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Fertility responses to climate change in West Africa

by

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Abstract We analyse the effects of climate anomalies on women's fertility in West Africa. We combine socioeconomic and fertility data from 10 rounds of Burkina Faso, Guinea, Nigeria and Mali 's Demographic and Health Surveys and long-term high resolution spatial temperature and precipitation records to assess how women and households adapt their fertility preferences and births in response to exposure to local temperature and precipitation anomalies. We also analyse the role of physical capital and livelihoods in such response. We find positive associations between higher than normal temperatures and the odds of desiring a larger family and births, while precipitation shocks show weakly robust results. We attribute this upward revision in women's fertility to higher labour demand or lower costs of childbearing.

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To the family and friends who have made this difficult summer easier, and to those who no longer are with us.

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1. INTRODUCTION

We analyse the relationship between climate anomalies, as a proxy to climate change, and fertility outcomes in West Africa. Climate change is already exerting an influence on human livelihoods, which are likely to affect demographic trends(Bongaarts and O' Neill, 2018). The effects of climate change may have already started to exert negative consequences on human health. Climate change either makes difficult or worsens agricultural production, in turn worsening food security (Fraser, 2006) and widespread poverty limits the ability of households to adapt to adverse shocks to their environment (Lewis and Buontempo, 2016). Given the strong dependence on agriculture of the West Africa region (Bjornlund et al., 2020) -often close to half of national GDPs depend on the agricultural sector in the region (Oluwatayo and Ojo, 2016) - the link between agricultural production, health and well-being is arguably even stronger than in other developing regions. West Africa has often been dubbed as one of the hot-spots of climate change in the World (Crawford, 2015). Temperatures in the region are rising at twice the global averages and rainfall is increasingly variable and unpredictable, leading to severe droughts as those experienced during the 70's and 80's (Crawford, 2015).

Rural households have devised strategies to adapt to environmental degradation and worsening climatic conditions for agriculture (Sissoko et al., 2011). Adaptation strategies to resource scarcity and climate change often involve the sale of household assets or livestock, farm diversification and specialization (Sissoko et al., 2011). However, adaptation strategies often also involve an intensification of natural resources and water use, which can exacerbate the effects of climate change on soil degradation (Jie et al., 2002). Increasing resource scarcity has been previously linked higher labour demand and increasing returns to childbearing through higher household labour demand (Biddlecom et al., 2005; Sasson and Weinreb, 2017). While households draw from a variety of strategies to adapt to climate change (de Sherbinin et al., 2008) deliberate adjustments in human fertility have been employed as an adaptation mechanism in response to a variety of shocks such as economic crises (Sobotka et al., 2011; Eloundou-Enyegue et al., 2000) or environmental degradation (Sasson and Weinreb, 2017). Household income shocks following self-reported crop failures and delays in monsoon onset have been related to increases in family planning use and drops in desire to have children and births (Alam and Pörtner, 2018; Sellers and Gray, 2019).

This brings the attention to the interplay of the environment and population dynamics. West Africa is experiencing exceptional population growth, growing at almost 3% per year since the early 21^{st} century (Crawford, 2015). In Sub-Saharan Africa, drops in Total Fertility Rates expected from the demographic transition have slowed down during the last decades (Bongaarts and Casterline, 2013), which may allow for continued population growth. Population growth in the region is considered pernicious for several reasons. Population growth may hinder economic development and entrench poverty and heighten vulnerability to environmental shocks(IPCC, 2014). Population growth, the environment and living standards are strongly linked. Population growth is set to increase the demand for food in the region, which in turn will lead to a further intensification of land use (to the extent that higher food demand is not partially covered by agricultural innovations (de Sherbinin et al., 2008), which is set to worsen soil degradation, furthering the pernicious effects of climate change (Sissoko et al., 2011). Population growth is a strong correlate of greenhouse emissions and economic growth emissions (Bongaarts and O' Neill, 2018; Bloom et al., 1998), which can further the effects of climate change, although West Africa is far from being a leader in CO2 emissions.

Despite the strong conceptual grounds upon the relationship between climate change and health and fertility is built (de Sherbinin et al., 2008; Grace, 2017), the empirical evidence for such relationship remains rather weak (Grace, 2017). These studies focus mostly on the developing world, since stunting, low birth weight and child and mother health problems and a strong reliance on livelihoods that directly depend on the environment for subsistence are more prevalent in the developing world (Grace, 2017). Studies pondering this relationship aim to link historical variations in temperature and precipitation with socioeconomic, demographic and health data. The bulk of the literature has devoted itself to study the effects of exposure to climate anomalies to children in utero to obtain insights of how climate shocks might affect child and mother's health, with a particular interest in the incidence of low birth weight -endemic in Sub-Saharan Africa and a strong predictor of child mortality-, finding negative albeit inconsistent health consequences (Molina and Saldarriaga, 2017; Deschenes et al., 2009; Bakhtsiyarava et al., 2018; Pereda et al., 2014; Grace et al., 2015; Walker et al., 2007). Acknowledging different livelihoods (strategies to smooth income, consumption or food intake) strategies may lead to different income or consumption smoothing patterns (de Sherbinin et al., 2008; Sissoko et al., 2011), a higher incidence of low birth-weight is found amongst households following the livelihood strategies that depend most on water and their environment for their livelihood, subsistence farmers and pastoralists (Grace et al., 2012, 2014, 2015; Bakhtsiyarava et al., 2018) Other authors, under the life course approach, have exploited exposure to temperature and precipitation anomalies during early childhood to evaluate adult socioeconomic outcomes (Randell and Gray, 2019; Carrillo, 2019; Wilde et al., 2017). Robust effects of climate variability have also been found on migration (Gray and Mueller, 2012; Thiede et al., 2016), mortality(De Waal et al., 2006) and educational outcomes (Randell and Gray, 2016).

However, less studies have been devoted to the relationship between climate variability on fertility (Grace, 2017). Despite theoretical (de Sherbinin et al., 2008;

Grace, 2017) and empirical (Biddlecom et al., 2005; Alam and Pörtner, 2018) work has been devoted to the effects of environmental degradation and resource scarcity on fertility. Nevertheless, recent empirical work has lend itself to study the effects of changing precipitation and temperatures on fertility intentions (Sellers and Gray, 2019; Eissler et al., 2019), birth-rates (Barreca et al., 2018) and timing of birth (Simon, 2017). However, these studies have reached different conclusions about the effects of temperature and precipitation anomalies on reproductive outcomes and intentions. While climate anomalies have been found to exert an effect on fertility preferences (ideal family size and desire to have additional children) and outcomes (births), a myriad of theoretical explanations, local environmental characteristics and the fact that most surveys only allow to study the second order effects of climate anomalies on fertility through the influence of socioeconomic and health shifts (Grace, 2017).

This study aims to contribute to illuminate the fertility adaptation to climate change by analysing the relationship between fertility preferences and outcomes and temperature and precipitation anomalies. We examine the relationship of climate anomalies with the desire to have additional children and births, constraints may not allow women to realize their fertility desires (Bongaarts and Casterline, 2013; de Sherbinin et al., 2008). Then, we examine how ownership of physical assets and access to services mediates the climate fertility relationship (Sasson and Weinreb, 2017), given that the adaptive capabilities of households are heightened by higher material wealth (de Sherbinin et al., 2008). Finally, inspired by the Rural Livelihood Framework (de Sherbinin et al., 2008), we expect adaptation to climate change to show heterogeneous fertility responses by different livelihood zones (food croppers, cash croppers and pastoralists) given their differential dependence on water (Grace, 2017), and adaptation strategies available to their livelihood mode.

We aim to reach our research objectives by estimating a battery of mixed-effects logistic regressions in which the dependent variables are fertility outcomes and preferences and the independent variables of interest are historical deviations from normal precipitation and temperature, followed by a series of models in which we interact climate anomalies with household wealth and livelihood categories, respectively. To estimate these models, we draw from women socioeconomic and fertility micro data obtained from IPUMS-DHS (Boyle et al., 2020) using 10 survey rounds from Burkina Faso, Guinea, Mali and Nigeria. The DHS project provides with GPS coordinates for its household clusters contained in its surveys. This allows us to geographically link survey data to our measures of climate anomalies, processed from the high resolution Terrestrial Air Temperature and Precipitation Monthly Time Series (1950 - 2017) (Willmott and Matsuura, 2001). We complement the analysis with livelihood zones provided by the US Agency on International Development's Famine Early Warning System Network (FEWS-NET).

We find robust positive associations between abnormally high temperatures and fertility preferences and births using both short and long-term climate anomaly measures. Higher (lower) than normal precipitation shows less robust results, but proportionally associated with higher (lower) desire to have additional children. This suggests that precipitation and temperature exert heterogeneous influences as conditions that impose constraints on agricultural production (high temperature and low precipitation) work in opposite ways to increase and reduce fertility preferences. We also find evidence of climate anomalies leading to reductions in fertility as material wealth grows and heterogeneous fertility responses across livelihood groups.

This study proceeds as follows. Section 2 provides context for climate change, fertility trends and plausible adaptation strategies in West Africa. Section 3 outlines the theoretical grounds and the main channels of fertility responses to environmental shocks. Section 4 presents the data and variables used. Section 5 explains the methods used to achieve our research goals. Empirical results are shown in Section 6. The study is finalised presenting the discussion of the main results in Section 7 and the main conclusions drawn from this research in Section 8.

2. CLIMATE CHANGE, ADAPTATION AND FERTILITY IN WEST AFRICA

2.1. The incidence of climate change in West Africa

West Africa is one of the regions most affected by climate change in the World. The region has experienced mean temperature increases of up to 2ºC since the 1970's, coupled with a region wide drop in rainfall (IPCC, 2014). Additionally, precipitation has become more unpredictable, recently reaching the wide decade rainfall variability that brought dramatic droughts during the 70's and 80's (Crawford, 2015).

Rainfall experiences great annual and 10-year variation, which does little to remedy the harsh scarcity of potable water. This is not the only constraint on agricultural activities, since poor soils and the pervasive poverty limit the growth potential of the agricultural sector (Sissoko et al., 2011). High rainfall variation coupled with increasing temperatures have also led to increasing water evaporation and expansion of arid lands (IPCC, 2014). Long dry seasons characterized by high water evaporation are followed by brief and uncertain wet seasons (Sissoko et al., 2011). Rainfall records of the West African arid environments from 1960-1990 speak of a stark fall in mean precipitation (Sissoko et al., 2011). Progressively meagre precipitation has become more variable for the same period, increasing drought risk in the region. This long drying period has been considered some of the most striking climate change process in recent history, and has resulted in the aridization -or desertification- of climatic zones in the region (Dietz et al., 2004). While projections for future climate scenarios vary widely (Paeth and Hense, 2004), extreme weather events, higher number of extreme dry and wet periods will increase in the region, as well as the world for the remainder of the 21st century (Huntingford et al., 2005). In short, West Africa is becoming hotter, its rainfall more unreliable, extreme weather events, drought and storms are ever more common and soils are becoming poorer(Crawford, 2015). Thus, the impact on climate change in the region is going to be some of the harshest on Earth (Lewis and Buontempo, 2016).

Climate change has led to a generalised withering of the already scant tree cover across the region during the second half of the 20th century (Gonzalez et al., 2012). Climate change has also exerted great strain on food systems, with more than half of West Africa's inhabitants estimated to be in risk of food insecurity (Clover, 2003). Water shortages have also become more pervasive and common (Epule et al., 2017). The region was expected to face up to 250 million tonnes food deficits by 2020 (Sissoko et al., 2011). Climate change is also considered a catalyst for several diarrheal sicknesses, limiting hopes of erasing these diseases from the region (WAT, 2015). Additionally, the plight of the communities most affected by climate change, as well as political marginalization among the communities most affected by climate change and resource scarcity in West Africa are said to be a prominent factor behind political conflicts and violence in the region (Raleigh, 2010), although the climate change-conflict relationship through resource scarcity may not be as strong as previously thought (Benjaminsen et al., 2012). Climate change is increasing the incidence of urban-rural and out-migration, as well as climate refugees, since climate change directly affects livelihoods and health (Epule et al., 2015; Brown, 2008). On a lighter note, climate change could also lead to an optimized use of water and environmental resources (Giannini et al., 2008), and the West African governments have actively engaged in climate adaptation initiatives, being the region which has recorded the most adaptation actions between 1975 and 2015 (Epule et al., 2017).

The dominant livelihood mode in the region is agriculture. Thus, increases in temperature, variations of the amount or distribution of rainfall around the year and the higher rate of occurrence of extreme weather events will invariably impact water availability, and thus crop yields (Sissoko et al., 2011). Therefore, climate change related weather events can be linked with a reduction in crop yields and thus food availability or income. Just as households feel the effects of climate change, they develop a myriad of strategies to adapt to worsening conditions for agriculture(Sissoko et al., 2011). Additionally, farmers have benefited from regional early warning systems providing them with a level of anticipation to climate shocks (Sissoko et al., 2011).

Climate stress is an especially salient factor impacting farmers livelihood strategies in Sub-Saharan Africa. Climate predictions expect a reshaping of the continent's regional staple crops, reducing agricultural productivity (Teixeira et al., 2013). Heat stress increase the negative health consequences of engaging in agricultural labour (Heal and Park, 2016). Rising temperatures over the long term and shifts in precipitation patters related with climate change can lead to aggregate household shocks, rather than idiosyncratic (Günther and Harttgen, 2009). While households can support each other within a community in the face of a catastrophe under idiosyncratic shocks, when whole communities are affected all community members are affected in some ways and therefore cannot provide a social safety net (Samphantharak and Chantarat, 2015).

The entrenched poverty present in the region limits the capabilities of agricultural communities to adapt to environmental and climatic anomalies. Pastoralism and subsistence farming remain the most prominent livelihood strategies among West Africa's inhabitants, creating a direct link between climate change and standards of living. Rising temperatures, neigh unpredictable rainfall, water shortages, as well human activity lead to degrading solid, which in turn reduce agricultural yields and thus incomes and consumption (Lewis and Buontempo, 2016). Additionally, the region's population is prominently young and under educated, with the highest out of school rates in the world, limiting sectoral change and the development of a solid agricultural sector (Crawford, 2015).

2.2. Adaptation Rural households

Food security and poverty are also being put to test through the degradation of environments. Up to 40% of the regions's GDP comes from agriculture, impacting local environments through land overuse. Soil mining is the main source of soil degradation, as nutrients from the soil are removed without renovation, which along with water, wind erosion and human activities are all factors behind land degradation (Sissoko et al., 2011). These strategies are aimed at smoothing income related to climatic shocks, and adaptation to changing environments (Davies, 1996). The most common adaptive strategy among rural dwellers involves income diversification, followed by water extraction, livestock sales soil preservation and the intensification in use of farm inputs, as well as switching crops to higher yielding plant varieties (Sissoko et al., 2011). Agricultural systems in the poorest areas in the region are marked by resource depletion (López-Ridaura et al., 2007). Meagre soils and few income generating activities besides smallholding agriculture lead farmers to land overuse, and, in the medium to long term, declining yields. The consequence is a downward spiral of unsustainable development (Sissoko et al., 2011).

In this context, poorer farmsteads are less able to generate surpluses to weather the scarcity generated by climate shocks, thus increasing the risk of food insecurity among these (Dietz et al., 2004). Even though technologies that a afford a higher water efficiency for agricultural activities could be applied with low financial resources, their adoption remains low due to the high labour requirements to install and operate them (Dietz et al., 2004). Though perhaps obvious, it must be stated that larger farms are more able to adopt coping strategies like the adoption of technical innovations or the shift to non-agricultural activities (Dietz et al., 2004). Generally, the higher the socioeconomic-status or farm size, the greater the adaptive capabilities of a household and lower risk of food insecurity (Dietz et al., 2004).

Rural communities also resort to informal group risk sharing as an adaptive strategy. Localized groups (family, kin or neighbours) can support each other in response to an idiosyncratic shock (Dietz et al., 2004). Self-insurance may be another channel through which households can cope with these disasters, basically through consumption smoothing, building up stocks or assets in high times, so they can be used in low times (Sissoko et al., 2011).

Urban dwellers are also set to feel first-hand the effects of climate change. However, they do not occupy a central role in our analysis. Climate change in the form of temperature shifts could increase energy demands, worsen air quality or create heat islands. Urban areas could also be impacted by higher flooding or landslide risks (Chu et al., 2016). Disasters and extreme weather events can drastically reduce water availability, increase food prices and damage household assets (Kousky, 2014). Urban areas could also see social tensions rise by the arrival of climate refugees, which could disrupt the provision of services and exert pressures on already scarce infrastructure (Salehyan, 2005).

2.3. The demographic transition in West Africa

Fertility in Sub-Saharan Africa stood at more than double the replacement level from 2005 to 2010 (Bongaarts and Casterline, 2013), leading to fast population growth in the region when coupled with robust, albeit slow, falls in mortality. Population growth in the region is one of the obstacles to the improvement of living standards and development (Bongaarts and Casterline, 2013). The demographic transition in West Africa has evolved much slower than the rest of Africa. While fertility is high by international standards (Bongaarts and Casterline, 2013). West Africa's slow progress in the demographic transition rises worries that the region may not fully benefit from the demographic dividend (Shekar et al., 2016). According to its age structure and poverty the region is not expected to achieve a prominent healthy and educated youth when the rest of Africa is arguably showing more promising expectations in this regard (Shekar et al., 2016).

In the demographic transition framework, the high fertility observed at the early stages is motivated by the desire to expand family size (Bongaarts and Casterline, 2013). Households may decide to increase their numbers so that they increase the number of hands available for work at the family business or farm or to ensure good care during old age (Bongaarts and Casterline, 2013). In the early stage of the fertility transition, high fertility coincides with high mortality, which may also lead to a higher desire for additional children to hedge against child mortality (Bongaarts and Casterline, 2013). Then, as development progresses, urbanisation and education disseminate, improved medical services push child mortality downwards (Bongaarts and Casterline, 2013). These factors lead to a decline in fertility, which are achieved through family planning. That is, the use of contraception, abortion abstinence or participation in family planning programs.

Most countries in Africa are found in the early stages of the fertility transition, and its fertility declines have been slower in Sub-Saharan Africa than have been in the rest of the developing world (Bongaarts and Casterline, 2013). This delay has led to some researchers to posit African exceptionalism in fertility transitions (Caldwell and Caldwell, 1987, 1988; Caldwell et al., 1992). The fertility decline in Sub-Saharan Africa has been slower than in Asia, Latin America, the Caribbean or Northern Africa from 1955 to 2015. However, SSA's paths became similar to that of Asia for the period 1985-1990, but still 20 years after a fertility decline was observed in the rest of the world. While SSA's path of fertility decline has been lagging behind other developing regions since the mid-20th century, its path of decline has been the fastest among developing regions into the 21st century (Bongaarts and Casterline, 2013). Countries in Central and West Africa have a higher level of unmet need for family planning than the South and Eastern countries. Due to lack of access to family planning services, a substantial portion of those women who would like to limit their births undergo undesired pregnancies (Bongaarts and Casterline, 2013). This is more prevalent in the Northern and West Regions, where unmet is a far greater component of family planning demand than contraceptive use. Unmet need is also higher in Africa than in Asia or Latin America, which are more advanced in their fertility transitions, which translates in to a higher availability and knowledge about contraception, allowing to avoid unplanned pregnancies (Bongaarts and Casterline, 2013).

3. LITERATURE REVIEW

3.1. Theoretical base and potential channels

Fertility behavior changes have been employed by households as an adaptation strategy to climatic or environmental shocks that change the availability of household resources (Eloundou-Enyegue et al., 2000; Sasson and Weinreb, 2017; Bilsborrow, 1987). The relationship between fertility and environment is developed on the notion that childbearing is part of the economic calculus of a household and that in rural subsistence societies the childbearing returns exceed costs (de Sherbinin et al., 2008). Evidence suggests that even in cases where children participate in resource gathering, they do not become net producers until they turn 11 (de Sherbinin et al., 2008). In turn, in societies where women marry early, their contribution to the household may be shorter. However, childbearing does not only involve economic incentives, as families may see cultural or social benefits, as well as old age insurance in childbearing (de Sherbinin et al., 2008). For instance, fertility (as well as mortality) adaptations to resource scarcity are central to Malthus (1798)'s work. In a Malthusian world, resource scarcity brought by climate change (like worsening food security or soil degradation), could, in subsistence economies, limit the availability of nutrients, triggering preventive (voluntary fertility restrictions) or positive checks (mortality hikes). This framework still fuels debate and remains relevant in the literature linking environmental changes and population dynamics.

Rooted in the *neo-Malthusian* tradition, lies the Vicious Circle Model (VCM). The VCM argues that high fertility is employed by households in subsistence rural areas as a strategy to fulfill the demand for labour at the household or the farm in response to resource scarcity(Dasgupta, 1995). As resources become scarcer and the labour requirements to collect them increase, poorest households demand more child labour and thus increase fertility (Sherbinin et al., 2007). Poverty can be related to high fertility given a higher demand for household labour, insurance births (given high child mortality) and the low social status of women. In turn, high fertility pushes population growth upwards, This raises resource and food demand given a static resource base. as per capita availability decreases with population growth, soils become less fertile, yields fall and environmental sanitation worsens (Sherbinin et al., 2007). This contributes to an encroachment of poverty, which contributes to the degradation of resources, as households are incentivised to employ techniques based on short-term soil exploitation, since poverty keeps land holders from using fertilizers and invest in fixed capital (Sherbinin et al., 2007).

However, Malthusian frameworks often disregard the introduction of innovations (Lam, 2011), improving the efficiency of resource collection and thus, breaking the circle. Additionally, households can undertake several adaptation strategies in order to avoid a Malthusian trap. Adopting new agricultural technologies, changing crops, expanding crop-lands to name a few (Boserup, 1987; Pan and López-Carr, 2016). Additionally, households often engage in several adaptation strategies at the same time, and may only turn to changing demographic behavior once other strategies have been depleted, under the *Multiphasic Response Theory* (MRT) (Bilsborrow H. W. O., 1992; Davis, 1963).

Similar to MRT , multi-disciplinary research has brought the *Rural Livelihood Approach* (RLF). The RLF (Reardon and Vosti, 1995; Davies, 1996; Ellis, 2000; de Sherbinin et al., 2008) proposes that rural households engage in livelihood strategies that comprise a combination of activities (farming, fishing, rearing livestock, off-farm employment, hunting or gathering), to adapt to their surroundings. The livelihood-fertility relationship derives from the household model of fertility (Becker and Lewis, 1973). Empirical studies have relied on this framework to disentangle the interdependence in households in terms of human capital (the number and quality of children), production consumption and labour market participation, identifying how households choose different livelihood strategies given their asset endowments and preferences.

The different livelihood activities allow households to maintain ownership and obtain different forms of capital that make up household wealth, formed by combinations of natural social, human, physical and financial capital (de Sherbinin et al., 2008). The combination and present availability of capital is determined by former capital accumulation approaches followed by the household. The household employs combinations of these forms of capital to thrive in their environment, also determining their impact on it. Institutional, cultural, economic and international factors further determine the accumulation and employ of these forms of capital (Sherbinin et al., 2007). Under this framework, the household, not the individual is considered a unit of production and human reproduction, where preferences are somewhat uniform and decisions, strategies, deciding how different risks are prioritized (Ellis, 2000).

As a result of climate change, livelihoods may no longer become available, income may be harder to generate and access to nutrition education and health services might be restricted. Thus, households may take up on several adaptation choices, including changes in farming, consumption and fertility (Davis and Lopez-Carr, 2010). Consumption choices can interact with fertility decisions, resulting in the well known child quantity-quality trade-off (Becker and Lewis, 1973).Women's fertility behaviors and preferences are then a product of the household's decision making process. Thus, having additional children represents an strategy to acquire human or social capital to be employed by the household to meet its objectives (Sasson and Weinreb, 2017). Due to the regional reliance on agriculture, shocks to natural capital (the local environment, quality of soils, climatic conditions), from which households obtain subsistence require a adaptation of livelihood strategies (de Sherbinin et al., 2008).

Because of differing household asset endowments, not all households respond in the same way to similar stressors, including those related to climate change, providing an opportunity for researchers to explore how environmental and demographic change interact in different settings (Sherbinin et al., 2007). Call et al. (2019) find small holders to show heterogeneous responses to 12-month and 60-month climate anomalies. In the short run, smallholders stave off heat waves increasing their investments in agriculture and partaking in complementary off-farm labour. Instead, in the long run, there is an association between lower agricultural income and less engagement in off-farm labour. While in the short term farmers can adapt to short term climate anomalies through on-farm strategies but are not sufficient to offset declining farm incomes in the longer run related with periods of long hot temperatures Call et al. (2019).

Thus, under the livelihood approach, adaptation to climate change shocks through fertility is only one of the many possible strategies followed by households. The VCM would imply, under the livelihood approach that households without capital would build their human and social capital (additional births, increased marriage and out migration of children) in order to improve their ability to obtain subsistence from their available natural capital (de Sherbinin et al., 2008).

Following Eissler et al. (2019)'s framework, exposure to local temperature and precipitation variability, as proxies for climate change, are expected to lead to a disturbance in the household's livelihood strategies by triggering changes in resource availability and risk expectations. Here, fertility behavior and intentions is considered one among a range of strategies households may use to adapt to climate change. While we follow by outlining several channels through which households may desire to modify their reproductive behaviors and intentions, available theoretical frameworks limit the ability to establish the strength or direction associations between climate anomalies and fertility may take. We follow by presenting the relevant channels through which climate anomalies may influence fertility decisions, namely: Socioeconomic status, intra household conflict, health and sectoral reallocation.

3.2. Socio-economic status

The main channel through which we expect households to shift their fertility preferences in response to climatic shocks is through shifts in socioeconomic conditions (Sutherland et al., 2004). Studies have found a negative relationship between fertility on the one hand, and farm-size, cattle and natural resource availability. Thus higher fertility households tend to be poorer (Sutherland et al., 2004). Alam and Pörtner (2018) assess the effects of self reported crop shortages on fertility, finding that the probability of having a pregnancy or giving birth amongst women who experience crop losses is lower than in those who do not. They find that this result derives deliberately as a response from the shock of crop loss to the household. However, other research has found weaker effects of crop losses on fertility (Kim and Prskawetz, 2010). Further, research has also found financial shortages to shift household behavior to economize on resources, among which, reductions in fertility (Eloundou-Enyegue et al., 2000) and timid increases in the use of contraception can be found (McKelvey et al., 2012).

First, climate induced changes may lead to an increase the demand for household labour. Higher household labour supply have been shown to appear as a response to resource scarcity, trying to make up for worsening yields (de Sherbinin et al., 2008). Women may increase their desired number of children, expecting these to provide additional labour (Sasson and Weinreb, 2017). In Nepal and Pakistan, increased collection times of fodder and wood resources as a result of local scarcity are associated with increases in intended family size (Biddlecom et al., 2005; Filmer and Pritchett, 2002; Brauner-Otto and Axinn, 2017). Additionally, if farming households respond to worsening yields by expand by expanding their land holdings, increased demand for labour and thus higher births, by increasing the returns to childbearing. But changes in labour demand could also be caused by shifts in occupations and roles within the household (Alston et al., 2018). In general, conditions that place a higher work burden on either the husband, the woman or both are shown to depress fertility preferences caused by higher opportunity cost of additional children (Van den Broeck and Maertens, 2015).

If environmental degradation may lead to higher returns to household labour (Biddlecom et al., 2005; Filmer and Pritchett, 2002; Brauner-Otto and Axinn, 2017), households could increase their fertility , leading to a quantity-quality trade-off (Becker and Lewis, 1973). Since individuals must allocate time and income towards taking care of children, parents are faced with the quantity-quality trade-off. The decision involves dedicating more resources towards adding children to the family, or investing in education or future of the child. Thus, increasing the costs of child-rearing and decreasing fertility (Casey et al., 2019). Research has found a link between rainfall shocks and educational outcomes. In Uganda, scarce rainfall is found to lead to lower enrollment in primary schools among older girls, due to their higher labour burden compared to their younger male and female siblings (Björkman-Nyqvist, 2013). Mani et al. (2013) finds for Ethiopia that higher than normal rainfall measured at the survey year was negatively correlated with enrollment and academic performance among boys, due to their higher participation in household farm labour. Good rains are also found to be positively correlated with the probability of school dropout among boys, while those who experience drought experienced no effect (Shah and Steinberg, 2017).

Since positive rainfall shocks are correlated with higher agricultural productivity, thus raising the returns of farm child labour relative to the returns of schooling. (Beegle et al., 2006) children from households who experienced severe crop losses increased their labour by 30% and were less likely to be enrolled schools, although this effect is only experienced by poorer households. In Honduras, exposure to Hurricane Mitch, led to a decrease in attainment in secondary education among children belonging to households which were experiencing a credit constraints (Gitter and Barham, 2007). Additionally, children can also be intended as insurance for long term household income security and old-age care for parents, leading to an incentive on fertility (Rosenzweig and Schultz, 1983).

Second, climate change could lead to a change in the relative costs of childbearing. The effect of shifting household resources as a result of disasters or climate events might go either way. Raising children can represent a financial burden for many households. Hence, a reduction of household resources as a result of a climate shocks could raise the relative cost of childbearing and reduce the desire for additional children and births (Eloundou-Enyegue et al., 2000). Additionally, resource scarcity can lead parents to postpone births on purpose waiting for more prosperous times since children are net consumers of resources, the non-dependent in the household could devote their time in productive activities towards smoothing food-intake (Bengtsson et al., 2004).

Women may also wish to limit their fertility responding to the negative economic consequences of unfavourable or unforeseen environmental conditions since households may perceive a higher child cost relative to available economic resources to the family (Lesthaeghe, 1989; de Sherbinin et al., 2008). This would imply that households may try to limit family size to maximize resources available to currently present family members, instead of in creasing the amount of labour supplied by the family. Evidence has found reductions in effective family size following economic recessions inn developing countries (Shapiro, 2015). Parents may also reduce the effective family size of their households by out-fostering their children under times of economic stress (Eissler et al., 2019).

Individuals in the tropics, where climate change is expected to affect the most agricultural productivity, may relocate towards agriculture for two reasons (Casey et al., 2019). Scarcity in agricultural goods may increase its relative price with respect with non-agricultural goods due to relevant in-elasticity between these goods (Ngai and Pissarides, 2007). Higher prices will command higher wages leading to labour reallocation towards agriculture (Ngai and Pissarides, 2007). Also, if climate damage lowers earnings, individuals will devote a greater percentage of their income on agricultural goods, incentives reallocation by higher wages. Since agriculture is a labour intensive task, climate damages rising the return of agricultural work could lead to a fall in the return to education (Alvarez-Cuadrado and Poschke, 2011). Thus, this would indicate parents would likely opt to increase the quantity of children rather than investing on their education. Then, sectoral reallocation towards agriculture could lead to fertility shifts of two signs. The lower returns to education could also mean women could be more available to rear kids than to engage in employment. If climate change triggers a reallocation towards agriculture could decrease the opportunity cost for women to raise children, thus increasing in fertility (Casey et al., 2019).

The agreement in the literature is that climate change exerts more dire effects on agriculture than on the non-agricultural sector. When agricultural production techniques rely on water, temperature and rainfall, shocks will directly modify productivity (Casey et al., 2019). However, non-agricultural sectors are also bound to feel the grip of a changing climate. For instance, higher temperatures can hamper labour productivity, worsen worker´s health in the long run, increase the incidence of extreme weather events and higher erosion. All in all, these effects will exert aggregate effects over the economy, and agriculture will, in addition, suffer from weather dependence (Casey et al., 2019).

Third, resource constraints caused by climate change can also lead to shifts in the household´s personal relations, leading to changes in fertility preferences. Leisure time of household members could shift in response to climate shocks, although it remains unclear if it leads to higher desired family size or increase pregnancy risks. Migration of household members could reduce the available time or household support needed to invest in additional children (Gray and Mueller, 2012). But evidence also shows climate shocks could also hinder adult employment, increasing leisure time and time availability to raise children (Burlando, 2014). Resource scarcity caused by climate change could also lead to inter-personal conflict, leading to a downward revision in the desire to have additional children (Meiksin et al., 2015). High temperatures have been linked to higher risk of inter-personal domestic violence (Sanz-Barbero et al., 2018). And negative income shocks are correlated with spousal violence (Cools et al., 2020). Thus, conflict due to climate related income shocks, can heighten inter-personal conflict and reduce fertility preferences (Meiksin et al., 2015).

3.3. Health

Maternal and child health can be adversely affected by climate change. Global crop yields and global crop nutrition have already been affected by climate change and poses a threat to food security (Ray et al., 2012; Zhu et al., 2018; Wheeler and Von Braun, 2013). Climate shocks can directly influence nutritional intake, and thus, household member´s health (Grace, 2017). Parents could also limit their conceptions in response to expectations of food scarcity, fearing early childhood malnutrition (Galloway, 1988). Grain prices have been previously linked to fertility in pre-Industrial Europe, showing strong responses to negative grain price shocks, stronger in poorer settings (Galloway, 1988). Environmental shocks leading to higher mortality have been linked to an increase in fertility intentions (Owoo et al., 2015). Climate change induced crop failure can directly restrict nutritional intake in households engaging in subsistence agriculture or other livelihood modes highly dependent on the weather and access to water, or through climate induced income shocks, like higher food prices, income losses or the production of food of lower nutritional quality (Grace, 2017). Thus there are mainly two channels through which climate anomalies could lead to a re-evaluation of household fertility decisions by worsening mother and or child's health.

First, mother´s reproductive health can deteriorate when exposed to climate anomalies. Evidence shows mothers lowering their food intake in the face of economic shocks to smooth child food intake (Block et al., 2004). Additionally, births have been shown to decrease strongly following months of extremely high temperatures, through a worsening of the reproductive health of couples (Barreca et al., 2018).

Second, spells of adverse weather can lead to women to adapt their fertility decisions upward through an insurance mechanism, among mothers expecting high child mortality (Rosenzweig and Schultz, 1983). Mortality shocks among neighbours have been strongly associated with higher fertility preferences in Ghana (Owoo et al., 2015). Worsening nutrition has been found to worsen pregnancy outcomes, leading to a higher incidence of stillbirth (Bhutta et al., 2013; Saigal and Doyle, 2008; Basu et al., 2016; Auger et al., 2017) and miscarriage risks (Asamoah et al., 2018), which can be exacerbated by higher mother stress levels due to heat stress (King et al., 2012). Short-term temperature and precipitation shocks can hinder fetal growth and lead to premature births (Walker et al., 2007). Drought affected areas in Rural Ethiopia have been found to have a higher child mortality than unaffected areas (De Waal et al., 2006). Both higher temperatures and low precipitation were related to a higher incidence of stunting and low birth weight rural Kenya and Mali (Bakhtsiyarava et al., 2018; Grace et al., 2015) and hot, dry periods have been previously liked with low nutrition among children across Sub-Saharan Africa (Davenport et al., 2017). However, the effects of precipitation on child health and mortality risk are not straightforward. Abnormally high precipitation has been shown to worsen child health and push mortality risk upward, through a higher incidence of diarrhea diseases (Singh et al., 2001). Acknowledging different livelihood strategies may lead to different income or consumption smoothing patterns, a higher incidence of low birth-weight is found amongst households following the livelihood strategies that depend most on water and their environment for their livelihood, subsistence farmers and pastoralists (Grace et al., 2012, 2014, 2015).

Thus, abnormally high temperatures and low precipitation may worsen mother and child health can lead to lower births through higher miscarriage risks and worsened reproductive health. Then, if expectations of future child mortality follow spells of bad weather, women should desire to have additional children and a higher likelihood of giving birth should be observed. However, the magnitude of child mortality may not be enough to change women´s risk perceptions, specially in the short term (Eissler et al., 2019).

3.4. Previous Research

This study is framed in the literature linking female health and reproduction to environmental or climatic shocks (Grace, 2017). The literature aims to link environmental records with survey data on women and their children to devise climate-health links. Historically high temperatures, rainfall shortages, delays (or leads) in seasonal precipitation patterns caused by climate change, can lead to income and consumption shocks, that can then shape child and women's health or reproductive behavior (Grace, 2017). The main commonality in this literature is its reliance on measures of deviations from historical normal weather, aiming to test the sensitivity of socioeconomic and health outcomes to weather shocks that resemble those of climate change (Grace, 2017).

The bulk of this literature has devoted itself to assess the links between weather-shocks and the incidence of low birth-weight (LBW), given the life course consequences of LBW (higher mortality) (Molina and Saldarriaga, 2017; Deschenes et al., 2009; Bakhtsiyarava et al., 2018; Pereda et al., 2014). Authors have also attempted to follow these early life shocks into adult socio-economic outcomes (Randell and Gray, 2019; Carrillo, 2019; Wilde et al., 2017), pointing to negative effects of exposure to weather anomalies.

Other studies have centered their interest on the several adaptation paths households may undertake as a consequence of climate anomalies. For instance, adaptation though migration (Gray and Mueller, 2012; Thiede et al., 2016; ?; Gray and Wise, 2016) or variations in education due to shifting preferences for household labour (Randell and Gray, 2016, 2019) or farming practices among smallholders (Call et al., 2019).

Given the potential conceptual links between climate shocks and fertility behavior outlined in Section 3, researchers have applied the methodologies employed in the studies reviewed above to shed some empirical light on the climate-fertility conundrum. Given that it is the topic of our study we are going to provide additional detail on studies dealing with the climate fertility relationship.

Data on women´s socioeconomic outcomes and fertility outcomes and intentions geographically linked to historical records of temperature and precipitation to assess the links of fertility to exposure to historical variations in weather, (Eissler et al., 2019) aims to uncover the links between temperature and precipitation variations and womens̀ fertility ideals (ideal family size and desire to have additional children). (Eissler et al., 2019) using DHS rounds from 18 Sub-Saharan Africa countries and 0.5°x 0.5° long-term monthly temperature and precipitation records. Higher deviations from historical temperatures are robustly found to be linked with lower ideal family sizes and lower desire to have additional children, which vary across women´s health and socio-economic outcomes.

Similarly, Sellers and Gray (2019) geographically links the longitudinal Indonesian Family Life Survey waves to high resolution satellite sensed data. Sellers and Gray (2019) use deviations short and long run daily temperature and precipitation historical records and delays of monsoon onset prior to assess their effects on the number of births, fertility preferences and contraceptive use. The authors find increases in the desire to have additional children and drops in contraceptive use as a response to delays in monsoon onset in wealthier households. The opposite effect is fund following long-spells of historically high temperatures, while effects on the number of births are generally weak and non-robust.

Simon (2017) studies the probability of giving birth in response of the interplay between deviations in 10 year moving average long-run precipitation records and climatic zones in Mexico using data from the Mexican Migration Project event history dataset. Periods of abnormally high precipitation increase the likelihood of giving birth in households dwelling in arid climate zones. However, the same effect does not hold in households residing in humid zones. Temperature also holds an influence over births in the US. (Barreca et al., 2018) generates an historical time series of monthly birth records crossed with temperature records both aggregated at the state level. Months with average temperatures over 80°F lead to a decrease in birth rates 8 to 10 months later through a worsening of reproductive health and induced heat stress.

4. DATA AND METHODOLOGY

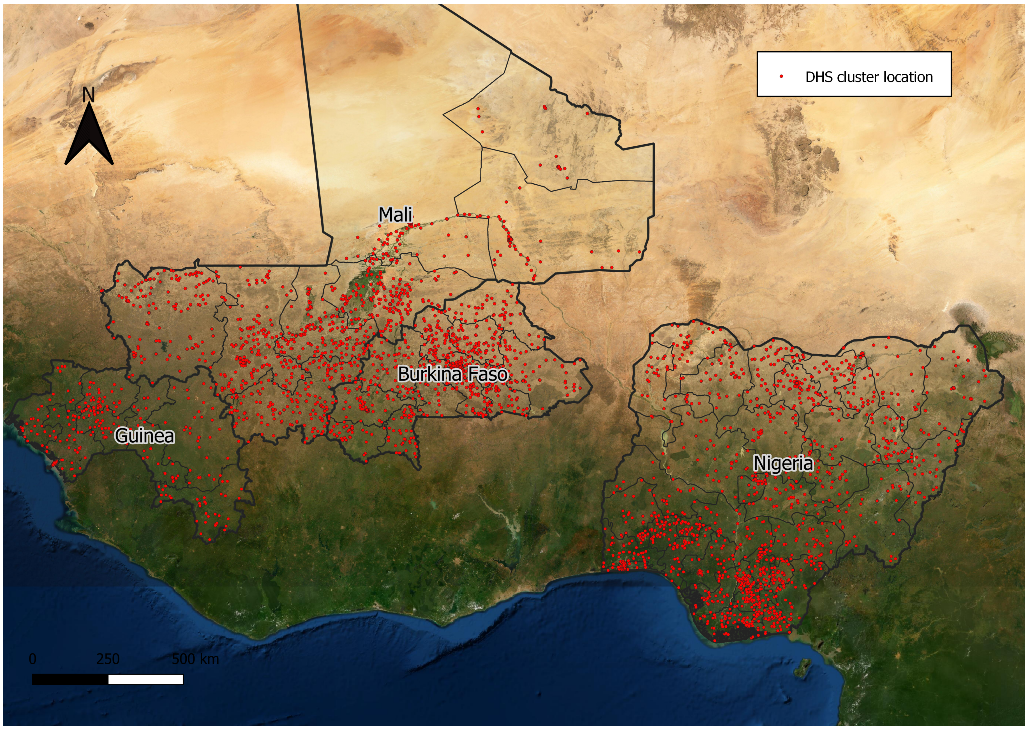
4.1. Data

Considering the proposed shocks on living standards that might affect fertility decisions described in Section 3 we analyse the association of short and long-term climate anomalies, and fertility decisions. Our study relies on microdata extracted from the Integrated Public Use Micro-data Series-Demographic and Health Surveys (IPUMS-DHS) (Boyle et al., 2020) For each country, households were randomly selected using two-stage stratification. Each cluster, can be identified geographically by a set of coordinates, which allows us to link the IPUMS-DHS data to climate data. Households within each cluster are sampled with the same probability, with all women in reproductive age (15-49) being eligible for the interview. The data set contains country-year samples of women in reproductive age (15-49 years old) from the Demographic and Health Surveys from Burkina Faso, Guinea, Mali and Nigeria for which household cluster location coordinates and livelihood zone information are available (Boyle et al., 2020).

To ensure the women in our sample experienced our proposed weather anomalies, we restrict the sample to those women regularly living in their current place of residence for at least 5 years -or 60 months- prior to the survey, or the maximum time-span of our climate measures. However, some modules of the DHS are not administered to comparable groups of women in every country. Crucial to our case, the DHS only administers. Thus, to ensure a comparable sample of women, we restrict our sample to include only ever married women. Finally, we further restrict the sample to only include women who are not currently infertile, to ensure women in our sample are at risk of conception. These restrictions lead to a total of 10 DHS samples over 4 countries between 1990 and 2008, or a total of 59778 women observations spread across 3528 household clusters. The sample restriction process can be observed in Table B1 and Summary Statistics are available in Table B2.

Household cluster location allows us to geographically link our IPUMS-DHS women samples to 0.5°x 0.5° resolution -approximately 56km by 55km grid at the equator- monthly precipitation and land surface temperatures gathered in the University of Delaware Monthly Surface Temperature and Precipitation Time Series dataset (Willmott and Matsuura, 2001), covering years 1900-2017. Hence, we selected DHS surveys in the region for which household cluster location coordinates were available for download at DHS. We link the 0.5°x 0.5° grid cell of the Weather Time series in which each DHS cluster falls into, using QGIS (Geographic Information System). Due to privacy protection, the DHS releases randomly displaced household cluster locations by up to 5km, with an additional 10 km random displacement in rural households. Thus, in limited instances, some household clusters may draw their climate values from grid cells neighbouring their true grid. This will introduce a limited amount of error. Nevertheless, this methodology is standard in social research studying climate change effects on social outcomes (Eissler et al., 2019; Gray and Wise, 2016). The geographic distribution of household cluster across Burkina Faso, Guinea, Nigeria and Mali are displayed in Figure 4.1.

Figure 4.1: DHS household locations



Source: Author's own elaboration from DHS GPS household cluster locations

4.2. Measures

The main dependent variables in our study are births and fertility preferences.

- *Had a live birth*: A binary variable indicating whether a woman gave birth within the 12 months preceding the month of administration of the DHS survey. This includes women who had either 2 or 3 births during the last year, as women recording more than one birth represented 0.3% of the sample.

- *Fertility preferences*: A binary variable standing for whether the respondent is willing to have another child in the future. Women were recoded as "Yes" to desire an additional child if they declared desiring a child within 2 years, after two years, or desired a kid but were unsure about timing. Women who do not desire additional children or were undecided were recorded as "No".

After establishing our principal outcomes, we can establish our independent variables of interest, precipitation and temperature anomalies.

- *Temperature and precipitation anomalies*: A weather anomaly is defined as the deviation in temperature and precipitation from the long term mean for all intervals from 1951 to 2008, during the m months preceding the administration of the DHS survey, for every DHS household cluster g during interval t. These measures have become the standard in the empirical literature examining the relationship of climate change with social and health outcomes (Gray and Wise, 2016; Randell and Gray, 2016; Eissler et al., 2019; Sellers and Gray, 2019; Gray and Mueller, 2012). These deviations are standardized over the standard deviation of all equivalent length intervals during the period 1951-2008. Acknowledging our since different responses may arise from short and longer run anomalies, we estimate our models over the 12 and 60 months prior to the survey. The z-score represents how much climate in a grid differed during the 12, 60 prior to the survey relative to the historical records of temperature and precipitation.

- *Basic controls*: This group of controls includes age (in years) and its square, and residence in rural or urban cluster in the form of a dummy variable with urban clusters as the reference group.

- *Wealth index*: Household wealth is an asset based measure of household economic status obtained placing households in a continuous scale of wealth, which the DHS orders into quintiles (Rutstein and Johnson, 2004). Households scoring lower in the wealth index own more rudimentary households (for instance lacking access to electricity, appliances, means of transportation or faltering access to basic services) (Rutstein and Johnson, 2004).This measure or their individual components have been previously used in the literature to assess the vulnerability of poorer households to climate change related shocks (Grace et al., 2015) or to assess the spatial dimension of climate change vulnerability (de Sherbinin et al., 2014).

- *Socioeconomic Characteristics*: This group of independent variables includes two categorical variables. First, maximum educational attainment, disaggregated into no education, primary education, secondary education and higher education. The group of women with no education is the reference group.

Second, employment status indicates whether a woman is not employed (reference group), is employed in the agricultural sector, or in the non-agricultural sector.

- *Other controls*: The final set of controls includes a battery of controls on women and household characteristics. Religious affiliation is a categorical variable indicating whether the woman follows Islam, Christianity or other religious groups. We also include the number of living children a woman has at the time of the survey, and a dummy indicating whether she is currently pregnant since we expect women with higher number of children and currently pregnant women to have a lower current desire for additional children and a lower probability of giving birth during the previous year. Finally, we also include the age (in years) and a dummy indicating the sex of the household head (1 is male).

- *Livelihood zones*: Finally, our fourth group is a categorical variable indicating to which of three livelihood zones a household cluster falls into. These categories are derived from the livelihood zone classifications available at the contextual data module in IPUMS-DHS. The livelihood zones themselves are derived from the US Agency on International Development
rq s Famine Early Warning System Network (FEWS-NET). The livelihood zones are classified according to information from local experts, climatic zones and geographical data to locate zones sharing common strategies to produce food and income.

  Following the classifications proposed by Bakhtsiyarava et al. (2018), we group the myriad of locally specific livelihood zones into three groups: Food croppers, cash croppers and pastoralists. The grouping is carried out qualitatively. Food cropper zones are dominated with subsistence agriculture, relying on food crops to generate both incomes and food. Cash cropper zones are dominated by the sale of cash crops (like cotton and groundnut), and rely onn their sale for income. Finally, pastoralist zones are dominated by farmers dedicated to the rearing of livestock, relying on their sales for income and food intake.

4.3. Empirical model

We employ a mixed effects logistic regression models to estimate the effect of climate anomalies on the probability of having a birth during the year prior to the survey on the one hand and, on the other, the probability of having a desire for additional children after the survey date. Environmental stress could lead to a fertility decline at the household level, which would in turn retract population growth. Our mixed effects strategy will allow us to mimic the DHS sample design, since households and individuals are nested within household clusters as well (Boyle et al., 2020). Additionally, as including survey round fixed effects to control for country-year effects. This model, as in Sasson and Weinreb (2017), allows us to compare individuals with other individuals in their communities, controlling for cluster-level household wealth and unobservables. These models can allow us to net out discrepancies in fertility between and within clusters, thus allowing to observe differences in fertility outcomes due to exposure to weather anomalies. The baseline models will take the form of the next equation (1), following Sasson and Weinreb (2017):

$$log(\frac{\lambda_{yij}}{\lambda_{nij}}) = \theta_j + \beta_{gi}X_{gi} + \beta_{ij}X^k_{ij} + \alpha_S + \alpha R\epsilon_g \quad (4.1)$$

$$\theta_j = \sigma_0 + \sigma_j j + u_j \quad (4.2)$$

The level-1 fixed effects are conditioned on level-2 random effects. Using the mixed effects strategy entails that women are compared both to others within their same community, controlling for unobserved factors at the community level.

At level 1, $log(\frac{\lambda_{yij}}{\lambda_{nij}})$ gives the log odds of fertility outcome taking place λ_{yij} or not λ_{nij} for woman i in cluster j. θ_j is the household cluster specific effect on our outcomes. β_{gi} gives the effect of the weather anomalies, from X_{gi}, which contain mean surface temperature (Celsius) and precipitation (cm^3) measures transformed into z-scores, which measure standardized climate anomalies to determine deviations from expected climate patterns, measured at grid cell g for individual i. X^1_{ij} is a vector of individual mother characteristics common to all three models (age, age squared, urban or rural residence, household wealth, employment status, educational attainment, religious affiliation, parity, pregnant dummy household sex and age). α_S and α_R represent Survey-Round (country-year) fixed effects. Finally, ϵ_g contains errors clustered at the grid in which each household cluster falls into. Thus, households falling into the same grid will be exposed to the same climate anomaly shocks. At level-2, σ_0 is a constant, σ_j is the effect of our cluster level fixed effects (average cluster wealth index) and u_j are random effects. Finally, we weight our models using sample weights provided by IPUMS-DHS.

The baseline models are then extended to test for heterogeneity in the association of fertility responses to climate variability across socioeconomic groups and livelihood strategies, following the RLF. Since poorer households in terms of physical assets and access to services might have less instruments to cope with climate anomalies as they may be more reliant or exposed to their environments or lack coping mechanisms. Then following (Bakhtsiyarava et al., 2018) we can expect heterogeneity in the fertility responses to climate anomalies according to the heterogeneous strategies available to the different livelihood zones (food croppers, cash croppers and pastoralists). Following this, our next set of models we first interact our measures of climate anomalies across household wealth. Then we provide a set of interaction models repeating the exercise across livelihood zones. As in the baseline model, we provide estimates using both our 12-month and 60-month climate anomaly measure.

5. EMPIRICAL ANALYSIS

We estimate a series of multi-level Logistic regressions so as to test the associations between 12- and 60-month climate temperature and Precipitation anomalies on fertility preferences. Results for the association between the 12- and 60-month climate anomaly measures with fertility preferences are shown in Table 5.1 and 5.2 and respectively, with coefficients expressed as odds ratios. Model 1 and 2 show the association between temperature and precipitation anomalies respectively, and the desire to have additional children at the time of the interview, net of age, age squared and rural residence. Model 3 includes the same controls and adds both temperature and precipitation as independent variables. In Model 4, we include household wealth index. Model 5 includes educational attainment and employment sector. Finally, Model 6 includes our full set of regressors.

Table 5.1: Mixed effects models of 12 month climate anomalies on births

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Z-Temp-12	1.044*		1.047*	1.017	1.012	1.013
	(1.904)		(1.953)	(0.847)	(0.581)	(0.557)
Z-Precip 12		0.999	1.010	1.001	0.998	0.985
		(-0.044)	(0.574)	(0.036)	(-0.105)	(-0.786)
Age	1.188***	1.188***	1.188***	1.192***	1.196***	1.086***
	(18.655)	(18.643)	(18.650)	(18.986)	(19.284)	(7.709)
Age^2	0.996***	0.996***	0.996***	0.996***	0.996***	0.997***
	(-23.103)	(-23.088)	(-23.099)	(-23.388)	(-23.549)	(-18.904)
Rural	1.340***	1.347***	1.339***	1.086***	1.079**	1.096**
	(6.993)	(6.667)	(7.001)	(2.682)	(2.439)	(2.552)
Wealth				0.846***	0.879***	0.862***
				(-8.864)	(-6.372)	(-6.825)
Education att						
Primary					0.959	0.986
					(-1.352)	(-0.436)
Secondary					0.868**	1.063
					(-2.182)	(0.952)
Higher					0.628***	1.016
					(-4.929)	(0.149)
Employment						
Non Agric. emp.					0.888***	0.860***
					(-4.635)	(-5.454)
Agric. emp.					0.947*	0.898***
					(-1.945)	(-3.486)
Constant	0.045***	0.049***	0.046***	0.052***	0.053***	0.474***
	(-20.591)	(-20.500)	(-20.608)	(-20.315)	(-20.063)	(-4.155)
Level 2:						
Wealth	1.014**	1.015***	1.013**	1.013**	1.012*	1.006
	(2.477)	(2.668)	(2.457)	(2.052)	(1.841)	(0.816)
Cons.	1.051***	1.050***	1.051***	1.042***	1.044***	1.070***
	(4.849)	(4.816)	(4.854)	(4.256)	(4.411)	(5.756)
Other controls	No	No	No	No	No	Yes
Survey-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778	59778	59778
chi2	1324.508	1338.615	1317.304	1446.684	1517.693	4603.841
ll	-34567.848	-34570.633	-34567.657	-34503.245	-34474.861	-30593.784

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Hotter than average years are positively associated with higher odds of the probability of desiring additional children at the 1% significance level, robust across all 6 models (Table 5.2). However, anomalous annual precipitation shows odds ratios very close to 1, non-significant, pointing to a lack of association in our sample. Older women show lower odds of desiring additional children, while its nonlinear component is very close to 1 (Both significant at the 1% level), pointing to an almost linear relationship between age and fertility preferences. Rural residence on the other hand, show a positive significant association with the odds of desiring additional children. A higher score on the wealth index, however, is significantly associated (at less than 5% significance level) with lower odds of desiring additional children. Compared to women without education, women with some educational attainment (primary or higher) show lower odds of desiring additional children. Women employed out of the agricultural sector have higher odds of demanding additional children compared to the non-employed, while agricultural employment show no association.

Cluster level Wealth index does not exert a noticeable effect on fertility preferences. Religious affiliation does not exert an influence on the probability of giving birth, but Christians do show a lower probability to desire to expand their families and higher probability of demanding family planning than do Muslims. Local religious groups do not seem to be associated with any of our dependent variables. If we turn our attention to Table A2 we find that, in the longer term, temperature does not play a significant association with the desire to expand one's family, although the coefficients are still greater than one. Precipitation however, plays a more important role in longer time spans. Precipitation deviations over a 5-year period is positively and significantly associated with a preference to expand a family in the near future.

If we first found significant associations between temperatures and the desire to have additional children, historical annual temperature and precipitation anomalies hold a more tenuous association with the odds of having given birth in the year prior to the survey (Table 5.1). The effects of climate anomalies on the probability of having a live birth during the year prior to the survey show only a weak association, with a 10% significance level and only slightly greater than 1 for temperature anomalies in Models 1 and 3. The effects of precipitation annual precipitation anomalies show no significant effect in Models 2 to 6, with an effect very close to 1. In contrast to fertility preferences, higher temperatures over a 5-year period are positively associated with the probability of having a live birth. This association however, is only weakly significant at the 10% significance level in models 1 and 6 and at the 5% in model 3 (Table A1). This also means that the effect cannot be said to be completely robust to the addition of controls, while precipitation has no significant effect.

Table 5.2: Mixed effects models of 12 month climate anomalies on fertility preferences

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Z-Temp 12	1.135***		1.154***	1.135***	1.128***	1.144***
	(3.145)		(3.390)	(2.999)	(2.841)	(3.176)
Z-Precip 12		1.024	1.056	1.050	1.040	1.017
		(0.714)	(1.623)	(1.481)	(1.191)	(0.488)
Age	0.892***	0.892***	0.892***	0.892***	0.889***	1.102***
	(-6.127)	(-6.113)	(-6.132)	(-6.083)	(-6.276)	(5.831)
Age^2	0.999***	0.999***	0.999***	0.999***	0.999***	0.997***
	(-2.950)	(-2.956)	(-2.944)	(-2.993)	(-2.871)	(-12.513)
Rural	1.365***	1.389***	1.360***	1.232***	1.249***	1.281***
	(6.972)	(7.761)	(6.943)	(3.870)	(4.054)	(4.537)
Wealth Index				0.932***	0.935**	0.909***
				(-2.588)	(-2.102)	(-3.610)
Education. att.:						
Primary					0.820***	0.850***
					(-5.431)	(-4.460)
Secondary					0.846***	0.723***
					(-3.498)	(-5.032)
Higher					1.227*	0.833
					(1.903)	(-1.519)
Employment:						
Non Agric. emp.					1.115***	1.136***
					(3.083)	(3.411)
Agric. emp.					0.968	1.040
					(-0.722)	(0.836)
Constant	201.070***	267.986***	217.294***	232.698***	247.507***	29.204***
	(15.042)	(15.784)	(15.043)	(15.301)	(15.272)	(9.810)
Level 2:						
Wealth	1.000***	1.000	1.000	1.000***	1.000	1.000
	(2.761)	(1.388)	(0.295)	(3.352)	(0.823)	(1.290)
Cons.	1.591***	1.601***	1.591***	1.581***	1.561***	1.593***
	(14.273)	(14.247)	(14.251)	(14.714)	(14.688)	(14.586)
Other controls	No	No	No	No	No	Yes
Survey-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778	59778	59778
Chi2	2877.117	2768.353	2868.400	3051.190	3182.562	3468.096
Log-Likelihood	-28245.020	-28254.493	-28242.605	-28234.183	-28197.308	-26486.056

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Age shows a concave shape, being positive on its linear component and negative on the squared all through the models (all strongly significant). Similar to Table 5.1, women residing in rural clusters tend to show higher odds to having given birth than their urban counterparts. The measure of wealth also takes a negative significant association. In Table 5.1 the effects of education are shown not to be as robust to the addition of other controls as the fertility preference measure was in Table 5.2.

Having more than primary education is associates with lower birth odds in model 5 but significance vanishes in Table 5.2. Generally, employed women are less likely to give birth during the previous year than those unemployed. Finally, here, Cluster wealth seems to play a role, with richer clusters having a higher probability of birth. The effect of wealth on cluster's random intercept however, is non robust to the addition of controls, being rendered non-significant and closest to 1 by Model 6.

Tables 5.3 and 5.4. include interaction models for the 12- month climate anomaly measures. Table 5.3 interacts our climate anomaly measures with the wealth index. Table 5.4 interacts the climate measures with our livelihood classifications (food cropper, cash cropper and pastoralist). Both Tables 5.3 and 5.4. include the full set of controls as in Model 6 in Tables 5.1 and 5.2.

The coefficient for the wealth index in previous regressions indicate a negative association between the desire to expand one's family and the probability of giving birth. This would resonate with the notion that most well off households have lower fertility and have a lower ideal family size (de Sherbinin et al., 2008; Sasson and Weinreb, 2017). Since we want to know the relationship between household assets and fertility, Table 5.3 interacts the 12-month weather anomaly measures with the DHS wealth index, following the specification of Model 6 from the previous mixed regression models. The interaction of temperature anomalies with household wealth is non-significant for both birth probability and fertility preferences. For the probability of birth, the relationship would be slightly negative, which is strongly significant using the longer horizon temperature measure (Table A3) while for fertility preferences, higher mean temperatures would be associated with a higher desire to have an additional child. Precipitation however, seems to be intertwined with household wealth. Higher mean precipitation during the year preceding the survey show a positive association both with birth probability and fertility preferences, as the wealth index takes higher values. We can find a similar result in Table A3, where the interaction between the 60-month precipitation anomaly measure and the wealth index is positively associated with our two outcomes of interest.

Table 5.3: Mixed-effects model of 12-month climate anomalies, fertility preferences and births: Wealth index interactions

	Birth		Fert. Pref	
	Temp.	Precip.	Temp.	Precip.
Z-Temp12 × Wealth	0.988		1.016	
	(-0.536)		(1.018)	
Z-Precip12× Wealth		1.029**		1.036**
		(2.152)		(2.238)
Age	1.084***	1.084***	1.100***	1.100***
	(7.478)	(7.466)	(5.719)	(5.728)
Age^2	0.997***	0.997***	0.997***	0.997***
	(-18.695)	(-18.685)	(-12.417)	(-12.426)
Rural	1.278***	1.273***	1.457***	1.441***
	(5.846)	(6.406)	(7.643)	(7.525)
Educational At.:				
Primary	0.938*	0.938**	0.820***	0.821***
	(-1.911)	(-2.024)	(-5.442)	(-5.399)
Secondary	0.932	0.932	0.658***	0.661***
	(-1.049)	(-1.125)	(-7.147)	(-7.209)
Higher	0.811**	0.806**	0.714***	0.712***
	(-2.072)	(-2.127)	(-3.171)	(-3.237)
Employment:				
Non Agric. emp.	0.851***	0.850***	1.125***	1.125***
	(-5 17)	(-5.860)	(3.144)	(3.142)
Agric. emp.	0.914***	0.914***	1.049	1.044
	(-2.957)	(-2.926)	(1.014)	(0.922)
Constant	0.470***	0.469***	35.533***	34.999***
	(-4.219)	(-4.285)	(10.878)	(10.844)
Cluster Cov.				
Wealth	1.002	1.003	1.000**	1.000**
	(0.309)	(0.432)	(2.026)	(2.282)
Cons.	1.078***	1.077***	1.613***	1.610***
	(6.132)	(6.204)	(14.505)	(14.313)
Other controls	Yes	Yes	Yes	Yes
Survey-year FE	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778
Chi2	5090.834	4494.586	3457.703	3384.346
Log-Likelihood	-30633.312	-30631.403	-26510.199	-26508.426

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Different agricultural specialization modes or livelihoods adapt to changing environments differently according to their endowment of capital. We interact our weather anomaly measures with the agricultural specialization categories (Food Crop, Cash Crop, Pastoralism) as shown in Table 5.4. For one, higher than normal temperatures seem to be weakly associated with higher odds of giving birth during the previous year among households residing in areas where food crop specialization dominates. Using our longer horizon measures (Table A4), we observe that it is among cash croppers and pastoralists where higher historical temperatures are positively associated with higher odds of giving birth, although the relationship is statistically stronger among cash croppers (1% significance level) than among pastoralists (10% significance level). The odds of desiring to expand the family is also positively associated with higher-than-normal temperatures in households where food crops or Pastoralism is the dominant mode of living. Longer horizon temperature anomalies are only positively associated with women desiring to expand their families among households where Pastoralism dominates. However, the short-term precipitation measures do not show any significant association when interacted against agricultural specialization anomalies. However, Table A4 points that this relationship may hold over a longer time span. Households living in food and cash crop dominated areas seem to experience a strong positive association with the odds of desiring to have additional children.

Religious affiliation does not exert an influence on the probability of giving birth, but Christians do show a lower probability to desire to expand their families and higher probability of demanding family planning than do Muslims. Local religion groups do not seem to be associated with any of our dependent variables.

Table 5.4: Mixed-effects model of 12-month climate anomalies, fertility preferences and births: Livelihood zone interactions

	Birth		Fert. Pref	
	Temp.	Precip.	Temp.	Precip.
Z-Temp 12 × Food crop	1.049*		1.164***	
	(1.764)		(3.351)	
Z-Temp 12 × Cash crop	1.028		1.070	
	(0.874)		(1.394)	
Z-Temp 12 × Pastoralism	1.030		1.328***	
	(0.804)		(4.777)	
Z-Precip 12 × Food crop		0.974		0.993
		(-1.227)		(-0.179)
Z-Precip 12 × Cash crop		1.008		1.008
		(0.287)		(0.161)
Z-Precip 12 × Pastoralism		0.973		0.934
		(-0.851)		(-1.261)
Age	1.084***	1.084***	1.099***	1.100***
	(7.459)	(7.466)	(5.674)	(5.706)
Age^2	0.997***	0.997***	0.997***	0.997***
	(-18.677)	(-18.682)	(-12.357)	(-12.392)
Rural	1.275***	1.287***	1.421***	1.457***
	(6.707)	(6.484)	(6.968)	(7.601)
Educational Att.:				
Primary	0.939**	0.936**	0.825***	0.820***
	(-1.975)	(-2.030)	(-5.266)	(-5.418)
Secondary	0.935	0.928	0.667***	0.658***
	(-1.083)	(-1.163)	(-7.013)	(-7.102)
Higher	0.817**	0.809**	0.728***	0.714***
	(-1.961)	(-2.075)	(-2.961)	(-3.160)
Employment:				
Non Agric. emp.	0.852***	0.851***	1.134***	1.126***
	(-5.788)	(-5.824)	(3.333)	(3.161)
Agric. emp.	0.918***	0.916***	1.056	1.046
	(-2.771)	(-2.866)	(1.153)	(0.954)
Constant	0.440***	0.456***	25.263***	33.581***
	(-4.656)	(-4.388)	(9.528)	(10.549)
Level 2:				
Wealth Index	1.000	1.001	1.000*	1.000**
	(0.014)	(0.159)	(1.919)	(2.309)
Cons.	1.079***	1.079***	1.594***	1.611***
	(6.307)	(6.306)	(14.624)	(14.579)
Other controls	Yes	Yes	Yes	Yes
Survey-year FE	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778
Chi2	4526.154	4576.527	3440.673	3450.429
Log-Likelihood	-30631.471	-30632.443	-26489.546	-26509.306

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.1. Discussion

In summary, our models find a positive association between short-term temperature anomalies and fertility preferences, but no association is found with precipitation. This is reversed over the longer term. 5-year temperature anomalies are unrelated to fertility preferences while higher than normal precipitation is strongly linked with the odds of desiring a larger family. Similar relationships are found on births. We find a weak association of short-term temperature and precipitation anomalies and the odds of a live birth. The longer-term measures confirm a weak positive association between higher temperatures during the 5 years preceding the DHS survey and birth probability, but no discernible link is found with precipitation.

Our results would indicate that exposure to historically higher temperatures leads to higher birth outcomes and fertility preferences. This would indicate that environmental stress decreases the relative costs of childbearing. This would lend support to the VCM, in which environmental degradation leads to higher labour requirements (Biddlecom et al., 2005; Filmer and Pritchett, 2002; Brauner-Otto and Axinn, 2017). Unfortunately, our empirical strategy does not allow to test for the validity of the VCM vis-a-vis other models of fertility, but this lies away from our research objectives. Sasson and Weinreb (2017) also finds support for the VCM. Lower than historical land cover (NDVI) leads to a lower number of births and a decline in fertility preferences. This goes against the household model of fertility, in which environmental stress increases the cost of childbearing and thus fertility drops (Sasson and Weinreb, 2017). Our results differ from similar studies to our work which find a negative association between fertility preferences and outcomes. Our results differ from Eissler et al. (2019) and Sellers and Gray (2019), who find that climate anomalies lead to lower ideal family sizes, fertility preferences and higher contraceptive use

Precipitation on the other hand, has been found to be positive and significant on a few occasions, slightly stronger when using our longer-term climate variability, which as a whole may point to a weakly robust association. Eissler et al. (2019) points to a distinction between fertility responses to short and long term precipitation shocks. In the short run, higher precipitation may decrease fertility by increasing the workload of the already existing household. On the contrary, fertility should increase following longer spells higher than normal rainfall, given the higher labour demand arising from improved agricultural yields, either increasing the desired family size due to labour demand, or expanding the family size the household can sustain following greater wealth, which our results would partially confirm.

Nevertheless, our results would also support that a decrease in one standard deviation in precipitation anomalies would lead to weakly significant decreases in fertility preferences and births. This would lend support to channels in which environmental degradation leads to a depression in fertility preferences and births.

Plausible explanations lie in an interplay of increases in the demand for household labour, increase the relative costs of childbearing and higher inter-personal conflict within the household.

Household wealth mediates the relationship of womens fertility behaviours and precipitation. Households with less rudimentary dwellings seem to be associated with higher odds of births and desire to expand family size following 12 months of higher-than-average precipitation, but not higher temperatures. Over the longer time horizon, we find the precipitation-wealth relationship with fertility strongly confirmed. Additionally, wealthier households seem to decrease their birth probability in response to 5-year long high temperature spells. These results are consistent with the Rural Livelihood Model proposed above, in which households
' response towards shocks is determined by the assets they own. Facing climate anomalies, households with more material wealth, will be able to adapt to climate change or environmental shocks (de Sherbinin et al., 2008). As our case suggests for instance, facing better environmental conditions, a relatively wealthier household will be better endowed with physical assets to better adapt to climate anomalies. Following Eissler et al. (2019)'s reasoning, wealthier households will be better endowed to capture the benefits of long term exposure to good rains. This would increase their labour demands or lower the relative costs of childbearing leading to higher fertility. On the contrary, scarce precipitation could have no effect among better endowed households but lead to fertility restrictions among the poorest.

Other studies have found women of higher socioeconomic status do not modify their fertility goals when exposed to climate eccentricities, while women with lower educational attainment reduce their fertility, signalling that relatively poorer women control their fertility more than their educated peers, against existing empirical evidence that women better endowed with capital should be more in control (Behrman, 2015; Sasson and Weinreb, 2017). This highlights the complexity in the relationship between the availability different forms of capital and fertility decisions, but more generally adaptation to climate change. Different mixes of capital will lead to different adaptation strategies.

Finally, we find higher historical temperatures to weakly associate with higher odds of birth among food croppers over the short term and with cash cropper and pastoralists dominated areas over the longer term. Higher temperatures are strongly associated with fertility preferences on the short term across all three groups, but only with pastoralist area dwellers over the long term. Precipitation again, only shows heterogeneous associations with fertility preferences over the long term, as women in food and cash cropper dominated areas show higher odds of desiring additional children but not in the probability of giving birth. All groups desire to increase their family size following abnormally higher short-term temperatures or long-term precipitation (among food croppers and cash croppers). These widespread effects on fertility preferences do not translate to fertility outcomes. Only food croppers and pastoralists are able to translate fertility desires to outcomes following short- and long-term temperature anomalies respectively. This could either mean that existing constraints limit their ability to translate preferences to outcomes due to their livelihoods.

The main livelihood strategy in the region is agriculture, highly dependent on rainfall and evaporation for agricultural yields. The three most common agricultural strategies are food cropping, cash cropping and pastoralism. Their interest for our study lies on the different adaptation strategies followed by each of the groups. Food croppers grow crops for subsistence and household food consumption, may rely on past food reserves and present yields. Cash croppers sell their crops for income, which might allow them to use cash reserves to sustain food and income security. Pastoralists breed and care livestock for trade, thus climate variability may lead to less healthy livestock with lower weight per animal and thus lower income.

Nevertheless, our study suffers from several drawbacks relatively common in the population environment literature. First, estimates of the association between climatic variability and fertility outcomes are most likely subject to attenuation bias. Womens desire to conceive children does not perfectly translate into conceptions. As we saw, at the household level, adaptation to environmental shocks through fertility may not be feasible due to competing livelihood strategies that may draw fertility in either direction (Sasson and Weinreb, 2017). However, access to family planning is the biggest constraint limiting women's ability to realize their fertility goals(Bongaarts and Casterline, 2013). Unmet need for family planning, a mismatch between women's demand for contraception and its availability, is endemic in Sub-Saharan Africa, but national family planning programs in West Africa is the main factor behind its slower drop in Total Fertility Rates than in the South-Eastern Africa (Bongaarts and Casterline, 2013). Women's household bargaining power and their parity also drive a wedge between fertility preferences and outcomes (Bongaarts and Casterline, 2013).

However, as much of the empirical fertility literature (de Sherbinin et al., 2008), our study relies on cross-sectional data that only provide with one time information on womens fertility behavior (de Sherbinin et al., 2008). Studies like ours inevitably the dynamic family formation process, as it is largely determined by past ideations of desired family size. A longitudinal approach would erase this endogenous relation by incorporating womens previous fertility experiences and preferences (de Sherbinin et al., 2008). These shortcomings lead our estimates to represent associations between climate anomalies and fertility behaviours, and should not be interpreted as causal effects. Difficulties to combine environmental and socioeconomic data have limited the empirical channels through which climate can affect women's reproductive patterns (Grace, 2017). Despite this, there remains strong conceptual channels through which climate anomalies can affect reproductive behaviour by altering the household's living conditions (Grace, 2017). Data constraints have forced empirical analysis on climate change and environmental impact on female health and reproductive outcomes in developing countries to employ pooled DHS samples. Grace (2017) also mention the LSMS-ISA survey program from the world Bank a sources of geographically referenced longitudinal surveys which, centring on farming and food security, information on female health and reproductive behaviour was severely limited.

Despite the attractiveness of the RLF, it has several shortcomings. For one, assuming unitary household fertility preferences may be too stringent. Both the costs and benefits of child rearing and bargaining power within the household may be asymmetrically distributed. Household members may also have preferences towards different ideal family sizes (de Sherbinin et al., 2008). Further, asset endowments and livelihood modes are most likely not the sole determinants of fertility. Family planning use, childcare and coital frequency, strong determinants of fertility, are determined by cultural factors (van de Walk and Meekers, 1992). Thus, due to the slow shift in cultural norms, fertility may show little variation in the face of environmental shocks (Sasson and Weinreb, 2017). Another caveat lies in the role of uncertainty in future resource availability may condition the choice of livelihood strategies. Strategies that may imply reductions (or increases) may be in conflict with one another or may not be undertaken due to other constraints (Sasson and Weinreb, 2017).

The DHS introduces random displacement on the GPS coordinates of household clusters to protect respondents' anonymity, up to 2km for urban clusters and 5km to rural clusters with an additional 10km displacement for a random 1% of rural clusters. Random displacement can introduce noise in the extraction of covariates from continuous raster data in the form of misclassifiaction error. Displaced DHS clusters with coordinates lying close to the 0.5ºx0.5º grid cell boundary will have a higher probability to truly belong to the contiguous grid cell from which we extract our climate covariates (Perez-Heydrich et al., 2013). However, the extraction of grid values using displaced points or the *true*location provide highly similar results in highly spatially correlated raster surfaces. Nonetheless, (Perez-Heydrich et al., 2013), misclassification error can lead to considerably noisy results in point extraction when spatial correlation is low. While other authors have used equivalent methods elsewhere (Eissler et al., 2019; Gray and Wise, 2016) and have not tested for spatial auto correlation in interpolated continuous raster surfaces, variation in spatial auto correlation can lead to biased coefficients.

This points to a limitation in the weather anomaly measures we use to identify climate change effects to the reproductive outcomes. The weather anomaly measures used in this paper inform on effects of variations of temperature and precipitation which aim to resemble climate change processes (Sellers and Gray, 2019,?). However, they do not allow to observe whether the effects on fertility are the result of extremely hot, cold, dry or humid. Other studies have previously used the frequency of climate anomalies that exceed 1 (or -1) z-scores (Jain et al., 2015; **?**), number of months or days exceeding a temperature (C^{o}) threshold (extreme heat) or falling under a precipitation (mm) threshold (drought) (Barreca et al., 2018; Bakhtsiyarava et al., 2018). This would lead to more precise interpretations, and to attribute our results to extreme weather events, which might exert an effect on fertility of greater magnitude than that of sole z-score based variation alone. At the same time, including measures that mimic extreme weather events that might trigger health effects and lead to higher perceptions of child mortality risk among mothers. This would make improve the plausibility of the health channel presented in Section 3. Unfortunately, time constraints did not allow us to include these. In a similar vein, including contextual data on the climatic zone or water availability as in (Simon, 2017) would allow for a perhaps more correct perspective on the effects of climate change, since similar z-score variations in temperature and precipitation should show heterogeneous effects on livelihoods and health around more or less humid climates. However, since our climate effects are clustered at the grid level, they should capture the effect of the local environment.

6. CONCLUSION

Given the stark projections of climate change (IPCC, 2014), and its dire consequences on human health (Grace, 2017) and rural livelihoods in West Africa (Sissoko et al., 2011), our study aims to contribute to a relatively scarce literature that evaluates fertility as an adaptation strategy to climate shocks linked with climate change (Sellers and Gray, 2019; Eissler et al., 2019; Barreca et al., 2018; Simon, 2017). We have combined historical high resolution temperature and precipitation records (Willmott and Matsuura, 2001) with socioeconomic and fertility data from IPUMS-DHS, carrying out mixed-effects logistic regressions. Further, our study is the first in the climate anomaly-fertility literature to incorporate livelihood zone data from FEWS NET inspired by Grace et al. (2014) , Grace et al. (2015) and Bakhtsiyarava et al. (2018), allowing us to observe heterogeneous fertility responses to climate change by food and cash croppers and pastoralists.

We find robust evidence of positive associations between unit increases in temperature z-scores (mimicking the effects of climate change) and the odds of giving birth during the year prior to the survey and higher desire to have additional children. The associations found for precipitation anomalies are somewhat weaker, slightly stronger in the long term. Higher (lower) precipitation is associated with higher (lower) fertility preferences and birth odds. Our results indicate that stringent climate anomalies (higher temperatures and lower precipitation) are associated with contrary fertility responses. Higher temperatures (and precipitation) would support channels that imply higher fertility, like higher labour demand or lower relative costs to childbearing and even child mortality risk insurance. On the contrary, lower than average precipitation would support channels implying lower fertility, such as spousal separation, higher intra-household conflict or higher relative childbearing costs. Adverse shocks however, lead to lower fertility among materially richer households, given higher adaptive capacity that wealth confers. Finally, livelihoods show heterogeneous fertility responses to climate anomalies, stronger at the longer term, but show generally associations with higher fertility among pastoralists and food croppers.

Our results support the notion that fertility behaviour is associated to local weather patterns and its environment. The fact that households resort to modifying their fertility households are subject to scarcity linked to climate shocks. This would support policies that help rural households hedge against climate shocks and stabilize livelihoods. These should be comprehensive programs aimed to improve food and income security, as well as rationalization of water resources like crop insurance programs, promotion of drought resistant varieties and supporting the implementation of more efficient water management and irrigation techniques (Sissoko et al., 2011). Additionally, policies directed to improving access to family planning would give women more agency in realizing their fertility preferences, especially when access to family planning services in West Africa is more limited than in the rest of the continent (Bongaarts and Casterline, 2013). Encouraging female participation in initiatives that drive forward natural resource management and improving femalestatus would also work towards improving their agency over fertility decisions and perhaps alleviate the trade-off between generating income and childbearing (de Sherbinin et al., 2008). Finally, Clay and Reardon (1998) argue that policies should not consider demographic behaviour as exogenous from environmental policy. Enhanced management of natural resources needs the understanding that households respond to environmental constraints.

Future research, and our understanding of climate and health and reproductive behaviour, would improve by using longitudinal data that would allow to account for the dynamic nature of fertility. Additionally, the lack of additional socioeconomic or agricultural information in surveys like the DHS, allows only to use reduced form models in which the outcomes that mediate the climate-fertility relationship must be assumed, and different causality channels cannot be properly tested. While some studies like Biddlecom et al. (2005) and Sellers and Gray (2019) incorporate these features, they are the exception rather than the norm.

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A. APPENDIX A: 60 MONTH CLIMATE ANOMALY MODELS

Table A.1: Mixed-effects model of 60-month climate anomalies, fertility preferences and births: Wealth Index interactions

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Ztemp 60	1.070		1.102	1.079	1.072	1.051
	(0.956)		(1.473)	(1.161)	(1.074)	(0.744)
Z-precip 60		1.200***	1.205***	1.196***	1.175***	1.126***
		(4.968)	(5.086)	(4.956)	(4.487)	(3.121)
Age	0.892***	0.892***	0.892***	0.893***	0.890***	1.102***
	(-6.113)	(-6.123)	(-6.125)	(-6.078)	(-6.275)	(5.848)
Age^2	0.999***	0.999***	0.999***	0.999***	0.999***	0.997***
	(-2.958)	(-2.958)	(-2.957)	(-3.005)	(-2.881)	(-12.543)
Rural	1.385***	1.397***	1.391***	1.255***	1.267***	1.297***
	(7.429)	(8.410)	(7.951)	(4.273)	(4.372)	(4.763)
Wealth				0.930***	0.932**	0.904***
				(-2.711)	(-2.250)	(-3.991)
Educ. Att.:						
Primary					0.827***	0.852***
					(-5.239)	(-4.366)
Secondary					0.856***	0.725***
					(-3.273)	(-5.042)
Higher					1.240**	0.832
					(2.004)	(-1.560)
Employment:						
Non Agric. emp.					1.114***	1.132***
					(3.059)	(3.337)
Agric. emp.					0.978	1.043
					(-0.487)	(0.903)
Cons.	231.486***	323.577***	282.253***	302.833***	318.936***	39.424***
	(14.967)	(16.532)	(15.590)	(15.872)	(15.792)	(10.403)
Level 2						
Wealth	1.000	1.000	1.000	1.000	1.000	1.000
	(1.358)	(0.749)	(0.242)	(1.498)	(0.270)	(1.530)
Cons.	1.600***	1.589***	1.587***	1.576***	1.560***	1.599***
	(14.262)	(14.008)	(14.038)	(14.483)	(14.453)	(14.460)
Other controls	No	No	No	No	No	Yes
Survey-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778	59778	59778
chi2	2789.183	2644.808	2679.131	2961.678	3087.148	3344.538
ll	-28254.026	-28233.818	-28231.880	-28222.957	-28188.869	-26487.561

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Mixed-effects model of 60-month climate anomalies, fertility preferences and births: Wealth Index interactions

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Z-Temp 60	1.087*		1.093**	1.050	1.039	1.067*
	(1.936)		(2.058)	(1.370)	(1.081)	(1.655)
Age	1.188***	1.188***	1.188***	1.192***	1.196***	1.086***
	(18.641)	(18.639)	(18.631)	(18.986)	(19.284)	(7.699)
Age^2	0.996***	0.996***	0.996***	0.996***	0.996***	0.997***
	(-23.091)	(-23.076)	(-23.075)	(-23.383)	(-23.540)	(-18.896)
Rural	1.341***	1.347***	1.342***	1.087***	1.080**	1.095**
	(6.842)	(6.739)	(6.951)	(2.729)	(2.455)	(2.536)
Z-Precip 60		1.017	1.024	1.011	1.004	0.987
		(0.874)	(1.194)	(0.551)	(0.186)	(-0.538)
Wealth				0.847***	0.879***	0.863***
				(-8.566)	(-6.184)	(-6.548)
Educ. Att.:						
Primary					0.960	0.987
					(-1.317)	(-0.405)
Secondary					0.869**	1.063
					(-2.157)	(0.950)
Higher					0.629***	1.017
					(-4.896)	(0.162)
Employment:						
Non Agric. emp.					0.888***	0.860***
					(-4.619)	(-5.445)
Agric. emp.					0.947*	0.896***
					(-1.912)	(-3.530)
Constant	0.043***	0.050***	0.044***	0.050***	0.052***	0.447***
	(-19.454)	(-20.175)	(-19.319)	(-19.324)	(-19.145)	(-4.286)
Cluster Cov.						
Wealth	1.014**	1.015***	1.014**	1.013**	1.012*	1.005
	(2.433)	(2.685)	(2.450)	(2.033)	(1.816)	(0.785)
Cons.	1.050***	1.050***	1.050***	1.042***	1.044***	1.070***
	(4.804)	(4.800)	(4.775)	(4.203)	(4.374)	(5.721)
Other controls	No	No	No	No	No	Yes
Survey-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778	59778	59778
chi2	1363.778	1328.325	1348.020	1506.179	1589.705	4673.633
ll	-34567.244	-34570.207	-34566.417	-34502.432	-34474.366	-30592.409

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Mixed-effects model of 60-month climate anomalies, fertility preferences and births: Wealth Index interactions

	Birth		Fert. Pref	
	Temp.	Precip.	Temp.	Precip.
Z-temp 60 × Wealth	0.943***		0.971	
	(-3.922)		(-1.458)	
Z-Precip 60 × Wealth		1.082***		1.087***
		(3.622)		(4.467)
Age	1.084***	1.084***	1.101***	1.101***
	(7.536)	(7.521)	(5.752)	(5.789)
Age2	0.997***	0.997***	0.997***	0.997***
	(-18.734)	(-18.728)	(-12.445)	(-12.483)
Rural	1.231***	1.238***	1.421***	1.393***
	(5.058)	(5.712)	(6.468)	(6.869)
Educ. Att:				
Primary	0.951	0.945*	0.826***	0.827***
	(-1.507)	(-1.792)	(-5.199)	(-5.249)
Secondary	0.969	0.956	0.671***	0.678***
	(-0.479)	(-0.706)	(-6.376)	(-6.741)
Higher	0.878	0.835*	0.741***	0.743***
	(-1.281)	(-1.775)	(-2.623)	(-2.849)
Employment:	1.000	1.000	1.000	1.000
	(.)	(.)	(.)	(.)
Non Agric. emp.	0.853***	0.853***	1.127***	1.128***
	(-5.683)	(-5.753)	(3.206)	(3.214)
Agric emp.	0.905***	0.904***	1.041	1.034
	(-3.247)	(-3.308)	(0.840)	(0.714)
Constant	0.470***	0.474***	35.208***	35.460***
	(-4.262)	(-4.205)	(10.857)	(10.885)
Level 2:				
Wealth	1.001	1.005	1.000	1.000
	(0.207)	(0.745)	(0.426)	(1.243)
Cons.	1.078***	1.076***	1.612***	1.606***
	(6.131)	(6.080)	(14.681)	(14.209)
Other controls	Yes	Yes	Yes	Yes
Survey-year FE	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778
chi2	4871.489	4575.532	3478.511	3323.354
ll	-30624.469	-30622.614	-26509.196	-26501.819

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Mixed-effects model of 60-month climate anomalies, fertility preferences and births: Livelihood zone interactions

	Birth		Fert. Pref	
	Temp.	Precip.	Temp.	Precip.
Z-Temp 60 × Food crop	1.070		1.052	
	(1.629)		(0.657)	
Z-Temp 60 × Cash Crop	1.182***		0.917	
	(3.679)		(-1.140)	
Z-Temp 60 × Pastoralism	1.090*		1.264***	
	(1.836)		(2.745)	
Z-Temp 60 × Food crop		0.998		1.128***
		(-0.089)		(2.590)
Z-Temp 60 × Cash Crop		0.982		1.188***
		(-0.529)		(3.135)
Z-Temp 60 × Pastoralism		0.951		0.913
		(-0.974)		(-1.147)
Age	1.083***	1.084***	1.100***	1.100***
	(7.453)	(7.474)	(5.727)	(5.706)
Age^2	0.997***	0.997***	0.997***	0.997***
	(-18.696)	(-18.658)	(-12.412)	(-12.424)
Rural	1.269***	1.278***	1.443***	1.453***
	(6.529)	(6.468)	(7.377)	(7.700)
Educational Att.:				
Primary	0.937**	0.938**	0.828***	0.826***
	(-2.065)	(-1.991)	(-5.129)	(-5.216)
Secondary	0.926	0.929	0.672***	0.667***
	(-1.260)	(-1.139)	(-6.580)	(-6.803)
Higher	0.811**	0.809**	0.730***	0.721***
	(-2.034)	(-2.073)	(-2.915)	(-3.032)
Employment:				
Non Agric. emp.	0.852***	0.851***	1.133***	1.127***
	(-5.842)	(-5.820)	(3.326)	(3.172)
Agric. emp	0.924***	0.915***	1.049	1.055
	(-2.611)	(-2.885)	(1.020)	(1.135)
Constant	0.411***	0.463***	31.149***	37.992***
	(-4.806)	(-4.258)	(9.707)	(10.970)
Level 2:				
Wealth Index	1.000	1.001	1.000	1.000
	(0.061)	(0.212)	(0.061)	(1.476)
Cons.	1.075***	1.079***	1.594***	1.606***
	(6.047)	(6.306)	(14.923)	(14.394)
Other controls	Yes	Yes	Yes	Yes
Survey-year FE	Yes	Yes	Yes	Yes
Observations	59778	59778	59778	59778
Chi2	4524.455	4706.542	3508.486	3357.958
Log-Likelihood	-30620.242	-30632.979	-26485.572	-26495.322

Coefficients expressed as Odds Ratios; z statistics in parentheses
Standard errors clustered at the Grid level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B. APPENDIX B: SUMMARY STATISTICS

Table B.1: Table 2: Case-wise deletion

	Observations
1. Full 15-49 y.o. sample	113,407
2. Current residents	111,039
3. Residing for ¿5 years	87,468
4. Ever married	71,969
5. Not infertile	59778
Nº of clusters	3528
Nº of grid cells	620

Table B.2: Summary statistics

	Mean	Std. Dev.	Min.	Max.
Dependent vars: Births	0.28	0.45	0.00	1.00
Fert. Pref.	0.71	0.46	0.00	1.00
Independent vars: Z-Temp 12	0.44	0.88	-1.90	2.82
Z-Precip 12	-0.15	0.96	-3.79	2.21
Z-Temp 60	0.86	0.75	-1.36	2.56
Z-Precip 60	-0.42	0.61	-2.28	1.72
Age	30.69	8.07	15.00	49.00
Age^2	1006.83	513.41	225.00	2401.00
Residence: Urban	0.25	0.43	0.00	1.00
Rural	0.75	0.43	0.00	1.00
Wealth Index	-0.13	0.95	-5.00	7.36
Educational Att: No education	0.76	0.43	0.00	1.00
Primary	0.14	0.35	0.00	1.00
Secondary	0.09	0.28	0.00	1.00
Higher	0.02	0.12	0.00	1.00
Employment: Not employed	0.30	0.46	0.00	1.00
Agric. Emp.	0.39	0.49	0.00	1.00
Non Agric. Emp.	0.31	0.46	0.00	1.00
Religious affiliation: Muslim	0.75	0.43	0.00	1.00
Christian	0.20	0.40	0.00	1.00
Other	0.06	0.23	0.00	1.00
Number of living children	3.55	2.25	0.00	14.00
Pregnancy: Non Pregnant	0.85	0.36	0.00	1.00
Pregnant	0.15	0.36	0.00	1.00
H.H. Age	44.33	12.85	13.00	98.00
H.H. Sex	1.08	0.27	1.00	2.00
Livelihood zone: Food croppers	0.53	0.50	0.00	1.00
Cash croppers	0.31	0.46	0.00	1.00
Pastoralists	0.16	0.37	0.00	1.00
Survey rounds: Guinea, 2005	0.06	0.24	0.00	1.00
Mali, 1995	0.09	0.29	0.00	1.00
Mali, 2001	0.12	0.32	0.00	1.00
Mali, 2006	0.17	0.37	0.00	1.00
Nigeria, 1990	0.07	0.25	0.00	1.00
Nigeria, 2003	0.05	0.22	0.00	1.00
Nigeria, 2008	0.22	0.42	0.00	1.00
Burkina Faso, 1993	0.06	0.24	0.00	1.00
Burkina Faso, 1998	0.05	0.22	0.00	1.00
Burkina Faso, 2003	0.11	0.31	0.00	1.00
Observations	59778			

Author´s own elaboration using IPUMS-DHS