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Chad: Human Fertility, Crop Production and Changing Weather Patterns

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BY

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ABSTRACT

The subject of this dissertation is the effect of changing weather patterns on human fertility in Chad, Sahelian Africa. There is a body of literature on the effect of extreme weather events-usually associated with large-scale mortality-and human fertility. However, there is less of a body of literature on the effects of less extreme changing weather patterns and human fertility. Chad has known substantial warming since the late 1960s, hence I use rising heat as a proxy for changing weather patterns. Using GIS-coded fertility and weather data, I look for correlations between the birth rate and the number of days in a month above 31 degrees Celsius, while partitioning data by climatic zone and by level of staple crop intensity. I then run the same models with sorghum and millet (Chadian staple crops) as the dependent variables. I find a general pattern that the same planting season high temperature days that have a negative effect on the birth rate, also have a negative effect on both sorghum and millet yields that is driven by the Sahel region. This accords with my adapted Beckerian theoretical model, but there are other more ambiguous results.

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CHAPTER 1-INTRODUCTION

In early 2011, I saw evidence of the drowned bodies of Senegalese refugees on the Southern Spanish coast. The desire to understand what pressures drove these young men to make such a perilous journey, was the start of the process that led me to the write this dissertation. My interest in answering some of the questions around what I discovered about the problems driving migrant flows from the African Sahel, led me to start my PhD in 2015. I wanted, initially, to study the link between climate change and migration in a Sahelian context. However, as I studied the area, I saw that the issue of population growth was a cause that underpinned a lot of the more noticeable symptoms of the growing problems of the area. While considering the question of Sahelian population growth, I discovered the under-researched country of Chad. This country, described as the 'dead heart of Africa'[1], lacks a large body of empirical work in English, or even in French. This work is an attempt to add to that nascent body of work, by answering some of the questions around the impact of changing weather patterns and population growth in the Sahelian context.

In this dissertation, I analyze the effect of an extra high temperature day on human fertility in the Chadian context. While there is a large body of work focusing on how extreme weather events leading to large-scale mortality, lead to a positive fertility rebound effect, there is a substantially smaller literature that considers fertility responses to changing weather patterns and in particular, rising heat. It is to this body of research I add. The foundation of my theoretical work is Gary Becker's

[1] It is easy to find references to Chad being described as 'the dead heart of Africa', however, it is difficult to find who initially used this phrase. The phrase has been attributed to S.H. Frankel in D.J.J. Botha's 'Reminiscences of an Economist', but in this article Professor Frankel is referring to an area shared by Kenya, Tanzania and Zambia as 'the Dead Heart of Africa' (Botha 1992).

‘Treatise on the Family’, and I concentrate on his chapter entitled ‘The Demand for Children’ (Becker 1991).

Building off Becker’s model for demand for children, I add changing weather patterns and hypothesize how rising heat would influence the demand for children in a rural Chadian context. There is also a large strand of literature that suggests that extreme heat has a negative effect on human fertility, which I discuss in the next chapter (Richards 1983; Becker, Chowdhury, Leridon 1986; Lam, Miron 1996; Nielson 2016).

I develop a theoretical model that extends Becker and hypothesize that there are two major routes whereby rising heat can affect fertility. Firstly, there can be a direct effect of rising heat on fertility through the effect of heat on human health. There can be many ways that this works; increased miscarriages, decreased sperm production or increased incidence of stillbirth, but we assume that they are all the direct effect of rising heat on fertility through the health route. Secondly, there is the effect of rising heat on fertility, through the effect of rising heat on staple crop yield. This can occur through: the-positive or negative-effect of crop yield on economic well-being and food security, which can then lead to a rise or fall in miscarriages; or the crop failure or bounteous crop that causes a family decision to not have or have an additional child.

The Sahel, and particularly Chad, has experienced significant warming since the late 1960s, hence we can assume the changing weather patterns means heat above the average in a Chadian context. So we use rising heat to represent changing weather patterns, and we proxy for rising heat by the creating variables based on the number of days above certain temperature thresholds in a month. Using a semi-log regression with temporal fixed effects I analyze the relation between high temperature days and the birth rate. I also analyze the effect of the same high temperature days on the yields of two staple Chadian crops, millet and sorghum. By partitioning the data by zone and by level of staple crop intensity, I suggest mechanisms for the results observed.

My results reveal that there is a strong negative correlation between planting season high temperature days and the birthrate. This result is driven by the (more arid) Sahel zone of Chad, and by those areas that have a higher amount of land given to the staple crops of sorghum and millet. I also see that those same high-temperature days have a negative effect on both miller and sorghum yields. This suggests that in the absence of any rebound effect, the effect of heat shocks in the Sahel zone of Chad may act as a natural break on population growth.

CHAPTER 2 GENERAL LITERATURE REVIEW AND CHAD BACKGROUND

This dissertation augments the weather and fertility literature and I look at that in the first section of the literature review. The climate and fertility link adds to the wider literature on population growth and climate change, hence I survey that afterwards. Turning to the Sub-Saharan African context, I look at an overview of literature on African demography and then more specifically issues in the African Sahel. I then turn to my focus country Chad, and look at its demography, history, weather, economics and politics. Chad has a unique and complex history, culture and political situation, which the reader needs to understand to add to their comprehension of the empirical results.

Weather and fertility literature

There is a large strand in the literature that looks at the responses to large-scale mortality caused by extreme weather events, without looking at how fertility responds to changing weather patterns. 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 et al. 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; C. Davis 2017; Brauner-Otto & Axina 2017; 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; Nielson 2016). Moreover, 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.

Some argue that the effect of heat on human fertility may be augmented by seasonal photoperiodic[2] effects on individual hormone levels (Levine 1994). However, changes in the length of day versus night cannot explain the effects of within season changes in mean temperature. Generally, the direct effect of heat on human fertility can be the result of two physiological processes; increased temperature can reduce male spermatogenesis as well as restrict female ovulatory function (Boserup 1985; Lam, Miron 1996; Scholte, Van den Berg, Lindeboom 2015).

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6 Photoperiodic effects: The idea that changes in the length of the day (or amount of sun) can affect human fertility.

Higher temperature can also directly lead to increased incidence of stillbirth (Strand, Barnett & Tong 2011; Basu, Sarovar & Malig 2016). Changing weather patterns can affect an area's disease environment as well as food security, through its effects on crop yields (Tiwari et al. 2017; Porter et al. 2013; Ray et al. 2012). This in turn can affect maternal malnutrition during pregnancy, which can affect the ability to carry a child to term (Kim & Prskawetz 2010). Additional evidence indicates that childhood and in-utero female malnutrition can cause adult sterility (Lumey & Stein 1997; Gluckman et al. 2005; Gardner et al. 2009; Song 2013). Finally, maternal malnutrition is also associated with increased rates of infant mortality and adverse birth outcomes (Nalumbamba-Phiri & Goldberg 2006; Snigal & Doyle 2008; Bhutta et al. 2013).

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 Sherbinan 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.

Conversely, households can respond to income shocks by deciding to have more children. This can be due to seeing more children as a source of cheaper labor, where the labor markets are undeveloped (Cain 1981). Other researchers found that some households exhibit a 'family-bonding response' to income or environmental shocks, which leads to a rise in fertility (D. Henry, Tolan & Gorman-Smith 2004; Kesler et al. 2006; Love, Rhodes et al. 2012; Cohan & Cole 2012).

POPULATION GROWTH AND CLIMATE CHANGE LITERATURE

Desrochers and Szurmak (2018) have questioned the link between population growth and climate change in the book 'Population Bombed'. Desrochers and Szurmak's argument points out that the data have often proved wrong the population pessimists' predictions. They also point out that large-scale development has led to environmental resilience and demonstrate the operation of the Kuznets curve, whereby as nations get richer, they invest more in environmental goods (Kuznets 1955, 1963). Moreover, they use [3]the Simon-Ehrlich wager to show the dynamism within the capitalist system in finding ways to find cheaper and more available sources of rare metals, and by extension raw materials.

However, though the market mechanism can work well in terms of privately owned and priced goods, there can be significant market failure in relation to environmental common property

[3] The Simon-Ehrlich wager: In 1980 Economist Julian Simon and Biologist Paul Ehrlich bet on the 1990 prices of four scarce metals. Ehrlich, believing that they would become scarcer, bet that their prices would rise. Simon, believing in the power of the market to find new sources of the metals, bet that the prices would go down. Simon won the bet.

resources (M. Dasgupta 2014). Desrochers and Szurmak (2018) point to the increased taste for environmental preservation as the nation developed (Kuznet 1963; Desrochers & Szurmak 2018). This would then leave the potential for very destructive use of environmental property resources by those nations lower-down the Kuznet's curve (Kuznet 1963). Many academics and international organizations observe the problem of such environmental devastation happening in the developed world (Arrow et al 2004; P. Dasgupta 2010; World Bank 2010).

The capitalist market system, and increasingly the global capitalist market system has a weakness in its inability to disincentivize the overuse of public environmental goods. Those local resources that the community may see as free; forests, lakes, fisheries or animal populations among others will be massively underpriced compared to what they are giving to the community (Arrow 1969; Dasgupta 2001; Stern 2006). Hardin explored the question of how to address the lack of incentives to preserve environmental public goods (Hardin 1968). Many authors have questioned Hardin's claims; the most famous being Ostrom (Ostrom 1990). Ostrom has shown that by observing certain 'design principles', communities can come together to manage common-pool resources. However, it is difficult to see how Ostrom's principles can be used to manage cross-border common pool resources, let alone the global management of the atmosphere's ability to absorb carbon (Dasgupta et al 1997).

I agree that a cycle of overuse of common property resources can trap developing world countries, and that can certainly be exacerbated by high population growth. One of the most unjust aspects of climate change is that the developed nations have burnt most historical carbon emissions, but the most vulnerable countries to its effects are in the developing world (Dasgupta

2014). There are many reasons for this: including the tropical geographical positioning of many developing nations; the agricultural[4] dependence of most of the developing nations; and inadequate health, physical and governmental infrastructure, which leads to a lack of resilience in the face of both large-scale climate disaster and smaller-scale incremental change (Stern 2006; World Development Review 2008).

This becomes clear when I look at the management of food and water resources. Global warming will decrease crop outputs at lower latitudes that will affect food security in many developing nations[5] (Stern 2006; Dasgupta 2014). Changes in rainfall patterns can contribute to droughts and variation in their timing and intensity, leading to agricultural disruption, crop devastation, low yields and increased food insecurity (Stern 2006). The lowering of the birth rate can improve the issues of feeding the population, as well as educating and providing for their health (Rosenzweig and Wolpin 1980; Alderman et al 2006; Joshi and Schultz 2007; Rosenzweig and Zhang 2009; Miller 2010). This, and the vast body of literature that investigates the positive aspects of the demographic dividend, leads us to conclude that population decline is good for developing nations (Kelley & Schmidt 2005).

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[4] The agricultural sector is the most climate sensitive of all economic sectors.

SAHEL BACKGROUND AND SPECIFIC LITERATURE

Chad is situated in the larger Sahel region of Africa (see Map 1). Since the Sahel droughts of the early 1970s and through to the present Mediterranean migrant crisis, the Western Media has portrayed the region as beset by environmental and social crises. Though the population disaster literature described previously has weakened due to the massive fall in fertility worldwide, it now focuses on Sub-Saharan Africa, and especially the African Sahel.

Many writers-since the Sahelian droughts of the 1970s-have pointed to the climate change and exponential population growth in the African Sahel as confirmation of some of Malthus's worse predictions (Malthus 1793). Chad is in the African Sahel region between Niger and Sudan and bordering Nigeria, Libya, Cameroon and the Central African Republic. The Sahel is the semi-arid region between the Sahara Desert in the North and Soudanese Savanna in the South, and it stretches across the African continent. The 'Sahel Crisis' is the idea that a mixture of climate change and unrestrained population growth is pushing the Sahel to the limits of its human carrying capacity and has become popular in the literature of many different disciplines (Seifert & Picardi 1977; Stein 1999; Fisher et al 2009; Potts et al 2012; Ehrlich & Ehrlich 2013). This 'crisis' is often framed as a rise in population as conceived by the 18th Century English Social Theorist, Thomas Malthus in his 'Essay on the Principle of Population' (Malthus 1793). According to this framing, the famines, wars and mass migration that we have seen since the early 1970's in this region are the outworking of a 'Malthusian break'[6] on unrestrained

[6] Malthusian break: An idea advanced by the Reverend Thomas Malthus in his 'Essay Concerning Human Population' (1793), that exponential human population growth would only be brought under control by the large-scale mortality brought about by disasters such as famine, floods and wars. His ideas have been largely discredited, but the seeming climate/population disasters of the Sahel and other parts of the developing world have caused a Neo-Malthusian school to arise.

population growth (IPCC 2001; Conley, Mccord & Sachs 2007; Potts 2013). Potts has published his Neo-Malthusian claims about the Sahel generally and Chad and Niger in particular, in high-level economics journals (Potts et al 2010, Potts et al 2012, Potts et al 2015). This understanding of the region's issues incorporates Malthusian theory and the 'environmental determinism' that is often applied to various Sub-Saharan African crises.

Map 1: Shading the African Sahel

THE DARK CONTINENT NARRATIVE

Sub-Saharan Africa is the global exception in terms of the start and pace of their fertility transition (Guengant & May 2013; Casterline & Agyei-Mensah 2017). Of the thirty-seven nations with the highest Total Fertility Rate, only one-Afghanistan-is outside of Sub-Saharan Africa (World Bank Data 2017). Sub-Saharan Africa has a Total Fertility Rate of 4.8, while the second highest region Middle East/North Africa is trailing far behind at 2.9 (World Bank Data 2017). There are cultural, social and economic reasons for this 'Sub-Saharan African' exceptionalism in this area and at this time, but there is a danger that this anomaly further fuels an image of an African continent that is dysfunctional, out of control and fundamentally 'other'.

Roe (1995) wrote 'Except-Africa: Postscript to a Special Section on Development Narratives'. In this, he specifically challenges the 'neo-Malthusian Doomsday scenario' that is often evoked when talking about social and environmental issues in Sub-Saharan Africa. He points out that writing on a broad range of topics in African development evokes the image of a wild, dysfunctional place, which lives one-step away from utter disaster that only Western technocrats can rescue them. He points out that the Sahelian desertification narrative came out of the fact that Western observers were looking for the next African disaster, which they can come and solve. His prescription, to look at individual situations to find solutions embedded in local dynamics and to put aside the disaster narratives could be fruitfully followed in looking at issues in the Sahel (E. M. Roe 1995).

SAHELIAN AGRICULTURE AND THE WIDER SUB-SAHARAN AFRICAN CONTEXT

Sachs (2008) describes 'The African Green Revolution', where he lays out two possible futures for the continent. He points out that the average grain yield per hectare/year in Sub-Saharan Africa is one ton, while many of the low-income countries that experienced the 'Green Revolution'[7] see yields of approximately three times that figure. Like many population optimists, Professor Sachs says that these technological and human ingenuity solutions were responsible for

[7] The Green Revolution: is also referred to as the 'Third Agricultural Revolution', was a series of agricultural technology breakthroughs from the early 50s until the late 60s, which were transferred to the developing world and caused a large increase in crop production.

the escape from the positive Malthusian break on population, in this case potential starvation (Sachs 2008).

Sachs has been very vocal about the possibility of a positive Malthusian breaks on Sub-Saharan African population if population growth continues at the same rate (Sachs 2007). In this short article, he writes on a similar theme, which I will quote in full:

"Africa's vulnerability to food insecurity has skyrocketed. The population has out stripped the food supply. Climate change is already wreaking havoc on crop yields. Depletion of soil nutrients has reached crisis proportions. Soaring world food prices have put a crippling burden on Africa as a net food importer. This way lies disaster." (Sachs 2008).

However, Sachs (2008) claims that a 'Green Revolution' can be that answer to this Malthusian trap, and hence human ingenuity can be the way forward to a very different future for the continent. Boserup (1965) claims that a move to higher agricultural output and technological/organizational development is driven by expanding population. She looked at the history of agricultural development showing that population growth is the major driver of agricultural change. Her theory would account for why the 'Green Revolution' occurred in the population dense countries of South Asia and the Far East and would suggest that the African agricultural revolution will occur as different societies reach their [8]agricultural carrying capacity (Boserup 1965).

[8] Note that Boserup uses the term carrying capacity in a very different way from Ehrlich. For her the agricultural carrying capacity is the amount of food produced under an agricultural technology regime, and when reached because of expanding population can produce the transition to a new technological regime.

Boserup (1965) challenges Malthus by saying that population growth drives agricultural development and behavior change. She stated that population growth pushes agricultural from use of the extensive margin to more intensive modern farming methods. As stated above, modern intensive farming methods required workers that are more skilled and hence change the parameters of the quantity/quality trade-off (Becker & Lewis 1973).

ADAPTING TO CLIMATE CHANGE-THE AFRICAN CONTEXT

Despite the large body of literature that frames the effect of climate change on Africa in terms of a Malthusian break on the population, many papers document adaption to climate change in the Sub-Saharan African context. Ghana, Nti and Barkley (2012) look at the different factors that equip farmers to adapt to changing weather conditions, citing higher human capital as the main driver of ability to adapt. Fosu-Mensah et al. (2010) look at how farmers are perceiving and reacting to climate change in Ghana by a mixture of crop diversification, short season varieties, changes in crop species and moving planting dates.

Turning to Chad, there is also a body of literature that documents the adaption that has happened in there due to changing weather conditions. There are studies on the growth of recession agriculture, as an adaption to the shrinking of Lake Chad that challenge the Neo-Malthusian idea that conflict in Soudanian Chad was driven by climate change, population growth and land pressure, by showing that the conflicts were caused by the influx of herders from central regions driven by government policy (Magrin 1996; Raimond 1999; Sougnabe 2013). Despite the large amount of literature about the negative elements of Lake Chad's shrinkage, Magrin et al (2010) show that the creation of strong market and communication links between the Lake area and the Capital N'Djamena have led to benefits at both ends. Choukou et al (2017) looks at the development of recession maize farming in the Sahelian Kanem Oasis and show how the presence of strong microcredit structures have helped agricultural development.

Chad Background

This dissertation focuses on Chad in Sahelian Africa. Chad is a unique country, with dynamics that are different from many other Sub-Saharan countries and even from its Sahelian neighbors. This lengthy Chad background gives a sense of Chad's singular history, as well as some of the deep structural and geographic problems it faces.

Chad is a landlocked country bordered by Sudan, Central African Republic, Cameroon, Nigeria, Niger and Libya. Chad has 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 traditional African 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 climate change globally (Abidoye & Odusola 2015).

Chad has suffered from extreme effects of climate change since the 1960s. Due to its Central African position, and hence the 'Continental effect'[9] exacerbating the normal pace of African climate change, Chad has warmed by 2.64 degrees Celsius since the late 1960's (Abidoye & Odusola, 2015). The warming has been clearly documented, but the effect of changing weather patterns on precipitation patterns is not so clear as Chad has suffered from increased drought, floods and changes in the onset of the rainy season since the early 70's and getting worse since the late 90's (Potts et al 2015).

Chad's demographic growth can be analyzed with comparison to the larger Sub-Saharan African context, or even more fruitfully with the Sahelian and particularly, Western Sahelian context. There is a large strand of demographic literature on what has been termed 'Sub-Saharan African exceptionalism'. This concentrates on the different nature of the fertility transition in Sub-Saharan Africa, relative to Asia or Latin America (Casterline et al 2010; Bongaerts & Casterline 2013). Demographic observers state that Sub-Saharan Africa started from a higher pre-transition fertility rate, and the transition to a replacement level fertility[10] has only been reached in a select group of countries (Guengant & May 2013; Casterline & Agyei-Mensah 2017). Many point out that Sub-Saharan Africa, especially Central and Western Africa is exceptional for its desire for extremely high family sizes, that has not shifted despite many attempts at government and NGO interventions (Bledsoe 2002; Casterline & Agyei-Mensah 2017). Where demographers have seen sharper falls in the total fertility rate, it has normally been in the context of rapid urbanization

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

[10] 'Replacement level fertility' is an amount of children per women that leads to a zero-population growth rate. It is roughly 2.1 children per woman.

(Galor 2005; Henderson et al 2017). This is related to higher expenditure on education, and hence a quantity-quality trade-off (Guinnane 2011; Fluckiger & Ludwig 2017).

The Sahelian countries of Africa are some of the fastest growing in the world. Chad has a Total Fertility Rate (TFR) of 5.95, high but dwarfed by its neighbor Niger with at TFR of 7.24 (World Bank 2016). Sudan's TFR is 4.53, Mauritania's TFR is 4.67, Mali's TFR is 6.06, Burkina Faso's TFR is 5.35 and Senegal's is 4.77 (World Bank 2016). These are very high figures in comparison with the world's TFR of just below 2.5 and even the African continent's at 4.1 (World Bank 2018).

A TFR of 5.95 leads to a population growth rate of 3.3% which means that Chad's current population of 16,268,459 would double in less than 22 years if we assume that this rate remains constant. Though Chad is the 22nd largest country (in terms of land area) on earth and three times the size of the US State of California, many observers point to the largely Saharan North and arid Sahelian Center as reasons for the unsustainability of its population growth.

I am also interested in what any drop-in fertility could do to Chad's future demographic projections. To this end, I use the demographic parameters advanced in the extensive overview of Chad's past, present and future demographic trends released in October 2013-'Population, développement et dividende démographique au Tchad' ('Population, Development and demographic dividend in Chad').

The authors have two hypotheses for Chad's future demographic growth. the high hypothesis and the low hypothesis. The high and low hypotheses: These are forwarded by Guengant & Guealbaye (2013) and describe two potential Chadian demographic futures. The high hypothesis is a 'business as usual' scenario, where with little government effort the population growth rate remains constant and there is no enjoyment of the 'demographic dividend. In the low hypothesis, there is large scale government intervention and a larger fall in the population growth rate, leading to the enjoyment of a small 'demographic dividend' by the mid-21st Century. They say that to reach the low hypothesis, there must be a more active and societal will to bring down the growth of population in Chad. Moreover, the authors say that Chad will only experience a demographic dividend under the low hypothesis, and then only a partial one (Guengant & Guealbaye 2013).

This dissertation looks at how Chad's changing weather patterns affect Chad's demographic trajectory. Guengant and Guealbaye (2013) do not factor in changing weather patterns in their report. Will rising heat in Chad cause a rise in fertility and hence push Chad's demographic future to the high hypothesis? Or will the effect of rising heat cause a drop in fertility and push Chad towards the low hypothesis.

Historical background

The history of Chad can be divided into four different periods: the pre-historic [11]'cradle of humanity' period, the years of the advance of Islam and Arab penetration in the region which

[11] Pre-historic Chad is famous because of the discovery of the oldest hominid skull in the Northern Area of Borkou in 2002. Researchers see it as one of the early 'Cradles of Civilization' as it would have had much wetter climatological conditions in the period around seven thousand BC (Collier 1990).

was an [12]age of various empires, the period of French direct colonial rule and finally post-independence Chad.

By 1905, most of Chad became part of French Equatorial Africa, a colony that included modern-day the Republic of Congo, Gabon, the Central African Republic and Chad. France perceived this as less profitable than its other Sub-Saharan African colony of French West Africa. Therefore, it was ruled from Brazzaville on the Atlantic coast, and the French government allowed exploitative and extractive companies to rule areas of Chad with little thought of development beyond pure economic gain (Collier 1990).

The French government only pacified the Sahelian center of Chad by 1924 and probably never more than nominally ruled Saharan Northern Chad. However, they perceived areas of Southern Chad to be suitable for the growing of cotton and hence called it 'Le Tchad Utile' (useful Chad). As the cotton industry was France's major economic activity in Chad, they invested more

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[12] The period between 900 AD and 1850 AD was an Age of Empires, as different powers fought over the strategic waters of Lake Chad and the riches of the African slave trade. One of Central Africa's most long-lasting empires, the Kanem Empire rose in the beginning of the second millennium AD. The Empire was formed from a confederation of nomadic groups and embraced Islam as early as the 10th Century AD. The Kanem Empire based in modern day Central Sahelian Chad, prospered through control of the Trans-Saharan trade routes. Another major source of prosperity was regular slave raiding against southern people groups and subsequent trade with the Arab world; this has had a long-term negative effect on North-South relations in Chad. By the 15th Century, the Kanem Empire started to weaken and merged with the rising Borno Empire based to the southwest of Lake Chad. The Kanem-Borno Empire finally fell in the 19th Century, as Fulani groups from present day Niger and Arab invaders from the North and East threatened it (Collier 1990).

Throughout the pre-colonial era other empires arose. The Baguirmi Empire, based to the southeast of Borno, expanded aggressively to the south at its height. The Wadai Empire was an offshoot of the Fur Sultanate, based in modern day Darfur. It arose to eventually conquer the Baguirmi Empire and attack Borno. However, by the start of the French military presence in Chad it was not a significant enough power to lead resistance against them (Collier 1990).

Initially, the remnant of the Wadai Empire resisted the French presence, but what was left of the Borno and Baguirmi empires saw the European presence as a counterbalance to Wadai power (Collier 1990).

heavily in the South and it became more connected with the French language, the Christian religion, and links with France and French education (Collier 1990).

France's interest in Chad was weak, even when compared with their interest in the other areas of French Equatorial Africa. The colonial administration only ever ruled the south of the country effectively and handed over power in the North and the Eastern Sahel to local rulers (Collier 1990). This meant that post World War II the rising political parties were a Southern-Based, left wing group-the Chadian Progressive Party (Parti Progressiste Tchadien-PPT)-and a more conservative party based around Sahelian traditional Muslim rulers, the Chadian Democratic Union (Union Democratique Tchadien-UDT) (Collier 1990).

Chad achieved independence from France in August 1960, with the Chadian Progressive Party led by Southerner Francois Tombalbaye taking power. Tombalbaye faced a large array of problems when faced with the prospect of building a nation. Chad was/is a vast country that was highly ethnically and linguistically fractionalized, in 1960 it was highly impoverished with few known sources or revenue, and it had very little communication, educational or commercial infrastructure. Unsurprisingly, Tombalbaye's period of leadership from 1960-75 was marked by dictatorial rule, rebellion of the Muslim North of the country and Civil War (Collier 1990).

Tombalbaye gained control of the Chadian Progressive party because of his diplomatic and political skills but embarked on a program of repression of political opposition from the eve of independence. The President moved against the former leader of the party, Gabriel Lisette one week before independence, declaring him a non-citizen and banishing him from the country. In the next few years, he concentrated on centralizing power in his hands and leaning on his own Sara ethnic group to retain power (Collier 1990).

The President's policy of 'Africanization' of the Chadian civil service was successful in replacing French colonial administrators with a new group of educated Chadians. However, because most educated Chadians at independence were from the South and had Sara ethnicity, they were perceived by those in the Muslim North and Center as nearly as foreign as the French. Furthermore, as they lacked experience, especially lacking cultural understanding of the Muslim Sahel and Saharan regions, they created a lot of regional resentment (Collier 1990).

Historians often see the start of the first Chadian Civil War, as an anti-taxation riot on November 1st, 1965 centered in Mangalme in Guera in the Southern Central Sahel region of Chad (Buijtenhuijs 1978). This left over five hundred people dead, and many Central and Northern Chadian groups saw it as violent government repression. In June 1966, the National Liberation Front of Chad (Front du Liberation Nationale de Tchad-FROLINAT) was founded in Nyala, North-Western Sudan. The Civil War gained momentum slowly, and by 1969 the government had little authority outside the major garrison towns of the North and Center (Collier 1990).
In 1969, Tombalbaye took the very unpopular step of calling in French forces to back up Chadian government troops. The French, backed by elements of Chadian civil society pressured the President into enacting various reforms that gave more power to traditional rulers, rationalized the tax system and reversed some of the worst excesses of government repression. These reforms, coupled with French military training and expertise significantly reduced the rebellion, and the French forces left by 1971 (Collier 1990).

After the French withdrawal, the President intensified his efforts at repression when claiming to discover a Libyan plot to remove him from power. This pushed Libya's leader Colonel Muammar Al-Gaddafi to recognize FROLINAT and provide a base for it in the Southern Libyan Sahara. Open Libyan support significantly strengthened FROLINAT, though it remained weak due to ethnic fractionalization (Collier 1990).

The Libyan intervention pushed Tombalbaye to take a new stance to win support in the North and Center and changed his largely Francophile image to an anti-colonial, pro Africanist stance. This won support for his regime in Sudan and Libya but alienated other sections of the Southern Chadian elites. His last power basis was the Chadian army, which he turned on in early 1975. On April 13th, 1975 he was removed from power and killed by a military coup led by junior army officers (Collier 1990).

The fall of Chad's president ushered in a long period of instability and Civil War. Felix Malloum, a Southerner, led the new military government that included more Muslims from the North and East of Chad. However, it was still widely perceived as a Southern based regime. Although it relaxed the level of repression from the Tombalbaye era, it quickly ran into problems due to an expectant urban civil society and the remaining elements of FROLINAT, especially those that had reformed as the Armed Forces of the North (Conseil de Commandement des Forces Armees du Nord-CCFAN) led by Goukouni Oueddei (Collier 1990).

The military weakness of Felix Malloum's government created an unstable situation where there were three centers of Chadian power supported by different foreign powers. The ex-FROLINAT elements divided themselves between the Libyan-backed forces of Gououni Oueddei, and the Sudanese supported forces under Hissen Habre. The two ex-FROLINAT groups, both from different sub-tribes of the Northern Toubou ethnicity competed with Malloum's French-backed government. In 1978 Habre formed a unity government with Malloum, which provoked open military confrontation with Oueddei's CCFAN. By 1979, Habre took over the unity government and Southerners fled the capital as Habre's and Oueddei's forces fought over N'Djamena (Collier 1990).

The fight over N'Djamena led to a period of increased fractionalization, and numerous attempts to broker peace between the numerous powers by Chad's African neighbors. At the heart of the conflict was the rivalry between Habre and Oueddei, and by 1982 Habre took power, forcing Oueddei into exile in Cameroon (Collier 1990).

Hissene Habre held power in Chad from 1982 until Chad's current president Idriss Deby, one of Habre's generals of Zaghawa ethnicity, deposed him in 1990. Habre's rule was marked by major Libyan intervention in Chad, continued civil war and brutal repression of any opposition to Habre's rule. It was also marked by major conflict between three of Chad's Muslim tribal groups; the Hadjerai, the Gorane (Habre's ethnicity) and the Zaghawa (Deby's ethnicity) (Collier 1990).

Idriss Deby's rule has seen the stabilization and growth of the Chadian state, and the strengthening of the Chadian Army, that has been helped by the growth of oil revenue since 2002. There was a second Chadian Civil War in Eastern Chad from 2005-2010, which was a spillover from the war in the neighboring Sudanese state of Darfur. This was coupled with Chad's involvement with the Nigerian originated Boko Haram insurgency around the Lake Chad area since 2012. However, relative to previous Chadian governments, Idriss Deby's rule has seen Chad develop into a more stable nation, with a (modestly) growing gross domestic product and human development index (Marchal 2016).

Geographical background

[13]Map 2: Chad regions

Chad is a landlocked country towards the north of the center of the African continent. It is surrounded by Sudan, the Central African Republic, Cameroon, Nigeria, Niger and Libya. Chad

[13] The Northern Regions of Tibesti, Borkou and Ennedi are the Sahara zone. Kanem, Bahr El Gazel, Batha, Wadi Fira, Lac, Hadjer-Lamis, Guera, Ouaddai, Dar Sila, Salamat and Chari-Baguirmi are the Sahel zone. Mayo Kebbi Est, Mayo Kebbi Ouest, Tandjile, Mandoul, Moyen-Chari, Logone Occidental and Logone Oriental are the Soudan zone.

covers 1 284 000 kilometers squared and is the fifth largest country in Africa (Inseed 2013). It lies fully between the Equator and the Tropic of Cancer, though the Tropic of Cancer touches the Northern part of Chad at one point.

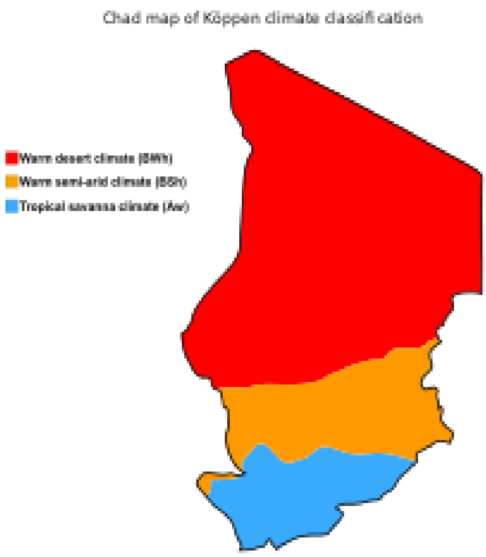
The Sahelian nation lies within the Lake Chad Basin and is named after the Lake, which is the second largest in West Africa and one of the continent's most significant wetlands. Lake Chad covered 25 000 square kilometers in 1963, but now covers 1 350 square kilometers. The Lake is fed by the Chari and Logone rivers, which rise in the Central African Republic (Collier 1990).

It has three geographical zones that have different climatological patterns, which I will describe later. The sparsely populated Northern area is situated in the Saharan desert with an associated lack of rainfall and green vegetation. The central Sahelian zone has areas of grassy shrub land and thorny, open savanna. The southern, Soudanian zone is the more fertile area of Chad and consists of woodland savanna as well as deciduous forests full of vegetation (Collier 1990).

Chad is largely a flat country but rises as it moves North and East away from Lake Chad. The highest point Emi Koussi is 3 100 meters and is part of the Tibesti mountains in the northern Saharan zone. Chad's eastern border with the Sudanese province of Darfur is marked by the Ouaddian Highlands and there are also some highlands in the central Sahelian province of Guera that rise to 1 500 meters (Collier 1990).

Climatological background

Chad has three major climatic zones that correspond to the geographical zones described above. The northern half of Chad is the Saharan zone that is marked by very low rainfall; this can be between 0 and 60 millimeters a year. The mean daily maximum temperature ranges from 32 degrees Celsius in January to 45 degrees in May (Pattyanak et al 2019).



Map 3: Map of Chad showing the Sahara, Sahel and the Soudan.

The majority of Chad is situated in the Sahelian[14] 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

[14] 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'.

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 [15]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).

The temperature of the African continent has risen; 2016 was 1.1 degrees Celsius above the pre-industrial era (World Meteorological Society 2017). This is in excess of the general global temperature rise of 0.75 (figure in 2007) degrees Celsius since the pre-industrial era (Trenberth et al 2007, IPCC 2007).

[15] 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).

This dissertation 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 been more intense in the Sahel region, but more focused on the East of 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).

However, though there is a clear warming trend across the continent, there are different regional patterns in relation to rainfall patterns (Pattayanak 2019). In West Africa/the Sahel, there has been a clear pattern of declining precipitation since the high of the 1950s (Trenberth et al., 2007).

Common across much of the Sahel, Chad has had three distinct rainfall regimes since 1950. The wetter than the mean period (1950-1965), then the dryer than the mean period (1966-1990) that caused worldwide focus on the Sahel region and then the recovery period (1991-2014) that has seen rainfall rise but not to the levels prior to the dry period (Pattnayak et al., 2019). This leads to a generally significant lowering of rainfall since the 1950s, even when accounting for the recovery period (Maharana et al., 2017).

The Chadian [16]rainy season of June, July and August coincides with its hottest months. Because the majority of rainfall occurs in these months and these are the hottest months, climate studies concentrate on the changes in these months (Caminade & Terray, 2009; Pattnayak et al., 2017; Maharana et al. 2018). Researchers have noticed significant changes in the intensity of Chadian rainfall in the monsoon months of June, July and August, but not in the other months of the year (Neill et al., 2005; E.Nkiaka et al., 2017).

Chad's economy

Chad-when it gained independence from France in 1960-was still largely a traditional subsistence economy. There was a very small industrial sector based on production for the agricultural sector, and at independence, there was no mining of natural resources. Furthermore, there was a very sparse transport and communication network and independent Chad had very few trained technicians and administrators (Collier 1990).

Cotton was the major agricultural export, which the French had developed since 1920's. This was the major source of government income, until the large-scale exportation of oil in the early

[16] These historical rainfall patterns are different in Chad's different climatological zones. Interestingly, the Saharan zone has seen a non-significant rise in rainfall since 1950, but this is starting from a very low level of rainfall. The Sahel zone has seen a lowering of rainfall, but often statistically insignificant even at the 10% level (Pattyanak et al., 2019). For example, Abeche the capital of Ouaddai region in Eastern Chad that borders Sudan's Darfur region has seen a rainfall reduction of 8mm per decade (Pattyanak et al., 2019). This is higher than the Central Chadian town of Ati (0.9mm per decade), but both cities are targeted by researchers as central to the climate change and conflict narrative, hence their lack of significant reduction in rainfall is surprising.

A consistently significant decadal drop in rainfall since 1950 has occurred in the South of Chad (Pattyanak et al., 2019). The tropical Soudanese Savannah zone, represented by the cities of Lere and Sarh has seen significant drops in rainfall since 1950, though the significance is at the 10% level (Pattyanak et al., 2019). The city of Moundou in Logone Occidental, which is in the Guinea-Congolian region of Chad, has witnessed a significant fall in rainfall at the 5% level.

2000s. Most of Chad's exports as well as most of its internal industrial processes were cotton related. Industrial processes included ginning raw cotton to export quality, spinning and weaving and producing edible cottonseed oil for local production. This has made the Chadian economy dependent on world cotton prices that were good (despite swings) up to the mid-eighties and then fell steeply in 1985. This crippled the Chadian cotton industry (and government revenues), and the industry only survived through a World Bank and foreign donor driven restructuring program (Collier 1990).

The rest of Chadian agriculture was/is mostly subsistence growth of cereals including sorghum, millet and berbere. These cereals mix with smaller scale growth of tubers, wheat (in the Lake Chad area) and some rice in the South. There is also large-scale meat production, usually as a pastoral aside in the Soudanian South and as the focus of semi-sedentary farmers in the Sahel. Bovine and ovine rearing is deeply embedded in Chadian culture, and there is export of 'on the hoof' animals to Sudan, Cameroon and Nigeria. However, this is not often recorded in official GDP, as state-run attempts to industrialize the process through abattoirs and meat-packing facilities have not proved successful. Finally, due to Chad's access to the Lake that bears its name and the Chari and Logone there is a large culture of subsistence fishing. Like the livestock, there is an outside market for dried fish, which are transported to the markets of Madhiguri Nigeria, but again this trade is largely unofficial (Collier 1990).

Initially, Chad was only mining sodium carbonate from Lake Chad and some wadis (river valleys) in the Kanem region. There are also small deposits of bauxite, quartz and uranium, but not enough to have any serious effect on GDP. Chad discovered small deposits of oil in 1970

North of Lake Chad, and an Exxon-led consortium discovered a much bigger field in Southern Chad in 1985. Due to the ongoing instability and low world oil prices, export of Chadian oil only started in 2002. The rise of Chad as an oil-producing nation caused a significant rise in GDP between 2002 and 2010, which has helped President Idris Deby create a strong Chadian state and military. However, many see Chad as a classic example of the 'resource curse' as very little of the oil revenue has focused on development and in 2006 the World Bank closed Chad's oil-revenue account, citing the lack of development use of the revenues (Marchal 2016).

The lack of transport networks in Chad contribute to its lack of internally functioning markets and ability to export goods efficiently. Chad suffers from its lack of access to the sea; Doula in Cameroon is the closest port to N'Djamena at 1700 kilometers. Chad also suffers from lack of all-weather roads. After the instability of the 1980s, there was no record of any paved highways in Chad. The country had only 1260 kilometers of all-weather roads, and hence most of the Chadian internal transport system was impassable in the rainy season. In 2018, despite many efforts by international donors, only 500 kilometers of Chad's 34000 kilometers of roads are paved. Chad has 58 airports, nine of which have paved runways and there is no Chadian rail system (Collier 1990).

By 1990, Chad's system of communication was one of the least developed in Africa. Up until the early 1990s, there was no postal service outside the capital and only a telephone service between the capital and some regional capitals. Radio has been the most robust system of communication in the country up to the mid-2000s, with one in every five Chadians owing a radio in 1997. Mobile phones are creating a communications revolution across Chad with 4.2 million users (one third of the population) in 2012. Though this mobile boom has not extended online, as in 2012, only 2.1% of the population were documented internet users (Collier 1990; Jean-Richard et al 2014).

Chad's currency is the Central African [17]CFA franc, which is also the currency of the Central African Republic, Cameroon, the Republic of the Congo, Equatorial Guinea and Gabon. There are two CFA zones, the Central African and West African which roughly (the ex-Spanish colony of Equatorial Guinea joined the Central African zone, and the ex-Portuguese colony of Guinea-Bissau is a member of the West African zone) correspond to the areas of French colonial Equatorial Africa and French West Africa. Both CFAs were convertible to the French Franc and are now convertible to the Euro at a fixed rate (Collier 1990; Zafar 2005).

Overall, Chad has a very weak economy; with a GDP per capita of $874. Furthermore, oil revenues dominate this GDP figure, which have only enriched a small section of Chadian society. Based on the United Nation's development index, Chad is the seventh poorest country on earth, which demonstrates the lack of human development resulting from Chad's discovery and exploitation of its oil resources (Marchal 2016).

[17] Since independence, the Bank of Central African States or BEAC (Banqur des Etats L'Afrique Centrale) has decided Chad's macroeconomic policy. This is located in Yaoundé, the capital of Cameroon since 1972 and replaced a similar body, also based in Yaoundé. The Central African CFA became the currency of colonial French Equatorial Africa in 1945 and remained the currency of the individual states after independence. The CFA with its history embedded in French Colonialism, is often criticized as a tool of Neo-Colonialism and counter-productive to the individual growth of the States. However, other writers point to the inflationary stability that the CFA brings to the Central African states (Saviddes 1998).

Chad's politics

Modern-day Chad was officially designated as within the French sphere of influence at the Berlin Conference of 1884. Chad was part of French Equatorial Africa, which comprised of the modern-day states of Congo-Brazzaville, Gabon, the Central African Republic and Chad. Chad typifies the negative effect of arbitrarily creating a nation-state without thought to the organic cultural, linguistic, tribal or religious make-up of the country. The post-independence history of Chad can be seen as an attempt to build the structure of a modern nation state's centralized government on an established system of tribal, regional and local governance (Collier 1990).

Though initially ruling as the head of a parliamentary democracy at independence, President Tombalbaye quickly transformed Chad into a despotic, single-party ruler. Subsequent rulers have continued that pattern, except for President Hissen Habre who was a skilled diplomat and politician. Attempts at elections and the creation of a more open culture, have usually been on a surface level to assuage French or other international concerns (Collier 1990).

President Idriss Deby came to power in 1990, as head of Patriotic Salvation Movement (Mouvement patriotique du Salut-MPS) and a member of the Bidyat clan of the Zaghawa ethnic group. He has survived various insurrections against his presidency and won the 1996 and 2001 elections. President Deby successfully managed to overturn the term limits that prevented him from continuing as President, leading to his election victories of 2006, 2011 and 2019. He is now one of Africa's longest servant leaders, has created a strong centralized state, and by building up a strong military has managed to project Chadian power into Sudan, the Central African Republic and the Western Sahel (Tisseron 2015, Marchal 2016).

Within the period of Deby's presidency, there have been several changes to Chad's regional and sub-regional structure. At Independence Chad was sub-divided into fourteen Prefectures; Batha, Biltine, Borkou-Ennedi-Tibesti, Chari-Baguirmi, Guera, Kanem, Lac, Logone Occidental, Logone Oriental, Mayo-Kebbi, Moyen-Chari, Ouaddai, Salamat and Tandjile. In 1999 the regional structure changed and there were twenty-eight departments that were further sub-divided into sixty-one sub-prefectures. In 2002 Chad was officially divided into regions, initially sixteen and then thirty-one and now the twenty-four that we will define later in our data section.

Chad's future

Idriss Deby's presidency has brought relative stability to Chad and it is rising as a regional military power. However, President Deby's power is largely due to the creation of a strong and repressive state and Chad's human, institutional, economic and educational development negatively compares with most African states (Marchal 2016). The figures on various international indices are largely negative; Fund for Peace's Fragile States Index consistently ranks Chad in the ten most fragile states on earth. Furthermore, Transparency International Corruption Perceptions Index named Chad as the most corrupt state on earth in 2005 and regularly is in the top ten and as stated, Chad is in the cohort of the poorest states on earth (Transparency International 2013).

This dissertation extends the weather and fertility literature, by looking at the effects of rising heat on the birth rate, rather than the effects of extreme weather events. This paper is also a micro-based analysis within the larger area of the population/climate change link, especially as it focuses on the African Sahel. Furthermore, with its concentration on the under-researched country of Chad, this dissertation uses the different climatological zones of Chad to answer questions on the weather fertility interaction that have implications for Chad itself, as well as the wider African Sahel region.

CHAPTER 3-RESEARCH QUESTION AND THEORY

Research Questions

This dissertation'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 dissertation, and touches on the climate change population link, as well as the more specific question of how human fertility responds to changing weather patterns. 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.

My second research question is: "could 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.

Thirdly, I ask: "are there health routes whereby an extra high heat day affects fertility?" As I discussed in the literature section, there are many routes by which the changing weather/fertility relationship can be driven by health.

Becker And Demand For Children

I analyze the determinants of the demand for children at an individual rural household level, and hypothesize how higher temperatures would affect this demand. I model the demand for children, consistent with Becker and extend the model to consider the impact of weather on a rural, Chadian community (Becker 1991). I assume that number of children (N) and consumption of other household goods (G) are choice variables. I also assume that individual health ($\overline{H}$) 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 ($\overline{H}$), where $\partial U/\partial \overline{H} > 0$, as increased household health increases utility. Note that household health ($\overline{H}$) 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 her current realization of health stock, she derives utility from it.

$$1)\ \ U_{N,G} = U(N, G; \overline{H}(C))$$

Health ($\overline{H}$) represents individual cumulative health stock, and though this is influenced by other factors, in this model I am only interested in the effect of rising heat on health. The parameter C is a general changing weather parameter that I assume to be rising heat as we are dealing with the Chadian context (and proxy for rising heat with the marginal effect of another high heat day in a month). I assume a negative relationship between changing weather patterns (C) and individual health ($\overline{H}$). This is a strong assumption, but I proxy changing weather patterns through rising heat, which makes this an appropriate assumption. I assume that 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 $\partial H / \partial C < 0$.

[KV1]

The utility function is subject to an income constraint, which has been reduced to isolate those factors influenced by changing weather patterns (C). I 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 ($\overline{H}$) and household crop yield (Y) are influenced by changing weather patterns (C). As we have already stated $\partial H / \partial C < 0$, due to the effect of rising heat on Chad's already arid environment. The sign of $\partial Y / \partial C$[18] is ambiguous, it depends on the area of Chad we are looking at and the original mean temperature of that area.

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

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

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

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

and

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

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

$$5)\quad dN = f_{p_N} dp_N + \; f_{p_G} dp_G + \; f_H \, H_C dC + \; f_I I_Y \, Y_C dC$$

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 $(f_{p_N} dp_N + \; f_{p_G} dp_G)$; 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:

$$6)\quad dN = f_H \, H_C dC + f_I I_Y \, Y_C dC$$

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

Firstly, there is the direct effect of change in weather patterns on household health.

$$f_H \, H_C dC$$

For this model, I assume that changing weather patterns (dC), are rising heat. I have already stated that the effect of rising heat on household health (H_C) is negative. So overall, I want to test that the direct health effect of rising heat on the amount of births in a household (dN) is negative. This route would be through a rise in the number of miscarriages due to heat (but not due to malnutrition), reduced spermatogenesis due to heat or decreased sexual activity due to heat.

The second route by which rising heat (dC) could affect the number of children (dN), is through the effect of rising heat on crop yield.

$$f_I I_Y \, Y_C dC$$

In this route, rising heat (dC) interacts with the effect of rising heat on yield (Y_C), this then affects the household income function (f_I), through the effect of crop yield on household income (I_Y). This is a more intuitive path and could occur for several reasons. However-as I have already stated-the sign of Y_C (or dY/dC) is ambiguous and could be different, in different regions in Chad (or even within different regions). Therefore, the overall effect of this route of transmission is ambiguous. Rising heat is positive (dC), the effect of yield on income is positive (I_Y), and the household income function is positive (f_I). So the effect of rising heat on the number of children that a household has (dN), would be positive if the effect of rising heat on yield (Y_C) is positive and negative, if the sign is negative.

TESTABLE HYPOTHESES

$$f_H \, H_C dC < 0$$

This is the direct effect of rising heat on the number of children, through the pure health route and in the Chadian context I 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 I can assume that this is the pure health effect. Moreover, if this is a pure health effect, I can assume that it happens in the high staple crop regions, as well as the lower staple-crop regions. I 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 Malthusian/Beckerian theory. Malthus said that a rise in household income would lead to a rise in fertility (Malthus 1791). 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 my 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.

However, Malthus talked about larger-scale macro population trends, and my research looks at the individual household effects of changing weather on human fertility. 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.

CHAPTER 4-DATA AND METHODOLOGY SECTION

Recalling equation 3.6, where I hypothesize the relationship between changing weather patterns proxied by an extra high heat day in a month and the birth rate. In this section I describe how I build a dataset and propose an identification strategy that can estimate equation 3.6, and differentiate the different effects through which an extra high heat day can influence human fertility.

In order to test the relationship between weather and the human birth rate, I create a dataset that can map changing weather patterns to changes in fertility response and agricultural production is necessary. To construct this dataset, I 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.

FERTILITY DATA AND COVARIATES

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[19].

Fertility Data

The 2014-15 DHS data includes self-reported reproductive histories for the 17,719 individual sample women, which I use to use to calculate the number of sample births by cluster, month and year. This leads to 135,539 cluster-month-year observations. I create a GIS cluster-specific birth panel by linking the self-reported year and month of birth of each sample woman's children to her GIS cluster. I 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. I 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, my dependent variable is the birth rate. In order to compare across the entire country where different clusters will have different amounts of fertile women, I standardize the variable by calculating the number of fertile women in each cluster by year. I 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:

[19] 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.

$$BR_{imt} = \frac{Births_{it}}{Female_{it}},$$

where $Births_{imt}$ is the number of sample births recalled for cluster i, in month m, and year t. $Female_{it}$ 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. Finally, BR_{it} 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.

HOUSEHOLD COVARIATES

From the DHS data I 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, my models would not pick this up.

For example, I use a control for whether a cluster is urban or rural, because I am interested in the results from rural Chad. However, these are the urban or rural clusters in 2014-2015, and it is safe to assume that there has been a process of urbanization since the 1990s (Guengant and Guealbaye 2013). Again, this would only be a problem if there were a much quicker rate of urbanization in one area in relation to another. A big part of urbanization in Chad is centered on the capital N’Djamena, which I take out of the data due to its very different socio-economic and cultural dynamics (Guengant and Guealbaye 2013). Furthermore, I do not use the Northern Sahara zone in my regressions, because of its extreme climatic situation. Therefore, I can assume that urbanization happens at the same rate in the central Sahelian zone, as in the southern Soudanian zone. This assumption would mean that the process of urbanization since the mid-1990s would not create zonal bias within the data.

The covariates that I 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.

High temperature days data

To achieve a deep granularity, I 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. I 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 a certain temperature threshold by month and mapped them to the GIS clusters of the Chadian DHS data. I ran regressions with number of days above 23 degrees Celsius, up to days above 50 degrees Celsius and found that the range between 31-37 degrees Celsius had a more significant effect on the birth rate, which confirms literature on this subject (C. G Turvey 2001; Texeira et al 2011).

With the number of high-temperature days in a month, I 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, I split the monthly high temperature days' data into the dry/preparation season, the planting/growing season and the harvest season. I 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. I 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, I create a violence index drawn from the data from the Uppsala Conflict Data Program[20] maintained by the University of Uppsala, Sweden.

I 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. I cut this off at 1000 km as I 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. I then take the natural log of the violence index to create a control variable.

[20] 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.

Agricultural Data

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. [21]

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 region-are very large and potentially cross different climatic zones. This would mean that the effect of high temperature days could be

[21] Kanem became Kanem and Bahr El Gazel; Chari-Baguirmi became Chari-Baguirmi and Hadjer-Lamis; Mayo-Kebbi became Mayo-Kebbi 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.

having different significant effects on different areas of the larger region, but 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.

Table 1: Description of variables

Variable	**Description of Variable**
The natural log of the normalized birth rate	The natural log of the normalized birth rate: this is the cluster/year/month specific birth rate, normalized by placing the birthrate over the population of that cluster. I then take the natural log of this variable.
Millet yield (Kg/Ha)	Millet yield: this variable is the amount of millet production in kilograms per hectare. This is recorded by region (as opposed to cluster), so lacks the cluster-level granularity of the other cluster-level variables.

Sorghum yield (Kg/Ha)	Sorghum yield: this variable is the amount of sorghum production in kilograms per hectare. This is recorded by region (as opposed to cluster), so lacks the cluster-level granularity of the other cluster-level variables.
Days above 31 degrees Celsius in dry/ preparation season	Number of days greater than 31 degrees Celsius in dry season: the dry/preparation season is each of the months of January, February and March and then averaged across those months.
Days above 31 degrees Celsius in planting season	Number of days greater than 31 degrees Celsius in planting season: the planting season is each of the months of May, June, July and August and then averaged across those months.
Days above 31 degrees Celsius in harvest season	Number of days greater than 31 degrees Celsius in harvest season: the harvest season is each of the months of September, October, November and December and then averaged across these months.
Days above 31 degrees Celsius in dry/ preparation season with one-year lag	Number of days greater than 31 degrees Celsius in dry season with one-year lag: the dry/preparation season is each of the months of January, February and March and then averaged across these months.

Days above 31 degrees Celsius in planting season with one-year lag	Number of days greater than 31 degrees Celsius in planting season with one-year lag: the planting season is each of the months of May, June, July and August and then averaged across these months.
Days above 31 degrees Celsius in harvest season with one-year lag	Number of days greater than 31 degrees Celsius in harvest season with a one-year lag: the planting season is each of the months of September, October, November and December and then averaged across these months.
Days above 31 degrees Celsius in dry/ preparation season with two-year lag	Number of days greater than 31 degrees Celsius in dry season with two-year lag: the dry/preparation season is each of the months of January, February and March and then averaged across these months.
Days above 31 degrees Celsius in planting season with two-year lag	Number of days greater than 31 degrees Celsius in planting season with two-year lag: the planting season is each of the months of May, June, July and August and then averaged across these months.
Days above 31 degrees Celsius in harvest season with two-year lag	Number of days greater than 31 degrees Celsius in harvest season with a two-year lag: the planting season is the months of September, October, November and December and then averaged across these months.

Number of days above 32-37 degrees Celsius	The same pattern of variables for temperatures between 32-37 degrees Celsius.
Millet area (Ha)	Millet area by hectare: this is the amount of area of millet production in a particular region. I use this as a control in the regressions using millet yield as the dependent variable.
Sorghum area (Ha)	Sorghum area by hectare: this is the amount of area of sorghum production in a particular region. I use this as a control in the regressions using sorghum yield as the dependent variable.
Region	Chadian geographical region: we use dummies for each of the twenty-one Chadian regions to control for geographical heterogeneity. Note that these twenty-one regions are different from the regional structure of the crop data by region and some of the smaller crop regions become one larger region.
Month	Calendar month: we use monthly dummies to control for within-year heterogeneity. This is very important, as we need to control for the yearly seasonal patterns of fertility.

Urban	Dummy variable on whether the region is primarily urban or rural: this is a 1/0 variable that defines a cluster as primarily urban (1), or primarily rural (0). I use this as a control variable because I am interested in the correlations within a rural setting.
Natural log of violence index	The natural log of violence index: we created the violence index through mapping the location of violent incidents in Chad and their level of mortality. I then create an index of the ratio between the mortality number of each incident and each cluster's distance from the violent incident. I then take the natural log of this index.
Year	Calendar year: in the model with the natural log of birth rate as the dependent variable, I use the data between 1997 and 2016 as that ensures a balanced sample.

Table 2: Summary statistics (excluding Sahara zone)

	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
Chad dry > 32	2.8	7.21	0.0	31.0
Chad plant > 32	5.5	10.11	0.0	31.0
Chad harvest > 32	8.6	12.81	0.0	31.0
Chad dry > 33	2.5	6.67	0.0	31.0
Chad plant > 33	4.9	9.33	0.0	31.0
Chad harvest > 33	8.1	12.41	0.0	31.0
Chad dry > 34	2.1	6.11	0.0	31.0
Chad plant > 34	4.1	8.37	0.0	31.0
Chad harvest > 34	7.6	11.95	0.0	31.0
Chad dry > 35	1.8	5.51	0.0	31.0
Chad plant > 35	3.3	7.25	0.0	31.0
Chad harvest > 35	7.1	11.39	0.0	31.0
Chad dry > 36	1.4	4.90	0.0	31.0
Chad plant > 36	2.4	6.00	0.0	31.0
Chad harvest > 36	6.4	10.64	0.0	31.0
Chad dry > 37	1.1	4.27	0.0	31.0
Chad plant > 37	1.6	4.68	0.0	31.0
Chad harvest > 37	5.6	9.69	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 have the highest number at each point.

Table 3: Sahel summary statistics

	mean	sd	min	max
Log of birth rate	2.0	0.46	1.2	3.9
Sorghum yield (Kg/Ha)	514.9	516.88	0.0	4888.7
Sorghum area (Ha)	76839.9	84306.74	25.0	436332.0
Millet yield (Kg/Ha)	386.8	246.16	0.0	899.7
Millet area (Ha)	101434.3	81286.36	2200.0	428420.0
Chad dry > 31	3.6	8.37	0.0	31.0
Chad plant > 31	6.5	11.01	0.0	31.0
Chad harvest > 31	8.9	13.06	0.0	31.0
Chad dry > 32	3.3	7.90	0.0	31.0
Chad plant > 32	5.9	10.38	0.0	31.0
Chad harvest > 32	8.4	12.70	0.0	31.0
Chad dry > 33	2.9	7.39	0.0	31.0
Chad plant > 33	5.2	9.61	0.0	31.0
Chad harvest > 33	7.9	12.31	0.0	31.0
Chad dry > 34	2.5	6.83	0.0	31.0
Chad plant > 34	4.4	8.67	0.0	31.0
Chad harvest > 34	7.4	11.87	0.0	31.0
Chad dry > 35	2.1	6.20	0.0	31.0
Chad plant > 35	3.5	7.57	0.0	31.0
Chad harvest > 35	6.9	11.33	0.0	31.0
Chad dry > 36	1.8	5.56	0.0	31.0
Chad plant > 36	2.6	6.32	0.0	31.0
Chad harvest > 36	6.2	10.64	0.0	31.0
Chad dry > 37	1.4	4.86	0.0	31.0
Chad plant > 37	1.8	4.95	0.0	31.0
Chad harvest > 37	5.5	9.77	0.0	31.0
Urban	0.3	0.45	0.0	1.0
Log of violence index	-3.3	0.94	-5.6	1.8
N	78192			

I observe that that though Sahelian sorghum and millet yield is lower than the Chadian mean and sorghum area is lower, the area given to millet production is larger than the Chadian mean. This is because the Sahel contains the region of Chari-Baguirmi that has a significantly greater amount of land given to Millet production than any other of Chad's regions, rather than any systematic difference between the Sahel and the Soudan. Also the Sahel has a higher number of high temperature days, especially in the dry/preparation season and the planting season. However, the harvest season in the Sahel has less high heat days than the Chadian mean and indeed than the Soudan zone. This demonstrates that though the Soudan is on average colder than the Sahel, there are more extreme bursts of heat in the harvest season.

Table 4: Soudan summary statistics

	mean	sd	min	max
Log of birth rate	2.0	0.46	1.2	4.2
Sorghum yield (Kg/Ha)	699.0	240.35	0.0	1973.0
Sorghum area (Ha)	93640.9	42150.54	25300.0	202674.0
Millet yield (Kg/Ha)	590.0	186.61	0.0	1092.0
Millet area (Ha)	43640.0	23734.28	15600.0	174000.0
Chad dry > 31	2.5	6.35	0.0	31.0
Chad plant > 31	5.6	10.24	0.0	31.0
Chad harvest > 31	9.3	13.38	0.0	31.0
Chad dry > 32	2.1	5.71	0.0	31.0
Chad plant > 32	5.0	9.59	0.0	31.0
Chad harvest > 32	8.9	13.01	0.0	31.0
Chad dry > 33	1.7	5.07	0.0	31.0
Chad plant > 33	4.3	8.77	0.0	31.0
Chad harvest > 33	8.4	12.58	0.0	31.0
Chad dry > 34	1.4	4.47	0.0	31.0
Chad plant > 34	3.6	7.77	0.0	31.0
Chad harvest > 34	7.9	12.09	0.0	31.0
Chad dry > 35	1.0	3.88	0.0	31.0
Chad plant > 35	2.8	6.61	0.0	31.0
Chad harvest > 35	7.3	11.48	0.0	31.0
Chad dry > 36	0.8	3.32	0.0	31.0
Chad plant > 36	2.0	5.37	0.0	31.0
Chad harvest > 36	6.6	10.65	0.0	31.0
Chad dry > 37	0.6	2.84	0.0	31.0
Chad plant > 37	1.3	4.14	0.0	31.0
Chad harvest > 37	5.7	9.56	0.0	31.0
Urban	0.2	0.40	0.0	1.0
Log of violence index	-3.5	0.96	-5.5	-1.5
N	43632			

Notice that the Soudan staple crop statistics are above the Chadian mean, both sorghum and millet yield and Sorghum crop area are higher than the Chadian mean, which makes sense as the Soudan is the more agriculturally productive area of Chad. Also, the amount of high heat days are less in the dry/preparation season. However, the amount of harvest season high heat days is greater than the Chadian mean.

Table 5: High staple crop intensity regions

	mean	sd	min	max
Log of birth rate	2.0	0.46	1.2	3.9
Sorghum yield (Kg/Ha)	693.8	385.86	0.0	2517.0
Sorghum area (Ha)	94330.2	72017.77	48.0	436332.0
Millet yield (Kg/Ha)	536.2	213.91	0.0	899.7
Millet area (Ha)	69507.9	74004.99	2200.0	428420.0
Chad dry > 31	3.5	8.02	0.0	31.0
Chad plant > 31	6.4	10.92	0.0	31.0
Chad harvest > 31	9.0	13.18	0.0	31.0
Chad dry > 32	3.1	7.51	0.0	31.0
Chad plant > 32	5.8	10.28	0.0	31.0
Chad harvest > 32	8.6	12.83	0.0	31.0
Chad dry > 33	2.7	6.96	0.0	31.0
Chad plant > 33	5.1	9.48	0.0	31.0
Chad harvest > 33	8.1	12.46	0.0	31.0
Chad dry > 34	2.3	6.36	0.0	31.0
Chad plant > 34	4.3	8.53	0.0	31.0
Chad harvest > 34	7.6	12.03	0.0	31.0
Chad dry > 35	1.9	5.70	0.0	31.0
Chad plant > 35	3.4	7.40	0.0	31.0
Chad harvest > 35	7.1	11.49	0.0	31.0
Chad dry > 36	1.6	5.02	0.0	31.0
Chad plant > 36	2.5	6.13	0.0	31.0
Chad harvest > 36	6.4	10.78	0.0	31.0
Chad dry > 37	1.2	4.32	0.0	31.0
Chad plant > 37	1.7	4.81	0.0	31.0
Chad harvest > 37	5.7	9.86	0.0	31.0
Urban	0.2	0.38	0.0	1.0
Log of violence index	-3.4	0.94	-5.5	-1.2
N	49248			

The cut-off between low intensity and high intensity staple crop areas is based on percentage of area given to staple crop production in a 2011 World Food Program report (WFP 2011). I denote a region to be a high intensity staple crop region if more than 5% of its land surface is given to the cultivation of at least one of the major Chadian staple crops, sorghum or millet[22]. The areas of low staple crop intensity would have a more diverse range of crops and livestock use. They would tend to have a larger area given to cotton cash crop production if they are based in the Soudan. Or they would have larger areas given to livestock pasture or transhumance if they are based in the Sahel (WFP 2010).

The high intensity staple crop areas tend to have a larger amount of high heat days than the Chadian mean, though this is mainly due to the larger amount of such regions in the Sahel rather than the Soudan (five in the Sahel, three in the Soudan). The high intensity staple crop areas also have a much larger area given to sorghum production, and also higher sorghum and millet yields.

[22] By this definition the Sahelian high staple crop areas are: Chari Baguirmi, Guera, Salamat, Bahr el Ghazal and Dar Sila. The Soudanian high staple crop areas are: Mayo Kebbi Est, Mayo Kebbi Ouest, and Tandjile. Most regions that are 6% or more in either area given to sorghum or millet production, are 6% or more in both. However, both Mayo Kebbi Est and Ouest have only 4% given to millet production, while their areas given to sorghum production are 8% and 9% respectively. The most borderline case is the Sahelian region of Bahr El Gazal, 6% of its land is given to millet production and 5% is given to sorghum production.

Table 6: Low staple crop intensity region

	mean	sd	min	max
Log of birth rate	2.0	0.46	1.2	4.2
Sorghum yield (Kg/Ha)	592.3	454.27	0.0	4888.7
Sorghum area (Ha)	75472.0	67631.20	25.0	436332.0
Millet yield (Kg/Ha)	478.8	203.87	0.0	1092.0
Millet area (Ha)	86154.3	67553.76	14630.0	428420.0
Chad dry > 31	3.2	7.70	0.0	31.0
Chad plant > 31	6.1	10.69	0.0	31.0
Chad harvest > 31	9.0	13.11	0.0	31.0
Chad dry > 32	2.8	7.18	0.0	31.0
Chad plant > 32	5.5	10.04	0.0	31.0
Chad harvest > 32	8.5	12.71	0.0	31.0
Chad dry > 33	2.4	6.64	0.0	31.0
Chad plant > 33	4.8	9.26	0.0	31.0
Chad harvest > 33	8.0	12.27	0.0	31.0
Chad dry > 34	2.1	6.09	0.0	31.0
Chad plant > 34	4.0	8.28	0.0	31.0
Chad harvest > 34	7.5	11.77	0.0	31.0
Chad dry > 35	1.7	5.53	0.0	31.0
Chad plant > 35	3.2	7.14	0.0	31.0
Chad harvest > 35	6.9	11.16	0.0	31.0
Chad dry > 36	1.4	4.95	0.0	31.0
Chad plant > 36	2.3	5.87	0.0	31.0
Chad harvest > 36	6.2	10.39	0.0	31.0
Chad dry > 37	1.1	4.35	0.0	31.0
Chad plant > 37	1.5	4.52	0.0	31.0
Chad harvest > 37	5.3	9.39	0.0	31.0
Urban	0.2	0.39	0.0	1.0
Log of violence index	-3.4	0.97	-5.6	1.8
N	61776			

Notice that the number of hectares given to millet production is larger in the low intensity areas than in the higher intensity areas. This is due to some of the larger Sahelian regions have a larger area given to staple crop production, but that is a much smaller percentage of the region's land area.

Recall that I want to estimate equation 3.6:

$$dN = f_H H_C dC + f_I I_Y Y_C dC$$

Here there are two major ways that changing weather patterns can affect demand for children. Through our identification strategy and the models we 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 3.6 represents the direct effect of changing weather patterns on the birth rate. This can be through the effects of changing weather patterns on health.

Due to the trajectory of changing weather patterns in Chad, I 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). I have documented the different routes by which this can happen, but for the purpose of this econometric model I 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 I have noted, I am interested in the effect of changing weather patterns on fertility in a Chadian context. I assume that changing weather patterns mean rising heat in Chad, and thus I allow for days above temperatures of 31 degrees Celsius as a proxy for the effects of rising heat.

Econometric Model

Based on equation 3.10 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 high heat days as follows:

$$(1)\ LnBR_{imt} = \alpha_0 + \beta_1 Hightmpdays31_{imst}$$

$$+\beta_2 X_{it} + \lambda_m + \eta_r + y_t + \varepsilon$$

Where $LnBR_{imst}$ is the natural log of the birth rate, and $Hightmpdays31_{imst}$ is the season's average number of days above 31 degrees Celsius per month, in cluster *i*[23]**.** X_{it} is a matrix of controls that includes an urban[24] indicator and the natural log of the violence index**.** I also

[23] If the month m is prior to the growing season in year *t* then the most recent growing season occurs in year *t-1*.

[24] 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.

include a vector of regional, $\eta_r$and monthly dummies, λ_i, and year fixed effects, y_t, to control for spatial and temporal trends in fertility and temperature.

I use a fixed effects semi-log regression to model the relationship between the birth rate and the number of high temperature days. I use year fixed effects to remove time trends from my right and left-hand side variables. Also, I 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.

I 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). I 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, I 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, I estimate the effect of average maximum growing season temperature on millet yield, one of Chad's staple food crops.

$$(2) \qquad MY_{rt} = \alpha_0 + \beta_1 Hightmpdays31_{imst}$$
$$+\beta_2 X_{it} + \lambda_i + \eta_r + y_t + \varepsilon$$

Where $MYrt$ is the total millet yield in kilograms per hectare for region r in year *t.* As with fertility, I 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 I also control for the area given to millet production by region in the vector of covariates X_{it}.

I also run the same model using sorghum yield SY_{rt} as the dependent variable.

$$(3) \qquad SY_{rt} = \alpha_0 + \beta_1 Hightmpdays31_{imst}$$
$$+\beta_2 X_{it} + \lambda_i + \eta_r + y_t + \varepsilon$$

[KV2]

I 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). I 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, I run the model with a zero lag, one-year lag and a two-year lag.

Identification strategy

I 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 I first run the models with data from the Sahel and Soudan combined, then I split the data into four sections. Firstly, I split the data by Sahelian and Soudanian climate zone, then I split the data by percentage of region given to the cultivation of the major staple crops of Sorghum and Millet. I then run all our models using the amount of days over a certain 31 degrees Celsius, as the independent variables in all three models. I then run the same models with a zero lag, a one-year lag and a two-year lag.

I 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. I 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.

CHAPTER 5-RESULTS

In this section I present the results of my three econometric equations; (1) Birthrate model (2) Millet yield model and (3) Sorghum yield model. I run each model with all Chad data (Soudan and Sahel), only Sahel data, only Soudan data, only High staple crop intensity and only Low staple crop intensity data. In each of these five categories, I run nine different regressions: firstly with days above 31 degrees Celsius in the dry season, then in the planting season and finally in the harvest season. Secondly, I run these three regressions with zero lag, one-year lag and two-year lag.

Table 7: Overall Chad (Soudan and Sahel)-Birthrate model: 0, 1 and 2-year lag

VARIABLES	Chad zero lag	Chad one-year lag	Chad two-year lag
lnnbirthrate	.	.	.
Dry season			
Days above 31 C in dry season	-0.0007	-0.0009	-0.0012**
	(0.001)	(0.001)	(0.001)
	0.237	0.113	0.025
Planting season			
Days above 31 C in planting season	-0.0011**	-0.0011**	-0.0010*
	(0.000)	(0.001)	(0.001)
	0.018	0.035	0.088
Harvest season			
Days above 31 C in harvest season	0.0014*	0.0007	0.0012**
	(0.001)	(0.001)	(0.001)
	0.06	0.287	0.034
Observations	33,723	33,723	33,723
R-squared	0.037	0.037	0.037
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1 (P-values in 3rd row)

Table 7 reports the results from nine different iterations of equation (1), the birth rate model, run with the data from across Chad (without the Sahara zone). Firstly, there is a significant negative correlation between the number of dry season days above 31 degrees Celsius, and the birth rate in the two-year lag iteration of the model. As stated previously, I assume that any significant correlations in the dry season are related to some sort of health route. The two-year lag suggests that this route could be through heat's effect on spermatogenesis or reduced ovulatory function, rather than any increased miscarriage effect and it is also worth noting that the one-year lag iteration of the model is nearly significant (Boserup 1985; Lam, Miron 1996; Scholte, Van den Berg, Lindeboom 2015).

Secondly, there are significant negative correlations between the number of planting season days above 31 degrees Celsius, and the birth rate in the zero, one-year and two-year iterations of the model. These are the most robust results that I observe, and I see later that this is driven by the Sahel zone. It is interesting to note that the significant negative correlations occur in the zero, one-year and two-year lag iterations of the model. Later on, I discuss the clear link between the results in the millet yield model (2)-and these results-and suggest a clear Beckerian economic/food security route (Becker 1981; Ray et al. 2012; Porter et al. 2013; Tiwari et al. 2017). However, the fact that there is such a clear negative significant correlation with the zero lag model, suggests that part of the effect could be through the effect of malnutrition on miscarriages and increased incidence of stillbirth (Strand, Barnett & Tong 2011; Basu, Sarovar & Malig 2016). However, the zero-lag iteration of the model is based on the most recent completed growing season, hence this effect could be coming from a variety of avenues.

Thirdly, there are significant positive correlations between the number of harvest season days above 31 degrees Celsius, and the birth rate in the zero and two-year lag iterations of the model. This is another result that occurs across several models and would be suggestive of a positive effect of harvest season heat on the optimal staple crop (particularly millet) harvest (De Wet, Bidinger and Peacock 1991; Yadav et al 2004). However, I don't observe a corresponding significant positive effect on crop yield in models (2), and (3).

Table 8: All Chad-Millet yield model: 0, 1 and 2-year lag

VARIABLES	Chad zero lag	Chad one-year lag	Chad two-year lag
Millet_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.0021	0.0414	-0.1705
	(0.139)	(0.154)	(0.12)
	0.988	0.792	0.177
Planting season			
Days above 31 C in planting season	0.026	-0.227**	-0.0716
	(0.184)	(0.105)	(0.088)
	0.89	0.049	0.430
Harvest season			
Days above 31 C in harvest season	0.0009	0.0516	-0.0911
	(0.332)	(0.16)	(0.28)
	0.998	0.765	0.75
Observations	86,688	86,688	86,688
R-squared	0.669	0.669	0.669
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

Turning to the nine iterations of model (2), the millet yield model with the pooled Chad data, I only observe one significant correlation. There is a significant negative correlation between the number of planting season days above 31 degrees Celsius, and millet yield in the one-year lag iteration of model (2).

This result is very important and relates to the planting season results that we observe in our results for model (1) run with the overall Chad data. The number of days above 31 degrees Celsius cause a drop in fertility, but also cause a drop in millet yield. This suggests a Beckerian mechanism operating-children as normal goods-as households have a negative food/economic shock and hence react by deciding to have less children (Becker 1991).

Table 9: All Chad-Sorghum yield model: 0, 1 and 2-year lag

VARIABLES	Chad zero lag	Chad one-year lag	Chad two-year lag
Sorghum_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.055	-0.1331	0.0258
	(0.186)	(0.182)	(0.187)
	0.772	0.477	0.892
Planting season			
Days above 31 C in planting season	-0.1074	-0.2614	-0.0820
	(0.324)	(0.294)	(0.161)
	0.746	0.391	0.619
Harvest season			
Days above 31 C in harvest season	0.2326	-0.1079	-0.021
	(0.363)	(0.284)	(0.371)
	0.533	0.711	0.956
Observations	79,536	79,536	79,536
R-squared	0.532	0.532	0.532
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In this estimation of model (3), there are no significant correlations, though there is a consistent negative point estimate for the correlation between extra planting season high heat days and the birth rate.

Table 10: Sahel-Birthrate model: 0, 1 and 2-year lag

VARIABLES	Sahel zero lag	Sahel one-year lag	Sahel two-year lag
lnnbirthrate	.	.	.
Dry season			
Days above 31 C in dry season	-0.001	-0.0004	-0.0006
	(0.001)	(0.001)	(0.001)
	0.132	0.426	0.387
Planting season			
Days above 31 C in planting season	-0.0013**	0.0014**	-0.0012*
	(0.001)	(0.001)	(0.001)
	0.043	0.046	0.077
Harvest season			
Days above 31 C in harvest season	0.0021***	0.0012	0.0017**
	(0.001)	(0.001)	(0.001)
	0.007	0.15	0.025
Observations	21,200	21,200	21,200
R-squared	0.048	0.049	0.049
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1 (P-values in 3rd row)

In the estimation of model (1) with purely Sahelian data, there is a similar pattern of significance to the results of model (1) run with the pooled Chad data. There are significant negative correlations between the number of planting season days above 31 degrees Celsius, and the birth rate in the zero, one-year and two-year lag iterations of the model.

I also notice significant positive correlations between the number of harvest season days above 31 degrees Celsius, and the birth rate in the zero and two-year lag iterations of the model.

Apart from one dry season result when we run model (1) with the overall Chad data, I observe the same pattern of correlations in model (1) run with purely Sahelian data. This suggests that the more climate vulnerable Sahel zone (Potts 2015) is the main driver of the results from the food security/economic route. The Sahel region is often cited as a clear example of food insecurity due to climate vulnerability and would be more vulnerable to a food security/economic route driving the effect of rising heat on fertility (Becker 1981; Ray et al. 2012; Porter et al. 2013; Tiwari et al. 2017).

Table 11: Sahel-Millet yield model: 0, 1 and 2-year lag

VARIABLES	Sahel zero lag	Sahel one-year lag	Sahel two-year lag
Millet_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.0267	-0.1466	-0.2717*
	(0.200)	(0.175)	(0.141)
	0.896	0.417	0.074
Planting season			
Days above 31 C in dry season	-0.1347	-0.342**	-0.1956
	(0.259)	(0.152)	(0.124)
	0.612	0.042	0.138
Harvest season			
Days above 31 C in dry season	-0.2015	-0.2068	-0.347
	(0.345)	(0.255)	(0.274)
	0.568	0.431	0.226
Observations	52,752	52,752	52,752
R-squared	0.708	0.708	0.708
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In the estimation of model (2) run with the Sahel data, there is a similar pattern with the same model run with across Chad data. Firstly, there is a significant negative correlation between the number of dry season days above 31 degrees Celsius, and millet yield in the two-year iteration of the model. Notice that this is a similar significant negative result (on the two-year lag iteration of the model) in model (1) run with overall Chad data. This result is difficult to interpret, but may be due to a high heat drying season hardening the ground and hence affecting the planting season (Yadav et al 2004).

Secondly-and similar to the same model run with across Chad data-there is a significant negative correlation between the number of planting season days above 31 degrees Celsius, and millet yield in the one-year iteration of the model. Again, this suggests that the Sahel zone is driving the linked results from models (1) and (2), which I see in the models run with overall Chad data. This suggests the Beckerian link between heat, crop yield and fertility that I have discussed is evident in Chad's Sahel zone (Becker 1991).

Table 12: Sahel-Sorghum yield model: 0, 1 and 2-year lag

VARIABLES	Sahel zero lag	Sahel one-year lag	Sahel two-year lag
Sorghum_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	0.1062	-0.4270*	-0.207
	(0.238)	(0.227)	(0.232)
	0.662	0.082	0.389
Planting season			
Days above 31 C in planting season	-0.2840	-0.4640	-0.1624
	(0.42)	(0.375)	(0.172)
	0.511	0.238	0.362
Harvest season			
Days above 31 C in harvest season	-0.0698	-0.8038	-0.0317
	(0.483)	(0.577)	(0.391)
	0.887	0.187	0.937
Observations	45,600	45,600	45,600
R-squared	0.576	0.576	0.576
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In our estimation of model (3), the sorghum yield model, we observe one significant correlation. There is a significant negative correlation between the number of dry season days above 31 degrees Celsius, and sorghum yield in the one-year iteration of the model.

The dry season significant correlation are difficult to interpret and demonstrate that I cannot assume a dry season significance means that it is a direct health effect. Furthermore, there is evidence that heat shocks in the Chadian dry season can affect the yield in the planting and harvesting season due to damage to the soil environment (Yadav et al 2004).

Table 13: Soudan-Birthrate model: 0, 1 and 2-year lag

VARIABLES	Soudan zero lag	Soudan one-year lag	Soudan two-year lag
lnnbirthrate	.	.	.
Dry season			
Days above 31 C in dry season	0.0010	-0.0007	-0.0015*
	(0.001)	(0.001)	(0.001)
	0.405	0.454	0.062
Planting season			
Days above 31 C in dry season	-0.0006	-0.0005	-0.0005
	(0.001)	(0.001)	(0.001)
	0.563	0.633	0.537
Harvest season			
Days above 31 C in dry season	-0.001	0.0002	0.0007
	(0.001)	(0.001)	(0.001)
	0.988	0.901	0.598
Observations	12,523	12,523	12,523
R-squared	0.018	0.018	0.018
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In the more agriculturally prosperous Soudan, there aren't any significant correlations in the more agricultural seasons in model (1), the birth rate model. In the more population dense areas of the Soudan, there has been more agricultural development and an advance in use of irrigation methods that mitigates against climate extremes (Boserup 1964; Sivakumar 1989).

There is a significant negative correlation between the number of dry season days above 31 degrees Celsius, and the birth rate in the two-year lag iteration of the model. Notice that this significant correlation is the same result that we observe in model (1) run with overall Chad data. This suggests that the Soudan zone is driving that result. This could suggest that there is an effect of heat on the birth rate in the Soudan, which is driven by one of the non-economic health routes suggested (Boserup 1985; Lam, Miron 1996; Scholte; Van den Berg, Lindeboom 2015).

Table 14: Soudan-Millet yield model: 0, 1 and 2-year lag

VARIABLES	Soudan zero lag	Soudan one-year lag	Soudan two-year lag
Millet_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.0837	0.2187	-0.0941
	(0.199)	(0.152)	(0.124)
	0.681	0.175	0.461
Planting season			
Days above 31 C in planting season	0.3141	0.3102	0.2034
	(0.214)	(0.178)	(0.170)
	0.166	0.105	0.253
Harvest season			
Days above 31 C in harvest season	0.7722	0.4157	0.6963
	(0.561)	(0.600)	(0.517)
	0.192	0.501	0.201
Observations	33,936	33,936	33,936
R-squared	0.157	0.157	0.157
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In the Soudan based estimation of model (2), the millet yield model, there aren't any significant correlations between the amount of days above 31 degrees Celsius and millet yield.

Note that there are not any significant correlations in the agricultural seasons in model (1) run with data from the Soudan. This suggests that the Soudan region is less vulnerable to the negative effects of heat shocks on agricultural yield, and indeed the number of planting season days above 31 degrees Celsius is very close to having a positive significant effect on millet yield in the one-year lag iteration of the model.

Table 15: Soudan-Sorghum yield model: 0, 1 and 2-year lag

VARIABLES	Soudan zero lag	Soudan one-year lag	Soudan two-year lag
Sorghum_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.2185	0.2396	0.2224
	(0.335)	(0.256)	(0.136)
	0.526	0.367	0.126
Planting season			
Days above 31 C in planting season	0.3425*	0.5208**	-0.0310
	(0.176)	(0.199)	(0.223)
	0.073	0.021	0.892
Harvest season			
Days above 31 C in harvest season	0.8970***	0.5342	-0.0638
	(0.250)	(0.462)	(0.766)
	0.003	0.268	0.935
Observations	33,936	33,936	33,936
R-squared	0.321	0.321	0.321
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In this estimation of model (3), the sorghum yield model, run with Soudan data, there are more significant correlations. There are significant positive correlations between the number of planting season days above 31 degrees Celsius, and sorghum yield in the zero and the one-year lag iterations of the model.

Also, there is a significant positive correlation between the number of harvest season days above 31 degrees Celsius, and sorghum yield in the zero lag iteration of the model.

In model (3) run with Soudan data, we see that millet and sorghum yield in the Soudan zone is less vulnerable to heat shocks than the Sahel zone. Indeed, we observe the opposite, high heat days have a positive effect both in the planting and harvest seasons. Also, the fact that these positive shocks to staple crop yield don't have a corresponding positive effect on the birth rate (in the Soudan zone) suggests that the simple Beckerian hypothesis we advance is not operating in the agriculturally more-developed Soudan zone, or that it is not the complete story (i.e. it's not operating through agricultural productivity).

Table 16: High staple crop intensity-Birthrate model: 0, 1 and 2-year lag

VARIABLES	High staple crop zero lag	High staple crop one-year lag	High staple crop two-year lag
lnnbirthrate	.	.	.
Dry season			
Days above 31 C in dry season	-0.0005	-0.0009	-0.0007
	(0.001)	(0.001)	(0.001)
	0.554	0.253	0.439
Planting season			
Days above 31 C in planting season	-0.0012	-0.0017*	-0.0012
	(0.001)	(0.001)	(0.001)
	0.139	0.07	0.124
Harvest season			
Days above 31 C in harvest season	0.0010	0.0001	0.0003
	(0.001)	(0.001)	(0.001)
	0.322	0.879	0.756
Observations	14,469	14,469	14,469
R-squared	0.024	0.024	0.024
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

I now turn to the models run with data from regions with high intensity staple crop use. In this estimation of model (1), the birth rate model, there is one significant correlation. There is a significant negative correlation between the number of days above 31 degrees Celsius, and the birth rate in the one-year lag iteration of the model, and both the zero and two-year lag iterations of the model are nearly significant.

This result-the significant effect of planting season high heat days on the birth rate-is now familiar across a variety of models, and suggests that the significant negative correlation is driven by the Sahel zone and regions with high staple crop intensity. This is also a further suggestion that this significant correlation is driven by a food security/economic route (Becker 1981; Ray et al. 2012; Porter et al. 2013; Tiwari et al. 2017).

Table 17: High staple crop intensity-Millet yield model: 0, 1 and 2-year lag

VARIABLES	High staple crop zero lag	High staple crop one-year lag	High staple crop two-year lag
Millet_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.0622	0.0815	-0.2564*
	(0.212)	(0.228)	(0.130)
	0.774	0.727	0.071
Planting season			
Days above 31 C in planting season	0.1213	-0.3714*	-0.0298
	(0.262)	(0.181)	(0.097)
	0.651	0.059	0.764
Harvest season			
Days above 31 C in harvest season	0.0323	0.0840	-0.0721
	(0.408)	(0.361)	(0.367)
	0.938	0.819	0.847
Observations	38,304	38,304	38,304
R-squared	0.646	0.646	0.646
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1 (P-values in 3rd row)

In our estimation of model (2), the millet yield model, there are two significant correlations. Firstly, there is a significant negative correlation between the number of dry season days above 31 degrees Celsius, and millet yield in the two-year lag iteration of the model.

Secondly, there is a significant negative correlation between the number of planting season days above 31 degrees Celsius, and millet yield in the one-year lag iteration of the model.

The significant dry season correlation is similar to other versions of our model, and is more difficult to interpret though is more suggestive of a health route.

The planting season result is now consistent across model (1) run with overall Chad, Sahel zone and high staple crop intensity region data, as well as model (2) run with overall Chad, Sahel zone and now high staple crop intensity data. This suggests that our simple Beckerian model has explanatory power in the Sahel zone and in regions that have a higher staple crop intensity. This makes intuitive sense as in regions where there is less dominance of staple crops, there will be the effect of other mechanisms on the birth rate, which won't be picked up by our simple model.

Table 18: High staple crop intensity-Sorghum yield model: 0, 1 and 2-year lag

VARIABLES	High staple crop zero lag	High staple crop one-year lag	High staple crop two-year lag
Sorghum_Y_kg_ha	.	.	.
Dry season			
Days above 31 C in dry season	-0.0240	-0.4232	0.0145
	(0.231)	(0.295)	(0.237)
	0.919	0.175	0.952
Planting season			
Days above 31 C in planting season	-0.5243	-0.8416	-0.0535
	(0.510)	(0.500)	(0.243)
	0.323	0.116	0.829
Harvest season			
Days above 31 C in harvest season	-0.2157	-0.6396	-0.322
	(0.627)	(0.497)	(0.757)
	0.736	0.220	0.677
Observations	35,616	35,616	35,616
R-squared	0.483	0.483	0.483
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

There are no significant correlations between the days above 31 degrees Celsius and sorghum yield in our estimation of model (3) run with data from regions with high staple crop intensity.

Millet and Sorghum have different resistance to extremes of heat, but I would expect heat to have similar effects on both staple crops. Though there is no significant negative relationship, there is a nearly significant correlation between planting season days and sorghum yield in our one-year lag iteration of model (3). This is further evidence that the heat shocks affect the birth rate through their effect on crop yields.

Table 19: Low staple crop intensity-Birthrate model: 0, 1 and 2-year lag

VARIABLES	Low staple crop zero lag	Low staple crop one-year lag	Low staple crop Two-year lag
lnnbirthrate	.	.	.
Dry season			
Days above 31 C in dry season	-0.0004	-0.0005	-0.0013
	(0.001)	(0.001)	(0.001)
	0.661	0.545	0.102
Planting season			
Days above 31 C in planting season	-0.0009	-0.0005	-0.0008
	(0.001)	(0.001)	(0.001)
	0.152	0.405	0.203
Harvest season			
Days above 31 C in harvest season	0.0022**	0.0017	0.0027***
	(0.001)	(0.001)	(0.001)
	0.047	0.103	0.001
Observations	16,965	16,965	16,965
R-squared	0.042	0.042	0.042
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

The final estimations of our models are run with data from the Chadian regions with low staple crop intensity. These regressions estimate model (1), the birthrate model. There are significant positive correlations between the number of harvest season days above 31 degrees Celsius, and the birthrate in our zero and two-year lag iterations of the model.

In model (1) run with data from the regions with low staple regions, there is a similar pattern in terms of harvest season positive correlations as in model (1), run with across Chad data. The fact that this pattern is driven by the low intensity crop regions, suggests that the positive significant correlation between harvest season heat days and the birth rate is more complicated than a simple case of high heat days leading to an optimal harvest.

Table 20: Low staple crop intensity-Millet yield model: 0, 1 and 2-year lag

VARIABLES	Low staple crop Zero lag	Low staple crop one-year lag	Low staple crop two-year lag
Millet_Y_kg_ha	.	.	.
Dry season data			
Days above 31 C in dry season	0.0161	-0.0029	-0.1166
	(0.150)	(0.148)	(0.142)
	0.916	0.985	0.424
Planting season data			
Days above 31 C in planting season	-0.0910	-0.1169	-0.1227
	(0.172)	(0.110)	(0.139)
	0.606	0.307	0.391
Harvest season data			
Days above 31 C in harvest season	-0.0427	0.0184	-0.0699
	(0.404)	(0.219)	(0.339)
	0.917	0.934	0.839
Observations	48,384	48,384	48,384
R-squared	0.675	0.675	0.675
Number of year	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

In our estimation of model (2), the millet yield model, run with data from the low staple crop intensity regions, there aren't any significant correlations.

Notice that in this estimation of the model-run with low intensity staple crop region data-there is neither a significant negative correlation between planting season high heat days and the birth rate nor a significant correlation with those same high heat days and millet yield. This is further evidence that our simple Beckerian hypothesis that relates the effect of heat shocks on the birth rate through staple crop yield is evident in regions of higher crop yield, and breaks down in areas where there those staple crops are not so dominant.

Table 21: Low staple crop intensity-Sorghum yield model: 0, 1 and 2-year lag

VARIABLES	Low staple crop zero lag	Low staple crop One-year lag	Low staple crop Two-year lag
Sorghum_Y_kg_ha	.	.	.
Dry season data			
Days above 31 C in dry season	0.0446	0.1365	0.0219
	(0.178)	(0.214)	(0.223)
	0.806	0.534	0.923
Planting season data			
Days above 31 C in planting season	0.0224	0.1176	-0.0334
	(0.214)	(0.167)	(0.134)
	0.918	0.493	0.807
Harvest season data			
Days above 31 C in harvest season	0.3053	0.0575	0.356
	(0.224)	(0.287)	(0.207)
	0.197	0.845	0.110
Observations	43,920	43,920	43,920
R-squared	0.615	0.615	0.615
Number of year	14	14	14

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
(P-values in 3rd row)

Here I estimate model (3), the sorghum yield model, with data from the low staple crop intensity regions of Chad. There aren't any significant correlations in these estimations of model (3).

There isn't much in this estimation of model (3) to note, except that the (non-significant) signs are positive and are nearer to significance with harvest season high temperature days.

Recalling Our Original Research Questions:

This dissertation'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 dissertation, 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.

Thirdly, we ask: "are there health routes whereby rising heat affects fertility?" As we discuss in the literature section, there are many routes by which the changing weather/fertility relationship can be driven by health.

Our first question is modelled through model (1), the birth rate model and we use model (2) and model (3) to draw conclusions about our second and third questions.

Recalling equation 3.10 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.

Planting Season High Heat Days

The clearest pattern in the data is the significant negative correlation between planting season days above 31 degrees Celsius and the birth rate, in the overall Chad, Sahel and high intensity crops data models.

In these same estimations (Chad, Sahel and high intensity crop regions) of models (2) and (3), millet yield and sorghum yield, I observe what effects the same planting season days above 31 degrees Celsius have on staple crop yield.

In terms of model (2)-the millet yield model-there is the same pattern of significant negative correlation, especially in the one-year lag model. Furthermore, though there are no significant negative correlations with model (3) sorghum yield, there is a constant negative relationship between planting season days above 31 degrees Celsius and Sorghum yield in the estimations run with overall Chad, Sahel and high intensity staple crop regions data.

Recall that the effect of rising heat on fertility through crop yield was ambiguous, because I was unsure about the effect of rising heat on staple crop yield. But I can say that in the Sahel region, the effect of rising heat on staple crop yield (especially millet) is negative, hence I can sign the second route in terms of Sahelian (or Sahelian dominated) models:

$$f_I(+)I_Y\,(+)Y_C\,(-)DC(+)$$

So overall, in estimations of our model run (or dominated by) data from the Sahel zone and high intensity staple crop regions, I can infer that the effect of rising heat on human fertility is negative.

This is what I observe in these negative correlations between planting season days above 31 degrees Celsius and the birth rate in the estimations run with overall Chad, Sahel and high intensity staple crop data.

Furthermore, this group of results is suggestive of a confirmation of our Beckerian understanding of the effect of income on human fertility (Becker 1991). Our model assumes that rising income would cause a rise in fertility and falling income would cause the opposite, as we don't model the quantity/quality trade-off that Becker suggests later for the reason of modern low fertility regimes (Becker 1991). This is also suggestive that the Sahel region of Chad could be in the 'Malthusian Epoch' as designated by Oded Galor (Malthus 1791; Galor 1999; Galor 2000).

Harvest Season High Heat Days

The second clear pattern across the various estimations is the model (1) significant positive correlation between the number of days above 31 degrees Celsius, and the birth rate in the zero and two-year lag iterations of the model. I observe the same result in the estimations run with Sahelian data, suggesting that this result is driven by the Sahel region. I also observe the same result in the estimations run with data from the low staple crop intensity regions, thus suggesting that this effect may not be driven by the effect of the same high heat days on staple crop yield.

When I turn to the effects of the high heat days on staple crop yield, it is more difficult to see a clear pattern. Recall that I observe this significant positive relationship in the estimations run with overall Chad, Sahel and low intensity staple crop data. When I look at the effects of high heat days on model (2) and model (3) in the estimations run with the same data, I don't observe any corresponding patterns. There are no significant correlations in the estimations run with overall Chad, Sahel or low staple crop intensity regions data.

There is one significant positive correlation between the number of harvest season days above 31 degrees Celsius and Sorghum yield, in the zero lag iteration of the model (3) run with data from the Soudan. However, this does not add to understanding as there is no corresponding significant relationship in model (1)-the birth rate model-run with Soudan data.

It is interesting to note that the only estimations where there seems to be a similar pattern between the models, is in the estimations run with data from low intensity staple crop intensity data. In these estimations, where I observe the pattern of significant correlations, I see that there is a (non-significant) positive relationship between the number of days above 31 degrees Celsius and sorghum yield. Furthermore, in the zero and two-year lag iterations of the model I can see that the relationship is nearly positively significant.

These results belie a clear interpretation, due to the pattern of significance manifesting in the estimations run with low staple crop region intensity data. I cannot say that there isn't a food security/economic route by which the harvest season high heat days influence the birth rate, but I don't see clear evidence that it is operating through the effect of rising heat on staple crop yield.

Dry Season High Heat Days

In terms of dry season significant correlations, there is a significant negative correlation between dry season days above 31 degrees Celsius, and the birth rate in the two-year lag iteration of the model in the overall Chad data. I see this same significant negative correlation in the estimation of model (1) run with Soudan data.

There are also significant negative correlations in the staple crop yield models-(2) and (3)-but not in the same estimations in which I observe the significant relations in model (1). I do not observe significant correlations between high heat days and staple crop yields in the estimations where there are significant correlations in model (1), the overall Chad and Soudan data estimations. In the estimations run with Sahel data, there is a significant negative correlation between the number of dry season days above 31 degrees Celsius and millet yield in the two-year lag iteration of the model. Furthermore, in the Sahel estimation there is a negative significant correlation between the number of dry season days above 31 degrees Celsius, and sorghum yield in the one-year iteration of the model. I also note a significant negative correlation between the number of days above 31 degrees Celsius, and millet yield in the two-year lag iteration of the model.

These results are difficult to interpret, as there are dry season heat shocks that affect staple crop yield. However, the heat shocks that significantly affect staple crop yield do not affect the birth rate and vice-versa. Hence, I assume that those dry season heat shocks that affect the birth rate are through some sort of health-related route.

CHAPTER 6 CONCLUSION

Summary of Method and Findings

In this dissertation I 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. I 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. I observe this effect in the models run with across Chad data, Sahelian data and high staple crop intensity area data.

Wider Implications

Due the planting season results, I can suggest that there is some predictive power to my simple 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 I cannot say that my simple model explains a lot of the interaction between rising heat and fertility in a Chadian context.

However, there is a generally negative link between rising heat and fertility as that is the pattern in both the planting season and the dry season, especially in the larger Sahelian part of the country.

My 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 1791; Galor 1999; Galor 2000).

Returning to Guengant and Guealbaye overview of Chad's demographic trajectory, I can hypothesize what the results could mean for Chad's future population growth (Guengant & Guealbaye 2013). Guengant and Guealbaye do not factor in the effects of climate change on Chad's population growth and it is clear that it would have some effect, especially if the present trajectory of rising heat continues.

However, I cannot assume that there is no fertility rebound effect as I only survey fertility decisions over a two-year lag. So, though the results suggest that rising heat may provide a brake to Guengant and Guelbaye's 'High hypothesis', I cannot categorically state that there will be no fertility rebound effect to the results we demonstrate.

That being said, based on climate projections, I can assume that rising heat will continue to be an issue in Chad, especially as the pace of climate change quickens (Potts 2015). Though I 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.

Caveats

Though there is a very clear result in the planting season that seems to tell a clear story, there are other more ambiguous results. Though I can say that the planting season results speak about a food security/economic route, it is more difficult to understand how the effect of an extra high heat day on the birth rate operates through the various health routes.

Future Directions

There are many ways that I want to develop this research in the future. Though the main interest of this dissertation is the food security/economics routes by which rising heat affect the birth rate, there are clearly health routes that need further investigation. Throughout this dissertation I have held the disease environment constant and assumed that there is no effect of changing weather patterns on the disease environment. In the future I would like to relax this assumption and find models that could investigate the effects of rising heat on particular aspects of the disease environment and test for how that effects the birth rate.

In this dissertation I have developed relatively simple theoretical and econometric models, but in the future I would like to use mediation analysis to parse out the different mediators of the effects of an extra high heat day on the birth rate. This could further develop our understanding of the food security/economic channels, as well as investigating the different health channels that could be mediating this effect.

Finally, throughout this dissertation I have controlled for violence as background noise. However, Chad has seen significant levels of national and localized conflict, especially since 2004. Violence could be a mediating variable between rising heat and the birth rate and in future I would like to investigate this.

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My final words on this dissertation are to give Glory to God in Jesus Christ. Amen