading to Chad being in the top ten of the Fragile States Index since 2005 (FFP 2019). In addition to this, its position at the center of the African continent and large Sahelian area make it vulnerable to some of the extreme effects of global climate change (Abidoye & Odusola 2015). Chad has suffered from the extreme effects of climate change since the 1960s. Due to its Central African position, and hence the ‘Continental effect’[1] exacerbating the normal pace of African climate change. Chad has warmed by 2.64 degrees Celsius since the late 1960’s (Abidoye & Odusola, 2015).

RELATED LITERATURE

There is a large strand in the literature that looks at the responses to large-scale mortality caused by extreme weather events. These studies demonstrate that households may increase their fertility as a response to the increases in risk and mortality caused by extreme weather episodes (Lackzo, Aghazarm 2009; Gemenne 2011; Das Gupta 2014; Salas 2017). Much of this literature focuses primarily on major environmental and/or weather events and the associated rise in child mortality (Owoo, Agyei Mensah & Onusha 2015; J. Davis 2017; Brauner-Otto & Axina 2017; Alam & Portner 2018). This response can be exacerbated in countries where a large amount of people survive through subsistence agriculture and children are an additional source of agricultural labor (Cain 1981). Increasing fertility may also be an insurance mechanism, where in the face of changing weather patterns parents may decide to have more children to provide for an uncertain future (Cain 1981; Rozensweig & Schultz 1983). All these studies suggest that extreme weather events cause a rise in fertility; however, this could be a response to the child mortality caused by the extreme weather event, rather than the change in weather patterns itself.

Changes in weather patterns can affect household fertility decisions both through biological and socio-economic channels. Rising temperature can biologically affect human fertility through a direct effect on reproductive capacity. Though the mechanism by which this happens is not clear, evidence demonstrates that extreme heat reduces human fertility (Richards 1983; Becker, Chowdhury, Leridon 1986; Lam, Miron 1996; Nilsson 2016). However, while this effect of heat has been observed in the United States and numerous developing countries, researchers have been largely unable to replicate it in Europe (Pasaminick, Dinitz, Knobloch 1966; Chaudhury 1977; Warren, Tyler 1979; Richards 1983; Kestenbaum 1987). Therefore, while heat has a negative effect on human fertility, the biological processes that cause this are still a source of debate.

In regions dependent on rainfed agriculture, changing weather patterns can affect crop yields and hence cause economic and food security shocks that the household needs to respond to. These responses can be another indirect route, by which changing weather can affect human fertility. Much has been written on the effect of scarcity on fertility, as scarcity changes the parameters of the child quality/quantity trade-off (Becker & Lewis 1973; de Sherbinin et al. 2008; Alam & Portner 2018). Changing weather patterns can result in a tightening of resource constraints that then may cause reduced or delayed fertility (Eloundou-Enyegue, Stokes & Cornwell 2000; Mckenzie 2003; Mckelvey, Thomas & Frankenberg 2012). Changing weather patterns and resulting agricultural instability may also affect expectations on future returns to child labor in agricultural households.

The majority of Chad is situated in the Sahelian[2] climate zone. This semi-arid region separates the Sahara Desert from the greener Soudanese Africa to the south. Chad’s Sahel zone has an average rainfall of 600 millimeters, though this varies across the zone. The Sahelian rainy season is from June to early September and the dry season is from October to May (Pattyanak et al 2019). The south of Chad is more fertile, it is classed as Tropical Savannah (Koppen 2011). It has more rainfall than Chad's Sahelian zone, with yearly rainfall of over 900mm. This allows it to be the center of Chadian agriculture with a long history of cash crop growth, particularly cotton (Collier 1990).

The effect of climate change on Chad takes place within the wider context of African and especially Sahelian[3] climate change. Chad is the largest country in the Western and Central Sahel, and the West African Monsoon, moisture carried from the Mediterranean zone and its interaction with the Intertropical Convergence Zone influences its climate (Maharana et al 2017). Due to its situation at the center of the African continent, it is subject to a higher rate of warming because of the continental effect (Winnick et al 2014).

This paper looks at the effects of changing weather patterns on fertility, and we assume that changing weather mean rising temperatures in the Chadian context. In Chad, the pattern of temperature rise is clear over the different regions. All the cities studied by Pattyanak et al. (2019) have seen significant rises in temperature by decade since 1950. These warming trends have intensified since 1980-85 (Maharana et al., 2018; Pattyanak et al., 2019). This warming has been generally more intense in the Sahel region, and more focused in Eastern Chad (Maharana et al., 2018). Indeed, Abeche (on the Eastern border with Sudan) has seen a rise of 0.42 degrees Celsius per decade, which is double the other Sahelian cities of Ati and Mongo (Pattyanak et al., 2019).

RESEARCH QUESTIONS

This paper's primary question: "What is the relationship between changing weather patterns and human fertility in the Chadian context?" In the Chadian context, changing weather patterns can be proxied by rising heat and I proxy rising heat by the marginal effect of an extra high heat day in a month.

Our second research question: "Is the main effect of an extra high heat day on the birth rate caused by changes in crop yield and related changes in food security/insecurity?" This question looks at the route by which changing weather patterns affect human fertility and questions whether changing weather patterns affect crop yields and hence household fertility, due to economic/food security routes.

CONCEPTUAL MODEL: BECKER AND DEMAND FOR CHILDREN

We model the demand for children, consistent with Becker and extend the model to consider the impact of weather (in this case, rising heat) on a rural, Chadian community (Becker 1991). We assume that number of children (N) and consumption of other household goods (G) are choice variables. We also assume that individual health $(\bar{H})$ is a factor in household utility, and I assume that is affected by changing weather patterns (C). Household utility is modeled as a function of the number of children N, and consumption of other goods, G, where $\partial U/\partial N$, and $\partial U/\partial G > 0$, as household members receive utility from having children and consumption of goods. There is also health $(\bar{H})$, where $\partial U/\partial \bar{H} > 0$, as increased household health increases utility. Note that household health $(\bar{H})$ is a non-choice variable, as this is a static model we treat health as an exogenous stock variable, so although an individual cannot change their current realization of health stock, they derive utility from it.

$$UN,G = U(N, G; \bar{H}(C)) \tag{1}$$

We assume a negative relationship between changing weather patterns (C) and individual health $(\bar{H})$. We assume that it would have a negative effect on health because Chad has an arid climate, and any rise in heat would increase water constraints and have a negative effect on the disease environment (Ward et al, 1999). Therefore $\partial H/\partial C < 0$.

The utility function is subject to an income constraint, which we have reduced to isolate those factors influenced by changing weather patterns (C). We assume the household income (I) is negatively constrained by expenditure on number of children (N), and the consumption of other household goods. Income is positively affected by crop yield (Y). Thus $\partial I/\partial Y > 0$ as a rise in crop yield would raise household income.

Both household health (H) and household crop yield (Y) are influenced by changing weather patterns (C). The sign of $\partial Y/\partial C$[4] is ambiguous, it depends on the area of Chad we are looking at and the original mean temperature of that area.

$$I(Y(C)) = P^N N + P^G G \tag{2}$$

This constrained optimization problem yields the Marshallian demand for number of children (N) and other goods (N). Specifically:

$$N = f(P^N, P^G, H(C), I, Y(C))) \tag{3}$$

$$G = g(P^N, P^G, H(C), I(\, Y(C))) \tag{4}$$

Moving towards our empirical estimation of fertility rate, total differentiation of (5) yields:

$$dN = f_{pN} dp_N + f_{pG} dp_G + f_H \, H_C dC + f_I I_Y \, Y_C dC \tag{5}$$

Equation (5) shows that the change in the number of children (dN), is a function of: the changes in the cost of an additional child and other goods ($f_{pN} dp_N + f_{pG} dp_G$); the household health function's interaction with the effect of rising heat on health, times the change in weather patterns ($f_H \, H_C dC$); t; and the household income function's interaction with the effect of yield on income, times the effect of rising heat on yield, times the change in weather patterns ($f_I I_Y \, Y_C dC$).

Holding prices constant yields:

$$dN = f_H \, H_C dC + f_I I_Y \, Y_C dC \tag{6}$$

This shows that there are two routes where change in weather patterns (dC), can affect change in number of births (dN).

TESTABLE HYPOTHESES (HOW DO THESE CORRESPOND WITH THE QUESTIONS?)

$$f_H \, H_C dC < 0$$

This is the direct effect of rising heat on the number of children, through the pure health route and in the Chadian context we hypothesize that this would be negative. If dry/preparation season high heat days have a significant negative correlation with the birth rate, especially in the same year, then we can assume that this is the pure health effect. Moreover, if this is a pure health effect, we can assume that it happens in the high staple crop regions, as well as the lower staplecrop regions. We can also assume that this effect would be clearer in the already high temperature, arid Sahel area, than in the more humid Soudan.

$$f_I I_Y \, Y_C dC < 0 \text{ if } Y_C \; is < 0 \text{ and } > 0 \text{ if } Y_C \; is > 0$$

This route-with its ambiguity with respect to the effect of rising heat on yield-is a simple test of Beckerian theory. If the models reveal that the effect of rising heat on yield is positive, and at the same time heat shocks in the planting or harvest season have a significant positive effect on the birth rate, this would be a confirmation that households treat additional children as normal goods (Becker 1991). Furthermore, if the effect of rising heat on yield is negative, and at the same time heat shocks in the planting or harvest season have a significant negative effect on the birth rate, this would further confirm our simple Beckerian model. This pattern should be clearer in the high intensity staple crop areas, as their household decisions would be more closely tied with staple crop yield. Becker modelled demand for children and assumed that children were normal goods, hence when household income goes up, the desire to have children goes up (Becker 1981). By extension, if children are normal goods, then as income (in this case proxied by millet and sorghum yield) goes down, then the household will want to have less children.

DATA

To test the relationship between weather and the human birth rate, we create a dataset that can map changing weather patterns to changes in fertility response and agricultural production. To construct this dataset, we use four sources of data. These are: fertility data and covariates from the 2014-15 Demographic and Health Survey (DHS) collected by the United States Agency for International Development (USAID); daily temperature from the Climate Prediction Center (CPC) at National Oceanic and Atmospheric Administration's (NOAA) National Weather Service; conflict data from the Uppsala Conflict Data Program from the University of Uppsala, Sweden; and agricultural data from the Department of Agricultural Engineering at the University of Lund, Sweden.

Our fertility data and many of our covariates are drawn from the 2014-15 Demographic and Health Survey (DHS) collected by the United Stated Agency for International Development (USAID). The survey sampled 17,719 women between the ages of 15 and 65 from 624 GIS coded clusters that represent the whole of Chad's population[5]. The 2014-15 DHS data includes self-reported reproductive histories for the 17,719 individually sampled women, which we use to calculate the number of sample births by cluster, month and year. This leads to 135,539 clustermonth-year observations. we create a GIS cluster-specific birth panel by linking the selfreported year and month of birth of each sample woman's children to her GIS cluster. We then aggregate these births within each month, year, and GIS cluster to generate the total number of births for each month and year in that GIS cluster, as represented by the sample. We exclude all births that occur before 1997 to account for the fact that older mothers are more likely to have systematically selected out of the cluster-specific sample due to death or migration.

In the first model, our dependent variable is the birth rate. To compare across the entire country where different clusters will have different amounts of fertile women, we standardize the variable by calculating the number of fertile women in each cluster by year. We then create a GIS cluster/month/year specific birth rate variable by dividing the number of births in a particular month of a year in a particular cluster, by number of women capable of giving birth in the sample by that year and GIS cluster:

$$\mathrm{B}Rimt = \frac{Births_{imt}}{Female_{it}}$$

where $Birthsimt$ is the number of sample births recalled for cluster i, in month m, and year t. $Femaleit$ is the number of sample women of childbearing age for each cluster in year t. I define a woman as capable of giving birth if she is between the ages of 15 and 45 in that given year. So, $BRit$ is the cluster-month-year specific sample birth rate. As some clusters are overrepresented in our data, I also weight this birth rate variable by population probability weights. Finally, I take the natural log of this variable to use as our dependent variable in the fertility model.

From the DHS data we also generate cluster-specific characteristics based on the cluster-specific sample mean of that variable. One weakness is that these covariates, and partitioned data by covariate are the 2014-15 values. If they have changed from 1996 until 2015, our models would not pick this up. The covariates that we use are the cluster mean of that covariate in the original data. For example, if a cluster is majority urban it will be coded as an urban cluster, and if less than 50% urban it will be coded as non-urban.

To achieve a deep granularity with the weather data, we use a dataset that contains daily temperature observations-the Climate Prediction Center (CPC) at National Oceanic and Atmospheric Administration's

(NOAA) National Weather Service Maximum daily global temperature data. However, we wanted to create a variable that would allow for correlations between the dependent variable of the natural log of the normalized monthly birth rate by cluster. Therefore, I created variables for the number of days above 31 degrees centigrade by month and mapped them to the GIS clusters of the Chadian DHS data.

With the number of high-temperature days in a month, we can see the effect of the extremes of high temperature that changing weather patterns create. These extremes can affect the birth rate (or sorghum and millet yield) in a significant manner. Both the birthrate and crop yield can be affected by extreme temperature shocks, and hence the extreme temperature shocks can affect the birthrate through direct health channels (Richards 1983; Becker, Chowdhury, Leridon 1986; Lam, Miron 1996; Nielson 2016), as well as indirectly through economic/food security channels (Eloundou-Enyegue, Stokes & Cornwell 2000; Mckenzie 2003; Mckelvey, Thomas & Frankenberg 2012).

To create a seasonal variable based on three different parts of the Chadian agricultural year, we split the monthly high temperature days' data into the dry/preparation season, the planting/growing season and the harvest season. We code the dry/preparation season as January, February and March; the planting/growing season as May, June, July and August and the harvest season as September, October, November and December. We create these variables by taking the mean number of high-temperature days across the months of each season.

Chad has a significant history of internal and external violence since its independence in 1960. This creates noise in the model. To control for this, we create a violence index drawn from the data from the Uppsala Conflict Data Program[6] maintained by the University of Uppsala, Sweden. We create a violence index for each GIS cluster by dividing the number of fatalities in a conflict episode by the distance from the center of the DHS GIS cluster to the location of the conflict episode. We cut this off at 1000 km as we assume that such a distant conflict would have little effect on the relationship between weather and the fertility rate. The climate data, the fertility data, the violence data and the covariates are all linked by GIS location and so the regressions are accounting for fine spatial-level correlations. We then take the natural log of the violence index to use it as a control variable.

The agricultural data come from the department of Agricultural Engineering at the University of Lund (Nilsson & Cintia 2018). It comprises crop area, production per hectare, and crop yield for all the major Chadian crops: sorghum, millet, rice, wheat, maize and recession sorghum. The data is by each one of Chad's twenty-two regions and it is by year from 1983 to 2016. The University of Lund data was collected under a different regional structure to the Chad 2014-15 USAID DHS Survey so in six instances, what was one region in the Lund data became two in the USAID DHS data.[7]

In exploring the relationship between high heat days and millet and sorghum yield-the difference in geographical scale is important to note. The climate data is by GIS location, while the agricultural data is by Chadian region. There are 626 GIS clusters in the DHS data, while there are only 20 Chadian regions in the University of Lund data. This means that the dependent variable lacks the same geographical granularity and temporal granularity, as there is only a single observation of yield across the year. The lack of temporal granularity is understandable because there is only one staple crop harvest a year. However, the lack of yield data at a finer geographical granularity could be a problem. For example, some of the regions-especially with the mapping of an old larger region, to smaller regions-are very large and potentially cross different climatic zones. This would mean that the effect of high temperature days could be having different significant effects on different areas of the larger region that are not picked up because they cancel each other out. Weather patterns can change over a large geographical region, and so any of our regression results will be an amalgamation of different amounts of high temperature days' correlation with the same yield results. This is problematic, and we are clearly losing something of the story, but this seems to be the best data that is available.

Summary Statistics (All Chad)

TABLE 1
SUMMARY STATISTICS (ALL CHAD)

	mean	sd	min	max
Log of birth rate	2.0	0.46	1.2	4.2
Sorghum yield (Kg/Ha)	580.8	447.17	0.0	4888.7
Sorghum area (Ha)	83901.7	70254.27	25.0	436332.0
Millet yield (Kg/Ha)	459.6	246.70	0.0	1092.0
Millet area (Ha)	78793.9	70962.01	2200.0	428420.0
Chad dry > 31	3.2	7.72	0.0	31.0
Chad plant > 31	6.2	10.75	0.0	31.0
Chad harvest > 31	9.0	13.18	0.0	31.0
Urban	0.3	0.44	0.0	1.0
Log of violence index	-3.4	0.96	-5.6	1.8
N	121824			

The high temperature days variables show that there are big differences between the three Chadian seasons. The dry/preparation season has the least high temperature days at each point, followed by the planting season; and the harvest season has the highest number at each point.

EMPIRICAL METHODOLOGY

Recall that we want to estimate equation 6:

$$dN = f_H H_C dC + f_I I_Y Y_C dC \tag{6}$$

Here there are two major ways that changing weather patterns can affect demand for children. Through the identification strategy and the models I run, we want to differentiate between the two major ways that changing weather patterns can affect the birth rate.

Firstly, the first term on the right-hand side in equation 6 represents the direct effect of changing weather patterns on the birth rate. This can be through the direct effects of changing weather patterns on fertility. Due to the trajectory of changing weather patterns in Chad, we use the marginal effect of an extra high heat day as a proxy for changing weather patterns in Chad (Abidoye & Odusola, 2015). Many writers observe the direct health link between rising heat and a drop in human fertility (Boserup 1985; Lam, Miron 1996; Scholte, Van den Berg, Lindeboom 2015). There are many different routes by which this can happen, but for the purpose of this econometric model we assume that there is one generic direct route of rising heat on the birth rate through the health route.

Secondly, there is the route of transmission which is via the effect of rising heat on the birthrate through shocks to household income. This is the effect of rising heat on the birth rate, through the effect of rising heat on yield's effect on income and hence on the birth rate. For example, households may decide to forego/have another child due a negative or positive shock to household income through a negative or positive effect on crop yield (Eloundou-Enyegue, Stokes & Cornwell 2000; Mckenzie 2003; Mckelvey, Thomas & Frankenberg 2012). As we have noted, we are interested in the effect of changing weather patterns on fertility in a Chadian context. we assume that changing weather patterns mean rising heat in

Chad, and thus we allow for days above temperatures of 31 degrees Celsius as a proxy for the effects of rising heat.

ECONOMETRIC MODEL

Based on equation 6 we estimate the following reduced form model where the natural log of the birth rate in cluster *i* and in month *m* and year *t* is a direct function of high heat days as follows:

$$LnBR_{imt} = \alpha_0 + \beta_1 Hightmpdays31_{imst} + \beta 2Xit + \lambda m + \eta r + yt + \varepsilon \qquad (7)$$

where $LnBRimst$ is the natural log of the birth rate, and $Hightmpdays31imst$ is the season's average number of days above 31 degrees Celsius per month, in cluster i[8]. Xit is a matrix of controls that includes an urban[9] indicator and the natural log of the violence index. We also include a vector of regional, $\eta r$and monthly dummies, λi, and year fixed effects, yt, to control for spatial and temporal trends in fertility and temperature.

We use a fixed effects semi-log regression to model the relationship between the birth rate and the number of high temperature days. We use year fixed effects to remove time trends from our right and left-hand side variables. Also, we use regional dummies to control for average differences between the regions that would affect the relationship between the birth rate and the high temperature days.

We run different iterations of model (1) with a mean of high temperature days in the dry/preparation season (January, February and March), the planting season (May, June, July and August) and the harvest season (September, October, November and December). We then run the same iterations on date partitioned by zone (Sahel or Soudan), and whether the region has a higher or lower reliance on staple crops. Finally, we run the model with no lag, one-year lag and a two-year lag to differentiate between shorter-term health driven mechanisms and longer-term food security driven mechanisms.

There are multiple mechanisms through which growing season conditions may affect fertility. Poor growing season temperatures may reduce fertility either due to the direct negative health effects of reduced food security or through household decisions to reduce or delay fertility in the face of negative shocks. On the other hand, favorable growing season conditions may increase fertility through the effects of increased food security and well-being. However, improved conditions could also reduce fertility if it causes household labor to concurrently decrease or if households are facing quantity/quality trade-offs in their fertility decisions (Becker, 1973). To better understand some of these mechanisms, we estimate the effect of average maximum growing season temperature on millet yield, one of Chad's staple food crops.

$$MY_{rt} = \alpha_0 + \beta_1 Hightmpdays31_{imst)} + \beta_2 X_{it} + \lambda_i + \eta_r + y_t + \varepsilon \qquad (8)$$

where $MYrt$ is the total millet yield in kilograms per hectare for region r in year t. As with fertility, we estimate equation 2 by separately using the no, one- and two-year lags for average high temp days. All right-hand-side variables in equation 2 are the same as those in equation 1, except that we also control for the area given to millet production by region in the vector of covariates Xit.

We also run the same model using sorghum yield $SYrt$ as the dependent variable.

$$SY_{rt} = \alpha_0 + \beta_1 Hightmpdays31_{imst} + \beta_2 X_{it} + \lambda_i + \eta_r + y_t + \varepsilon \qquad (9)$$

We run different iterations of model (2) and (3) with a mean of high temperature days in the dry/preparation season (January, February and March), the planting season (May, June, July and August) and the harvest season (September, October, November and December). We then run the same iterations on the data partitioned by zone (Sahel or Soudan), and whether the region has a higher or lower reliance on staple crops. Finally, we run the model with a zero lag, one-year lag and a two-year lag.

We want to use a strategy that differentiates between the effect of rising heat on human fertility through health channels, and the effect of rising heat on human fertility through changes in agricultural output. To look at this we first run the models with data from the Sahel and Soudan combined, then we split the data into four sections. Firstly, we split the data by the Sahelian and Soudanian climate zones, then we split the data by percentage of the region given to the cultivation of the major staple crops of Sorghum and Millet. We then run all our models using the number of days over a certain 31 degrees Celsius, as the independent variables in all three models. We then run the same models with a zero lag, a one-year lag and a two-year lag.

We also split the high-heat days into three seasons, to check if the effect of heat days on the dependent variable is due to an agricultural or non-agricultural channel. We code the months of January, February and March as the dry/preparation season; the months of May, June, July and August as the planting season; and the months of September, October, November and December as the Harvest season.

RESULTS

Recalling Our Original Research Questions:

This paper's primary question is "What is the relationship between changing weather patterns and human fertility in the Chadian context?" This question is the basis of the paper and touches on the climate change population link, as well as the more specific question of how human fertility responds to changing weather patterns.

Our second research question is: "is the main effect of rising heat on the birth rate caused by changes in crop yield and related changes in food security/insecurity?" This question looks at the route by which changing weather patterns affect human fertility.

Our first question is modelled through model (1), the birth rate model and we use model (2) to draw conclusions about our second question.

Recalling equation 6 and remembering that there are two ways that an extra high heat day in a month can affect the birth rate. Firstly, through the effect of that extra high heat day on the birth rate through a health route, or secondly through the effect of that extra high heat day on the birth rate through the effect of heat on crop yield. Note that we only show the results for the millet yield regression, model (2), as the additional results from the sorghum yield model (3), do not provide additional explanatory power.

The important (and most pronounced) result is the significant negative effect of planting season high heat days (>31C) on both the birth rate and on millet yield, in the overall Chad (Saheldominated), Sahel, and high intensity crop models. Recalling our testable hypotheses, the tendency that the same high heat days have a significant negative effect on both the birth rate and millet yield suggests that the Beckerian model is predictive in the Sahel region of Chad.

One questionable aspect of this result is that these planting season high heat days have a negative effect on the birth rate with a zero lag. This could mean that this significant negative correlation in the zero-lag regression is picking up the direct effects of heat on fertility, either through the route of malnutrition causing miscarriage or some direct negative effect of heat in-utero, rather than the effect of a household decision to forego another child due to food constraints in the previous year.

TABLE 2
RESULTS

	Chad-Birthrate			Sahel-Birthrate			High intensity-Birthrate			Low intensity-Birthrate		
	Zero	One	Two	Zero	One	Two	Zero	One	Two	Zero	One	Two
Dry	-0.0007	-0.0009	-0.0012**	-0.001	-0.0004	-0.0006	-0.0005	-0.0009	-0.0007	-0.0004	-0.0005	-0.0013
	0.237	0.113	0.025	0.132	0.426	0.387	0.554	0.253	0.439	0.661	0.545	0.102
Planting	-0.0011**	-0.0011**	-0.0010*	-0.0013**	-0.0014**	-0.0012*	-0.0012	-0.0017*	-0.0012	-0.0009	-0.0005	-0.0008
	0.018	0.035	0.088	0.043	0.046	0.077	0.139	0.07	0.124	0.152	0.405	0.203
Harvest	0.0014*	0.0007	0.0012**	0.0021***	0.0012	0.0017**	0.001	0.0001	0.0003	0.0022**	0.0017	0.0027***
	0.06	0.287	0.034	0.007	0.15	0.025	0.322	0.879	0.756	0.047	0.103	0.001
Observations	33,723	33,723	33,723	21,200	21,200	21,200	14,469	14,469	14,469	16,965	16,965	16,965
R-squared	0.037	0.037	0.037	0.048	0.049	0.049	0.024	0.024	0.024	0.042	0.042	0.042
Years	15	15	15	15	15	15	15	15	15	15	15	15
	Chad-Millet yield			Sahel-Millet yield			Low intensity-Millet yield			High intensity-Millet yield		
	Zero	One	Two	Zero	One	Two	Zero	One	Two	Zero	One	Two
Dry	-0.0021	0.0414	-0.1705	-0.0267	-0.1466	-0.2717*	0.0161	-0.0029	-0.1166	-0.0622	0.0815	-0.2564*
	0.988	0.792	0.177	0.896	0.417	0.074	0.916	0.985	0.424	0.774	0.727	0.071
Planting	0.026	-0.227**	-0.0716	-0.1347	-0.342**	-0.1956	-0.091	-0.1169	-0.1227	0.1213	-0.3714*	-0.0298
	0.89	0.049	0.43	0.612	0.042	0.138	0.606	0.307	0.391	0.651	0.059	0.764
Harvest	0.0009	0.0516	-0.0911	-0.2015	-0.2068	-0.347	-0.0427	0.0184	-0.0699	0.0323	0.084	-0.0721
	0.998	0.765	0.75	0.568	0.431	0.226	0.917	0.934	0.839	0.938	0.819	0.847
Observations	86,688	86,688	86,688	52,752	52,752	52,752	48,384	48,384	48,384	38,304	38,304	38,304
R-squared	0.669	0.669	0.669	0.708	0.708	0.708	0.675	0.675	0.675	0.646	0.646	0.646
Years	15	15	15	15	15	15	15	15	15	15	15	15
*** p<0.01, ** p<0.05, *p<0.10												
P-values in 2nd row												

CONCLUSION

In this paper we have adapted Becker's simple model to a rural Chadian context and hypothesized how changing weather patterns (here proxied by the effect of one more high heat day in a month) would affect the birth rate. We estimate three econometric models to differentiate between the effect of the extra high heat day a month through health channels or through economic/food security channels.

The major consistent result is the significant negative correlation between planting season high heat days and the birth rate, and a corresponding effect of those same days on millet yield. We observe this effect in the models run with across Chad data, Sahelian data and high staple crop intensity area data.

Due the planting season results, we can suggest that there is some predictive power to our simple adapted Beckerian model for demand for children, and the effect of rising heat on that demand. However, there are other results that are less clear, and we cannot say that our simple model explains a lot of the interaction between rising heat and fertility in a Chadian context.

Our simple development of Becker's model shows that at a micro household level, and in the Sahel zone, there is a negative relationship between rising heat and both the birth rate and crop yield. This implies that as crop yield/household income goes down then the birth rate goes down as implied by our adaption of Becker's model (Becker 1991). This is tentative micro evidence that the Sahel zone of Chad is still in the 'Malthusian Epoch', as described in Oded Galor's Unified Growth Theory (Malthus 1872; Galor 1999; Galor 2000).

Based on climate projections, we can assume that rising heat will continue to be an issue in Chad, especially as the pace of climate change quickens (Potts 2015). Though we cannot categorically state how this will affect Chadian demographic projections, it is clear from the results that there is an interaction between rising heat and fertility, and this must be understood in future analysis of Chadian and even wider Sahelian demographic projections.

Any projection of the trajectory of Chadian, and by extension Sahelian climate change and demographic growth must consider the relationship between the two processes. This makes sense on a macro-level, but the wider micro implications of the negative relationship between rising heat and fertility suggests a wide range of health and economic damage that changing weather patterns cause. That lack of crop yield and direct health effects of rising heat are reaching a level to lower human fertility, means that the same rising heat is doing large scale health damage as well as damage to the agricultural/economic environment. This must be quantified when looking at the overall effect of changing weather patterns on the Sahel region of Africa.

ENDNOTES

[1] The continental effect is a phenomenon observed by climatologists, whereby the center of a continental land mass warms faster than its coastal edges.

[2] The word Sahel, like Sahara and Soudan, are originally Arabic terms. Sahara means desert in Arabic, Sahel means coast or shore (i.e. the shore of the desert), and Soudan is derived from the Arabic word for black, so signifies 'where the blacks are'.

[3] Climate change: The earth's surface temperature has risen by 0.9 degrees Centigrade since the late 19th Century, and most of this warming has occurred in the last 35 years. There is a large scientific consensus that this warming is due to the buildup of Carbon Dioxide and other greenhouse gases in the atmosphere (IPCC 2019).

[4] We test the sign of this derivative in econometric models (2), millet yield and (3), sorghum yield.

[5] Due to the vast geographical dispersion of parts of Chad's population, there is a need to use weighting to ensure equal cluster sample sizes.

[6] The Uppsala Conflict Data Program scans media from all over the world to find reports of conflict incidents. This program started in the seventies and has refined its methodology. The database consists of a media report of a conflict, a GIS location of the conflict, and a range of the amount of fatalities in the conflict incident.

[7] Kanem became Kanem and Bahr El Gazel; Chari-Baguirmi became Chari-Baguirmi and Hadjer-Lamis; Mayo-Kebbi became MayoKebbi Est and Mayo-Kebbi Ouest; Moyen-Chari became Moyen-Chari and

Mandoul; Ennedi became Ennedi Ouest and Ennedi Est; and finally, Ouaddai became Ouaddai and Sila. The structure of the 2014-15 DHS data allows us to map the old regions to the new regions, with a slight loss of granularity. Furthermore, all our other covariates are by a focused GIS location, while the agricultural data is by a larger region.

8. If the month m is prior to the growing season in year t then the most recent growing season occurs in year t-1.

9. If I partition the data by urban and rural, we see that urban Chad reacts very differently to the rising heat. As we want to look at the rural story, we control for whether the cluster is urban so we can concentrate on the rural results.