Fertility Response to Climate Shocks*

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Abstract

In communities highly dependent on rainfed agriculture for their livelihoods, the common occurrence of climatic shocks such as droughts can lower the opportunity cost of having children, and raise fertility. Using longitudinal household data from Madagascar, we estimate the causal effect of drought occurrences on fertility, and explore the nature of potential mechanisms driving this effect. We exploit exogenous within-district year-to-year variation in rainfall deficits, and find that droughts occurring during the agricultural season significantly increase the number of children born to women living in agrarian communities. This effect is long lasting, as it is not reversed within four years following the drought occurrence. Analyzing the mechanism, we find that droughts have no effect on common underlying factors of high fertility such as marriage timing and child mortality. Furthermore, droughts have no significant effect on fertility if they occur during the non-agricultural season or in non-agrarian communities, and their positive effect in agrarian communities is mitigated by irrigation. These findings provide evidence that a low marginal price of having children is the main channel driving the fertility effect of drought in agrarian communities.

Keywords: Drought; Fertility; Agrarian Communities; Price of a marginal child

JEL: C12, C13, C14, J12, J13, O12.

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1 Introduction

Climatic shocks such as droughts are increasingly posing severe challenges to economic activities, labor market outcomes, and individual wellbeing in high climate-change sensitive countries. The geography-induced overrepresentation of developing countries among those threatened by recurrent episodes of extreme weather events is of great concern. Not only are most of these countries already experiencing food insecurity (FAO, 2017), they also have high fertility rates and rapid population growth (UN, 2017). As climatic shocks are expected to become common occurrences in these countries due to climate change, there are growing concerns that, if unattended, the occurrence of such shocks could heighten the prospects of an inescapable neo-Malthusian trap, owing to their negative impact on agricultural production (FAO, 2015). However, these fears could only materialize if at-risk communities fail to adjust their fertility behaviors in response to climatic shocks. Yet, how do extreme weather events such as droughts affect fertility?

Addressing this question is important, but is complicated because there are three possible channels through which drought can affect household fertility. First, if drought increases the risk of child mortality, this will provide households with an incentive to raise their fertility, to maximize the number of surviving children. Second, if drought depresses household income (Jayachandran, 2006), households with teenage daughters may marry them off early to adjust household size and possibly increase income through the bride price (Corno, Hildebrandt and Voena, 2019). In this case, fertility rises because of marriage timing. Third, if drought affects the price of a marginal child, positively or negatively, it will provide households with an incentive to alter their fertility behaviors. So far, however, there is no study that investigates these different channels in a unified empirical framework. What is more, to the extent that droughts can be viewed as income shocks (Jayachandran, 2006), addressing the question of the fertility effect of drought constitutes an important contribution to the current debate about the effect of household income on fertility. Indeed, there is no consensus in the literature that studies this topic, owing to endogeneity issues (e.g., Lindo, 2010; Cohen, Dehejia, and Romanov, 2013). The existing literature either resorts to indirect tests (e.g., Cohen, Dehejia, and Romanov, 2013), or, when the test is direct, it investigates the effect of husband's income (Lindo, 2010). Moreover, the existing empirical literature mainly focuses on developed countries. Yet, addressing this question in an institutional context that offers almost no means to cope with income shocks is likely to settle the ongoing debate about both the sign and the causal interpretation of the correlation between household income and fertility.

In this paper, we present new empirical and theoretical evidence that droughts induce a permanent increase in household fertility in communities where women are highly dependent on rainfed agriculture for their livelihoods. We use longitudinal data from Madagascar in combination with climatic data that pin down the timing of droughts in this African Island to obtain exogenous variation in household income. We also fully test the three channels outlined above. Our findings are not only of theoretical interest, but they also have significant policy implications, especially in a context in which a large majority of women are employed in the agricultural sector and are highly vulnerable to droughts. Indeed, while our results obtain in the context of Madagascar, its underlying institutional and sociocultural context extends to all high climate-change sensitive countries with agrarian economies, such as those from sub-Saharan Africa and South Asia. Nearly 70 percent of employed rural women in South Asia and more than 60 percent in sub-Saharan Africa work in agriculture, almost all of which is rainfed (FAO, 2011). The high vulnerability of these women to climatic shocks such as droughts stems from the gendered nature of resource entitlements that advantages men, by limiting their access to credit, and preventing them from pursuing off-farm activities (Doss, 2011; Jost et al., 2015). Our analysis thus implies that the common occurrence of climatic shocks in these regions could open up a wider neo-Malthusian trap than the one anticipated on the basis of The United Nations' population projections for sub-Saharan Africa and South Asia (UN, 2017).

To substantiate our claim that droughts increase fertility, we exploit information on plausibly exogenous rainfall shocks, combining them with longitudinal data from Madagascar. We follow the existing literature (e.g., Jayachandran, 2006; Shah and Steinberg, 2017; Kaur, 2018) in measuring drought, in a given locality, as a normalized deviation of rainfall intensity below the 20th percentile during the rainy season. We focus on the rainy season because it coincides with the onset of the agricultural calendar in most developing countries. Our econometric specifications take advantage of the yearly panel structure of the data, which allows us to follow a cohort of young male and female adults from 2004 to 2011. Estimation results show that droughts have a positive and statistically significant effect on both the timing and the quantum of fertility. In particular, exposure to agricultural drought in the past year or two increases the probability that a woman residing in an affected agrarian community experiences a childbirth in the current year by 4.7-8.5 percentage points. Such exposure also increases the number of new births a woman has by 0.085-0.138.

There are two main challenges to identifying the causal effect of drought on fertility. The first challenge stems from the concern that household may form expectations about future drought occurrences, which in turn will bear on their current fertility decisions. Indeed, a key identification assumption underlying our results is that households do not anticipate the occurrence of future droughts when making their current fertility decisions. However, if past, present, and future drought occurrences are correlated, this can provide household with a basis for forming expectations about future drought occurrences. Such expectations, in turn, may lead them to adjust their fertility behavior accordingly, in which case our baseline estimation results would be biased. We address this threat to identification by regressing fertility (both the timing and the quantum of it) on one-year and two-year leads of our drought variable, to determine whether households do indeed anticipate the effect of future occurrences of this phenomenon, and we find no effect.

The second challenge to identifying the causal effect of drought is temporal displacement or harvesting (Deschênes and Moretti, 2009). If births induced by drought are principally those that would have otherwise taken place, then current births are only a near-term effect of drought that will be compensated for by a decline in births in future years. In our empirical context, where all women in our database remain young adults throughout the eight periods covered by the surveys, temporal displacement thus would imply that the positive fertility effect of drought is not permanent. To address it, we estimate the effect of contemporaneous and various lagged droughts on both the timing and the quantum of fertility. This analysis allows us to determine whether households displace fertility choices over time, by reducing births in future years to compensate for an increase in fertility following a drought occurrence. We find no compensating effects, implying that droughts are likely to have a long-lasting effect on fertility.

We next explore the nature of mechanisms driving the causal effect of droughts on fertility. We examine three possible channels. The first channel is family formation. If drought affects the timing of marriage or cohabitation, then, the well-known correlation between age at first marriage and age at first birth would explain its effect on fertility. First, we test whether drought affects family formation, by regressing the timing of marriage/cohabitation on droughts that occurred during the current year or a year or two previously. Estimation results show that drought has no significant effect on family formation, thus invalidating this potential mechanism. Another potential channel of the fertility effects of drought is child mortality. Testing this channel, we find no significant effect of drought exposure on child mortality.

Finally, we test whether the fertility effect of drought is driven by the opportunity cost of having children, in a context where women depend highly on rainfed agriculture for their livelihoods. In this context, the price of a marginal child is the forgone income from committing more time and energy to unpaid care labor, instead of working exclusively in the farm. However, since a woman's opportunity cost of having children is not observable in our empirical setting, we rely on several indirect tests. First, we test whether the fertility of urban households responds differently to drought than does the fertility of rural households. In urban areas, women tend to have access to a wider range of economic activities, particularly in the services sector, thus making them less dependent on rainfed agriculture as their main source of livelihoods. This means that exposure to drought in urban areas is less likely to alter a woman's opportunity cost of having children. Interestingly, we find that exposure to drought actually decreases the quantum of fertility among urban households, while it has no significant effect on its timing—the opposite of what we find in rural areas. Second, we test whether fertility is affected by drought occurrence during the non-rainy season. If this is the case, the effect would pass through a channel not related to agricultural activity. However, we find that droughts in the non-rainy season have no significant effect on fertility.

As part of testing the opportunity cost mechanism, we also explore the effect of irrigation as a resilient factor against drought in rural areas. Indeed, if the opportunity cost of children in farming is the mechanism driving the fertility effect of drought, the presence of an irrigation system is likely to mitigate this effect, thus reducing its effect on fertility. We test this prediction by interacting the drought variable with the irrigation variable in the fertility timing equation. We find that the presence of irrigation in a given rural locality almost cancels the positive effect of drought on the timing of fertility. We take these test results as validating the opportunity cost of having children as the mechanism driving the fertility effect of drought in communities where women are dependent on rainfed agriculture for their livelihoods.

We then develop a Becker-type model of household occupational choice to organize the intuition underlying the opportunity cost mechanism as a driver of the fertility effects of drought in communities where women draw their livelihood from rainfed agriculture. In such communities, women, as wives and mothers, balance their primary responsibility of providers of unpaid care-labor with work in family farms (Budlender, 2008; Doss, 2018). Very often, these women work in farms while also supervising or caring for their younger children (Samman *et al.*, 2016; Doss, 2018). This balancing act unfortunately has an adverse effect on their on-farm productivity (Samman *et al.*, 2016), as a result of, for example, numerous breaks taken from work to nurse newborns and infants, to prepare food for children, or simply from exhaustion due to lack of adequate rest time. We conceptualize this loss of labor productivity as a woman's opportunity cost of having children in this agrarian setting, and relate it to total factor productivity (TFP) in rainfed agriculture. Drought, by depressing TFP in rainfed agriculture (Jayachandra, 2006; Shah and Steinberg, 2017), decreases a woman's opportunity cost of having children in our model, thus raising her fertility. This argument is similar to the one discussed in Galor and Weil (1996) who argue that an increase in women's relative wages reduces fertility by raising the cost of children more than household income.

The main takeaway from this paper is that extreme weather events such as droughts are income shocks that slow the much needed demographic transition in countries where women draw their livelihoods predominantly from rainfed agriculture. Public intervention should, therefore, focus on promoting resilience and adaptation strategies among women in particular, as well as enhancing a transition from rainfed to irrigated agriculture, to reduce fertility rates in countries experiencing slow fertility transitions. This may involve the design and implementation of public policies aimed at empowering women and promoting female education, to enhance their adaptive capacities to climate hazards.

This paper contributes to the large literature on income shocks and life outcomes (Jenson, 2000; Almond, 2006; Jayachandran, 2006; Deschênes and Moretti, 2009; Banerjee *et al.*, 2010; Almond *et al.*, 2009; Bengtsson, 2010; Akresh *et al.*, 2012; Dinkelman, 2016; Jessoe *et al.*, 2017; Shah and Steinberg, 2017; Blakeslee and Fishman, 2017, Corno *et al.*, 2019). This literature analyzes the adverse effects of climatic and weather hazards on individual and aggregate outcomes, including child mortality and health (e.g. Almond, 2006; Deschênes and Moretti, 2009; Dinkelman, 2016), the wellbeing of rural landless laborers (Jayachandran, 2006; Jessoe *et al.*, 2017), the future economy-wide human capital (Dinkelman 2016; Shah and Steinberg, 2017), and crime (Blakeslee and Fishman, 2017). Corno, Hildebrandt and Voena (2019) study the effect of aggregate economic shocks, measured by drought exposure, on the timing of marriage in sub-Saharan Africa and in India, showing that this effect depends on the direction of marriage payments. Our contribution to this literature is to address a new question. We theoretically and empirically investigate how droughts that reduce the opportunity cost of having children in agrarian communities affect women's fertility. Moreover, by emphasizing the negative impact of drought on the opportunity cost of having children as the mechanism driving its fertility effect, our analysis has clear implications for policies aimed at accelerating fertility decline in high climate-change sensitive communities. Clearly, increasing the opportunity cost of having children, by expanding the range of income-earning opportunities to which women have access to, would likely induce a decline in fertility, and accelerate fertility transitions needed to avert the specter of a neo-Malthusian future in high-fertility developing countries.

This paper also contributes to the literature on fertility and demographic transition (Galor and Weil, 1996; Tertilt, 2005, Bloom *et al.*, 2009; Ashraf *et al.*, 2014; Lambert and Rossi, 2016; Doepke and Tertilt, 2018; Rossi, 2018; Alam and Pörtner, 2018). Part of this literature emphasizes polygyny, women's concern for old-age security, and their lack of bargaining power as factors driving fertility rates upwards in sub-Saharan Africa. We contribute to this literature by providing new evidence that droughts that disproportionately affect women drive their fertility rates upwards, as a result of a decrease in the opportunity cost of having children.

The rest of this paper unfolds as follows. Section 2 describes the data used for our empirical analysis. Section 3 lays out our empirical strategy. The main findings are presented in section 4. Section 5 tests the possible mechanisms through which droughts affect fertility. Section 6 presents a theoretical model that formalizes the effect of drought on fertility, by emphasizing the opportunity cost of children as the mechanism driving this effect. Finally, concluding remarks in section 7 close the paper.

2 Data and Measurement of Key Variables

2.1 Context and Data

The setting of our empirical analysis is Madagascar, a large Island in the south-eastern coast of Africa, with a poverty rate of nearly 80 percent at 1.90 PPP per day in 2012 (World Bank, 2016). In this African Island agriculture is a source of livelihoods for roughly 70 percent of the population (Minten and Barrett, 2008), cultivating less than 1.5 hectares per household (WFP-UNICEF, 2011) and being highly dependent on rainfed production. In recent years, it has become the site of frequent occurrences of extreme climatic events, such as cyclones, droughts, and floods, known to have adverse effects on agriculture (World Bank, 2012). Indeed, according to the World Bank, between 2005 and 2010, 93 percent of Malagasy households were affected by shocks, with climatic hazards accounting for the vast majority of them. In particular, weather shocks affected 83 percent of the rural population, and 63 percent of the urban population in the years 2009-2010. Rural households, most of which rank no higher than the second quintile of the consumption distribution, responded to these shocks by further entrenching their dependence on rainfed agriculture, as their ability to transition into non-agricultural activities was weakened by a combination of poor transport infrastructures and limited business opportunities in the non-agricultural sector (World Bank, 2016). Interestingly, according to the World Bank estimates, in 2016, the average total fertility rate for the first two quintiles in the consumption distribution was 6.35 births per woman, which is nearly twice as high as the average total fertility rate of the top two quintiles (3.55 birth per woman). These facts make Madagascar an interesting setting for investigating the causal effect of agricultural droughts on household fertility.

We build our analysis sample from the two latest rounds of a survey that follows a cohort of young adults born in the late 1980s. They consist of the Madagascar Life Course Transition of Young Adults Survey (2011–2012) and the Progression through School and Academic Performance in Madagascar Survey (EPSPAM 2004). Both rounds of the survey contain comprehensive information on cohort members (hereafter CMs, for short) and their family members. In particular, the survey questionnaire includes modules on CMs' education, labor, migration, health, fertility and nutrition. In addition, there is also information on households' asset holdings, as well as on CMs' children. The cohort-based sample also includes considerable retrospective data collected using recall techniques. For example, we know the exact month and year in which a female CM gave birth to a child, as well as the exact month and year during which a CM migrated. In addition, this survey is complemented by a community survey of social and economic infrastructure, as well as by general information on key historical developments in the villages where the CMs were living in 2004. We also rely on another data set, the 2001 Commune Census, which provides information on services, infrastructure, and agricultural production (among others) for all Malagasy communes.[1]

To construct our climatic shock variable (*i.e.*, drought), we use rainfall data from the *African Rainfall Climatology, version 2.0 (ARC2)*, of the *National Oceanic and Atmospheric Administration*. This rainfall data represents gridded daily precipitation estimates from 1983 to 2011, centered on Africa at 0.1 degree (about 10 x 10 km) spatial resolution. We refer to these geographic units as Satellite-based units (SBUs). For rural areas only, at the baseline we have a total of 55 SBUs.

We build an 8-period panel of observations based on information about 1,119 CMs living in rural areas of Madagascar (572 of which are women) who were aged $21-23$ at the time of the 2011–12 survey. Of these 1,119 rural CMs, 316 (including 146 women) left their community of origin between 2004 and 2011 to move to another Malagasy area – rural or urban. We define these CMs as internal migrants. In the period going from 2004 to 2011, the attrition

[1] Recensement des Communes 2001, http://www.ilo.cornell.edu/ilo/data.html.

rate represents roughly 10 percent of the sample.[2] Table 1 presents summary statistics for female CMs. Fertility rates among these CMs (aged between 14 and 23) increases with age. The average age at first cohabitation (with or without marriage) and at first birth are both 18 years for female CMs. Female CMs have on average 0.01 children when aged 14 and 0.95 children when aged 23. Several women with children do not live with their partner. The percentage of such women drops with age, going from 70 percent for female CMs aged 16, to 27 percent for those aged 23. At the same time, cohabitation among young female CMs is common even in the absence of a child: 40 percent of female CMs aged 14 to 17 already live with a partner, albeit without any child yet. This shows that in Madagascar cohabitation at a young age is not uncommon, though not always related to pregnancy. Almost 17 percent of female CMs in our sample are enrolled in school in 2011, while 79 percent of them participate in the labor force. The vast majority of these working female CMs are employed in family farms or businesses, with only 9.9 percent of them holding a salaried job, while 31 percent are own-account workers or employers. On average, over the whole 2004-2011 period about half of the female CMs in our sample are not employed.

2.2 Measures of Fertility

We measure household fertility in two ways. First, we look at the timing of fertility, by constructing an indicator function for child birth, which is equal to 1 if a female CM gave birth to a child in the current year and zero otherwise. Second, we also consider the quantum of fertility, by constructing a count variable measuring the number of births a female CM has had up to the current year.

Despite the young age of the individuals comprising our analysis sample, our measurement of fertility is highly relevant for the following reasons. First, in the fertility context of Madagascar, all the female CMs in our dataset fall well within the range of women with a high fertility risk. Indeed, female CMs in our dataset entered the survey in 2004 aged $14-16$—which for most females coincide with the onset of menarche—, and were aged 21-23 by the end of the survey in 2011. Second, average age at first birth in Madagascar is 19.5 (CIA Factbook, 2018)[3], which is well below the minimum age (21 years of age) of these female CMs when the survey ended in 2011. Third, Madagascar ranks 13th in the world

[2] Missing and re-interviewed cohort members are fairly similar with respect to many individual and household characteristics including gender, various crystallized intelligence scores, CMs and parents' years of education, wealth, and area of residence.

[3] Accessible on https://www.cia.gov/library/publications/the-world-Factbook/fields/2018.html

in terms of the prevalence of child marriage among females aged $20 - 24$ (UNICEF, 2017).[4] Indeed, in 2017, UNICEF estimated that 41 percent of Malagasy women married before the age of 18. Although this figure falls to 12 percent for women married before the age 15, it is still quite high by international standard. Fourth, in our sample, 61 percent of female CMs had at least one new birth by the end of the period covered by the survey (see Figure 1).

Figure 1 reports the proportion of female CMs who had at least one child during the survey period, by age. This figure clearly shows that the hazard of having a child increased significantly during this period.

2.3 Measuring Drought

Drought is a natural hazard that originates from a deficiency of rainfall over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector (Wang *et al.*, 2016). The focus of this study is agricultural drought—a negative rainfall shock that usually occurs on time scales of 1–4 weeks or longer, and can have a direct impact on crop growth and yield (AMS, 2013). Therefore, we want our measure of drought to capture low rainfall occurrences during a climatological wet season, which, in the context of Madagascar, is referred to as the rainy season—a period of time considered crucial for the development of crops.

We follow the existing literature (e.g., Jayachandran, 2006; Shah and Steinberg, 2017; Kaur, 2018), by measuring drought as a transitory negative rainfall shock. More formally, our drought variable, $DROUGHT_{s,t-l}$, is equal to 1 if, over the entire agricultural season, standardized rainfall deviation in SBU s falls below the 20th percentile in year $t - l$, and 0 otherwise. The variable l denotes the number of lagged years, with $l = 1, 2$. Standardized rainfall deviation is the difference between rainfall in a given year and its historical mean within the SBU over the agricultural season, and normalized by its historical standard deviation. Thus, our measure of drought is localized, as it does not involve a comparison of actual rainfall levels across districts or SBUs. The 20th percentile is recognized as a reasonable low rainfall intensity threshold by the *American Meteorological Society* (see Bergemann *et al.*, 2015), and is widely used in the economics literature (e.g. Jayachandran, 2006; Shah and Steinberg, 2017; Kaur, 2018).

[4]Child marriage can be defined as a marital union (formal or informal) between two individuals, at least one of which is under the age of 18 at the time of marriage.

2.4 Timing of Drought, Fertility, and Agricultural Activities

As mentioned above, the focus of this paper is agricultural drought. In the developing world, in general, one of the primary impacts of drought during the rainy season is crop failures.

To fit the rainy season into the agricultural calendar in Madagascar, we focus on the crop calendar for rice and maize. Rice is the main staple food of people in Madagascar, followed by maize. Outside Asia, Madagascar has the longest history of rice production, with rice cultivation found in almost all districts of the country. Indeed, in our analysis sample, more than two thirds of households report rice as their main cultivated crop, followed by maize, which has roughly the same growing calendar as rice.[5] According to the FAO, the sowing seasons for rice and maize start in November and end in January, for rice, and in December, for maize. The rice growing season goes from February to March, which is a month later compared to the end of maize's growing season.[6] Thus, the sowing seasons for both crops are set such that they develop during the rainy season, when rainfall is expected to be abundant.

For the rainy season, therefore, our drought variable, $DROUGHT_{s,t-1}$, captures the onset of drought from November (or Month 11) in year $t-2$ to April (or month 4) of the year $t-1$, as indicated in Figure 2. Based on this time range, the historical means and standard deviations for rainfall are estimated for the period running from November to April of all years back to 1991.

Consistent with the rice crop calendar (which is expected to affect the timing and extent of crop failure), we assume that a one-year lagged drought would affect household fertility starting immediately after the end of the rainy season (or just before its end) in the year $t-1$. We justify this assumption by the fact that couples anticipate or experience a drop in agricultural productivity as a result of a meagre rainfall or a delayed onset of the rainy season. Also, as women are normally significantly involved in selling crops, their time value after the rainy season drops if the agricultural production has been negatively affected by a drought. This implies that, to be associated with a drought episode in year $t-1$, childbirth must occur sometime between January and December of year t, as shown in Figure 2. This is an immediate effect of drought on household fertility. In addition to this immediate effect,

[5]See, FAO, *International Rice Year 2004*, available online at http://www.fao.org/rice2004/en/p9.htm

[6]See FAO-GIEWS, 2018. *Country Briefs: Madagascar*, Reference date is 11 January 2018. Accessed online at http://www.fao.org/giews/countrybrief/country.jsp?code=MDG

we also consider a two-year lagged drought variable, to account for the fact that pregnancy may take time to materialize, for various reasons, including biology.

One may argue that using the month of birth to capture the fertility effect of drought would have been a better alternative to the year of birth considered in this study. However, our data show that the distribution of births after one-year or two-year lagged drought is fairly constant across the year. Individual biologically related disparities in the onset of pregnancy, is a possible explanation as to why there are no peaks in births around 9 months after the end of the drought.

2.5 Frequency and Incidence of Droughts

We next present the spatial distribution of drought occurrences and incidence, by linking these occurrences to climatic zones in our sample. There are 8 climatic zones in Madagascar, labelled Zone 1 – 8, as depicted in Figure 3. This figure shows the incidence of drought nationally, and by climatic zones in Madagascar, between the years 2000 and 2011. As shown in Figure 4, rural communities in our sample are spread over the entire country, but are more concentrated in the (continental) warmer temperate zones (Zones 5 - 8), and to a certain extent in the equatorial climate zone (Zone 1) along the eastern coast.

Nationally, each little blue-colored circle in Figure 3 indicates that drought occurred in that year (as depicted in the x-axis). Between 2000 and 2011, drought occurred nationally in all but 2 years (2003 and 2007), with its corresponding incidence recorded on the y-axis. Our study focuses on the period 2004-2011.

In terms of incidence, the year 2000 was the most hit by drought: indeed 70 percent of the country's SBUs were hit by drought that year. This was followed by the years 2010 (around 30 percent nationally) and 2008 (20 percent nationally). However, as can be seen in Figure 3, there is significant heterogeneity in terms of both frequency and incidence of drought across the country's climatic zones, and over the period of analysis. For example, nationally, in terms of incidence over time, the average incidence of drought in 2003-2005 and in 2007 was close to zero, compared to 20 percent in 2008, and 30 percent in 2010. Across climatic zones, in the year 2008, while almost all zones were hit by drought, Zones 4 and 7, by contrast, were not. In terms of frequency of drought episodes over the period covered by our study, Zone 3—Equatorial Savannah climate with dry winter—was the most affected area, with drought occurring in nine of the twelve years covered by our study, 2003, 2004 and 2007 being the only exceptions. It was followed closely by Zone 2—Equatorial Monsoon climate— where drought occurred in eight of the twelve years covered by our study. However, in terms of incidence, Zone 7—Warm temperate climate— was hit by the hardest drought, with roughly 100 percent of the SBUs affected in 2010. It was followed by Zone 4— Steppe climate — with 60 percent, and Zone 3 with roughly 40 percent in the same year.

3 Identifying the Impact of Drought on Fertility: Empirical Strategy

3.1 Econometric Specifications

The panel structure of our data allows us to follow all CMs along the entire period (2004-2011). We use robust standard errors clustered at the the station-based unit (SBU) level to account for potential spatial correlation in droughts. We estimate the effect of a drought on fertility for female CMs residing in rural areas, where dependence on rainfed agriculture as a source of livelihood is highest. In such setting, rainfall deviations are known to affect agricultural yields (Jayachandran, 2006; Bengtsson, 2010; Shah and Steinberg, 2017). Therefore the covariate of interest is the occurrence of a drought at time $t-l$ in SBU s, denoted as $DROUGHT_{s,t-l}$, an indicator function equal to 1 if a drought occurred in SBU s, at time $t-l$, and 0 otherwise. The term $l \in \{1,2\}$ identifies the number of lagged years.

One concern that may arise from the estimation of the effects of drought on fertility is that drought may be associated with some unobserved determinants of fertility decisions. For example, if the occurrence of a drought in a given locality is followed by relief efforts by local public authorities, then it becomes unclear whether the effect estimated is due to drought itself or to the relief efforts, or both. To address this concern, as in Shah and Steinberg (2017), we control for SBU effects in our estimations.

Another concern arises from the fact that individual unobserved heterogeneity may be correlated with droughts. For example, the resilience ability of an uneducated, unmarried, or poor female CM to drought may differ from that of her more educated, married, or richer counterpart in a context where farm work is the only paid employment opportunity for women. To address this unobserved heterogeneity, we control for female CMs' levels of education, marital status, and the level of asset holdings of their respective families of origin.

Our baseline estimations control for unobserved heterogeneity at the SBU or district levels. In order to test whether unobserved heterogeneity at the individual level is correlated with drought, we run additional estimations where we also control for CMs' individual fixed effect. Our key identification assumption therefore is that, conditional on individual and climatic-zones fixed effects, changes in drought are not correlated with unobserved variables affecting fertility decisions. This assumption is justified by the fact that we control for all unobserved time-invariant individual and climatic-zone factors likely to affect fertility decisions. In addition, we control for observed individual and community characteristics that vary over time.

We measure fertility by both its timing and its quantum. With respect to the timing of fertility, the outcome variable is childbirth, $CB_{i,s,t}$, an indicator function equal to 1 if a female CM i residing in SBU s gave birth to a child at time t, and 0 otherwise. Thus our baseline specification for the estimation of the effect of droughts on the timing of fertility is a linear probability model (LPM) with robust standard errors and fixed effects:

$$CB_{i,s,t} = \sum_{l=1}^{2} \beta_{1,l} DROUGHT_{s,t-l} + \gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t}, \tag{1}$$

where the terms $X_{i,t}$ and X_i include individual/household and village time varying and time fixed characteristics of the female CM, respectively. Using data from the 2001 Commune Census, we include an indicator function equal to 1 if there are irrigation facilities in the commune (defined as if there are irrigated rice fields by a dam or a pumping station), and 0 otherwise. The inclusion of this variable as part of our empirical strategy for identifying the causal effect of droughts can be justified by the fact that in communes where the practice of irrigated agriculture is more widespread, agricultural TFP is likely to be less responsive to drought. We also include the number of vaccination campaigns, as well as the number of health centers in a village, as these may influence women's reproductive health—a determinant of her fertility outcome. The term ω_1 captures the CM's age effect, while the terms ω_2 and ω_3 capture the SBUs and temporal fixed effects, respectively. The large spatial, and temporal, variation in rainfall deviations at the SBU level, should allow for an unbiased identification of $\beta_{1,l}$, as these are most likely to be uncorrelated with any unobserved factor affecting household fertility. The explanatory variables are listed in Table 2 and their summary statistics are reported in Table 1

Following Shah and Steinberg (2017), we first estimate Eq. (1) using a linear probability model (LPM) with robust standard errors and fixed-effects at the SBU level. Nevertheless, we also check the robustness of our results by estimating a non-linear model (probit).

In estimating Eq. (1), we exclude CMs who migrated during the period 2004-2011. Indeed, over the course of the eight year time period 2004-2011, about 30 % of sampled CMs in our data moved to another Malagasy locality. Some of these migrant CMs moved to urban areas, where drought is unlikely to have had the same impact (if any) on their fertility, as on the fertility of CMs who remained in rural areas. For those who moved to urban areas, the opportunity cost of having children is higher. Hence, we expect that the inclusion of migrants in our estimation sample would weaken the effect of droughts on fertility. Moreover, the migration decision may be endogenous to drought occurrences [7]. Nonetheless, as discussed in the results section, for robustness checks we also run the main estimations on the sample including migrants.

Eq. (1) regresses fertility as a flow on the occurrence of a drought at time $t - l$, and thus essentially captures the timing, but not necessarily the level or quantum of fertility. For the estimation of the effect of drought on the quantum of fertility, the outcome of interest is the number of children a female CM i residing in SBU s has at time t, $F_{i,s,t}$. The main issue in estimating the effect of droughts on the level of fertility is the problem of censored observations. Indeed, 74 percent of women-year pairs in our sample do not have children, implying that the variable $F_{i,s,t}$ is clearly left-censored. If we ignore this censoring, the drought coefficients would underestimate the true effect. The most suitable model for censored regressions with fixed effects is the semiparametric trimmed estimator developed by Honoré (1992). Thus, our baseline specification for the estimation of the effect of drought on the quantum of fertility is a censored regression model with time-variant and time-fixed effects, in the tradition of Honoré (1992):

$$F_{i,s,t} = \max\left\{0, F^*_{i,s,t}\right\}$$

where $F^*_{i,s,t}$ is a latent variable given by

$$F^*_{i,s,t} = \sum_{l=1}^{2} \beta^F_{1,l} DROUGHT_{s,t-l} + \gamma^F_1 X_{i,t} + \gamma^F_2 X_i + \omega^F_1 \theta_{i,t} + \omega^F_2 \mu_s + \omega^F_3 \sigma_t + \varepsilon^F_{i,t}. \tag{2}$$

[7] However, as shown later, by regressing the migration decision on our drought variables, we concluded that this is not the case.

3.2 Challenges to Identification

An important challenge to our identification of the causal effect of drought on fertility is that not accounting for the possibility that households form, then act on, expectations about future drought occurrences when making their current fertility choices can bias our estimates. Indeed, if past episodes of drought are correlated with present episodes in any SBU, then cohort members may anticipate future droughts based on event histories, and adjust their fertility decisions accordingly. If true, then our baseline estimates will be biased. To test whether households anticipate the future drought occurrences in their current fertility decisions, we regress the timing of fertility on future droughts. The covariates of interest thus are indicator functions $DROUGHT_{s,t+L}$, and equal to 1 if a drought occurs at time $t + L$, and 0 otherwise, where L denotes the lead count, with $L = 1, 2$. The OLS specification for the regression on lead value of rainfall deviations writes as follows:

$$CB_{i,s,t} = \sum_{l=1}^{2} \beta_{1,l} DROUGHT_{s,t+L} + \gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t} \quad (3)$$

Another equally important challenge to identification is the potential temporal displacement of the positive effect of drought on fertility. The idea is that births induced by drought in the current year may not imply a permanent increase in fertility, if these current births are later compensated for by a decrease in births in future years. This is likely to be the case if births occurring in the current year because of drought are principally those that would have otherwise taken place in subsequent years, particularly given that all female CMs in our database remain young adults throughout the 8 periods covered by the surveys, and thus are still expected to bear children. This argument is similar to those discussed by Deschênes and Moretti (2009) who study the effect of extreme temperatures on social outcomes (Deschênes and Moretti 2009), and Hsiang and Jina (2014) who study the effect of cyclones on economic growth. If this argument holds true in our empirical setting, it would imply that the uncovered positive effect of drought on fertility is only temporary, and thus may not have a permanent effect on women's completed fertility. We address this issue by testing whether the fertility effect of a drought that occurred up to four years ago changes sign overtime, with respect to either the timing or the quantum of fertility. If years following a drought occurrence have a birth response that is opposite in sign to the contemporaneous birth response, this indicates the presence of temporal displacement or harvesting (Hsiang, 2016). Therefore, there is no harvesting, if years following drought have birth responses of an identical sign to that of the contemporaneous birth response; or if they have birth responses that are not statistically significant.

With respect to the timing of fertility, the adjusted regression equation for this falsification test thus writes as follows:

$$CB_{i,s,t} = \sum_{l=1}^{4} \beta_{1,l} DROUGHT_{s,t-l} + \gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t}, \tag{4}$$

where $\sum_{l=1}^{4} \beta_{1,l}$ gives the dynamic causal effect of droughts, which corresponds to the sum of the coefficients of the immediate and past drought variables.

In line with Eq. (2), the corresponding adjusted regression equation for the quantum of fertility writes as follows:

$$F^{*}_{i,s,t} = \sum_{l=1}^{4} \beta^{F}_{1,l} DROUGHT_{s,t-l} + \gamma^{F}_1 X_{i,t} + \gamma^{F}_2 X_i + \omega^{F}_1 \theta_{i,t} + \omega^{F}_2 \mu_s + \omega^{F}_3 \sigma_t + \varepsilon^{F}_{i,t}. \tag{5}$$

4 Estimation Results

In this section, we report our main results on the effect of droughts. For the estimation of the effect of drought on the timing of fertility, we contrast the LPM and probit specifications. As stated above, the semiparametric Tobit with fixed effects is used to estimate the effect of drought on the quantum of fertility.

4.1 Effects of Drought on The Timing and Quantum of Fertility

Table 2 reports estimates of the LPM (columns 1 and 2), the probit (columns 3, 4, 5, and 6), and the censored regression model with fixed effects (columns 7 and 8). Columns 1 to 6 address whether droughts affect the timing of fertility, and reports results with, as well as without, controls. Test results show that estimates of the probit model are consistent with and very close to the linear model specification. Indeed, both models return a statistically significant and positive effect of droughts for both the one-year and the two-year lags. In particular, experiencing a drought at time $t-1$ increases the probability of having a child at time t, by 6.4 percentage points in the linear model, and by 4.7 percentage points in the probit model. For the two-year lag, corresponding figures are 8.5 percentage points for the LPM and 6.9 percentage points for the probit [8].

Columns 7 and 8 report the results of the estimation of the censored regression model with time-variant and time-invariant fixed effects. This model estimates the effect of droughts on the number of children a female has. Test results show that droughts have a statistically significant and positive effect on the number of children a rural woman has. In particular, experiencing a drought at time $t-1$ increases the number of children a woman has at time t by a factor of 0.085, while experiencing a drought at time $t-2$ increases the number of children a woman has at time t by a factor of 0.138. These empirical tests show a sufficiently strong evidence that droughts have a causal effect on both the timing and the quantum of fertility in rural areas dependent on rainfed agriculture.

4.2 Results of Falsification Tests

As mentioned above, our identification strategy summarized by Eqs. (1) and (2) may come under threat, if it can be established that drought episodes in each SBU (or climatic zone) are correlated overtime. This is because under these circumstances, households may anticipate the future occurrence of drought when making their current fertility choices, causing our estimates to be biased. We use the regression equation (3) as the basis for testing whether households do anticipate the occurrence of future droughts when they make their current fertility choices. Results of this test are reported in Table 3. We find no statistically significant effect of future droughts on the timing of fertility among female CMs. We take this result as indicating that the effect of drought is indeed causal.

We also run a falsification test with respect to the issue of temporal displacement of drought-induced births. This test is run on both the fertility timing regression equation and the quantum of fertility regression equation (Eqs. (4) and (5) above). Both regressions are performed on the sample of women aged 18 years old or higher, to focus on the subset of women who were more likely to have reached the reproductive age 4 years earlier (i.e., the maximum number of the year lags used for this test). Table 4 reports the results of this test for both the LPM (column 1), the probit (column 2) and the censored (column 3) specifications. For the fertility timing model, test results for the probit specification are

[8] We also ran probit estimates with climatic zones fixed effects–instead of SBUs fixed effects–and the results do not vary substantially.

consistent with those obtained using the LPM specification. Both specifications show that the coefficients of the one, two and three-year lag droughts are positive and significant, while the four-year lag drought has no significant effect. As for the quantum of fertility model (column 3), the effect of drought remains positive and significant from the one-year to the four-year lags, indicating that there is no temporal displacement effect. Both these test results reinforce our confidence in the existence of a causal and long-lasting effect of droughts on fertility.

4.3 Robustness checks

In the estimations presented above, migrants are excluded from our analysis sample. However, if female CMs respond to agricultural droughts by leaving rural areas, then our estimates are likely to be biased. We conduct a robustness test with respect to this issue in two steps. First, we regress the migration decision on drought, to determine whether a female CM's migration decision is influenced by drought. Results for this test are reported in Table 10. We find that the migration decision of female CMs is not endogenous to drought.

Second, as discussed in the empirical strategy section, including migrants is likely to underestimate our results, as these migrants are less likely to be dependent on rainfed agriculture for their livelihoods. This is likely to be the case, in particular, for female CMs who migrated to urban centers, where there are relatively more employment opportunities. For these female migrants, their opportunity cost of having children is likely to be invariant to drought-induced income shocks, and may even be higher, if there are better-paid employment opportunities in cities. Nevertheless, we test the robustness of our results to the inclusion of migrant CMs. Our main results for this robustness test are reported in Table 11. For the estimation using a linear probability model specification (LPM), the causal effect of drought disappears for the one-year lag. For the two-year lag, the positive causal effect of drought persists, but is only weakly significant. The results are more robust under the probit specification. However, as expected, the probit coefficients, though still strongly significant, are weaker than those derived from the analysis sample in which migrant CMs are excluded.[9]

[9]Because of the large increase in the number of SBUs as effect of the migration, in the probit specification we used the climatic zones fixed-effects rather than the SBUs fixed effects. Relatedly, a relative large number of new SBUs included in the sample after migration includes 5 or less CMs each. Hence, in this specification, LPM and probit results are not strictly comparable and we consider the LPM ones more reliable.

We also test the robustness of our results to the inclusion of any time-invariant individual fixed effect, to account for unobserved heterogeneity at the individual level. Indeed, if, for instance, a female CM's ability is systematically correlated with drought occurrences, this may bias our estimates upward, as ability is a potential resilience factor against the adverse effects of droughts. Therefore, to account for time-invariant unobserved individual heterogeneity, we control for CMs' individual fixed effects, in addition to climatic-zones and year fixed effects we controlled for in our main regression equations. Estimates for this robustness test are reported in Table 12, for both the timing and the quantum of fertility. We find that the positive causal effect of drought on the timing of fertility is virtually unchanged: the one-year lagged drought raises the probability of having a new birth by 6.4 percentage points, while the two-year lagged drought increases it by 8.8 percentage points (see column 1). As for the the quantum of fertility, the coefficient for the one-year lagged drought is no longer statistically significant. Only the coefficient for the two-year lagged drought variable remains significant (column 2). We can conclude that our results are robust to any eventual time-invariant individual unobserved heterogeneity.

5 Mechanisms

An obvious question linked to our results is why would droughts cause a demographic explosion in rural areas. There are three possible answers to this question: (i) droughts affect the timing of marriage/cohabitation, causing more women to have children; (ii) droughts cause child mortality, causing households to have more children, to achieve their desired fertility; (iii) droughts depress total factor productivity in rainfed agriculture—the source of livelihood for many rural women—, making it cheaper for women to have many children.

5.1 Droughts and Marriage/Cohabitation

First, women who marry may be those who intend to have children. If droughts affect the timing of marriage/cohabitation, this may establish marriage/cohabitation as the mechanism through which droughts affect the timing and the level of fertility. We test this mechanism in two ways. First, we regress a female's marriage/cohabitation status on drought occurrences the previous years. The LPM specification for this regression writes as follows:

$$C_{i,s,t} = \sum_{l=0}^{2} \beta_{1,l}^{C} DROUGHT_{s,t-l} + \gamma_1^C X_{i,t} + \gamma_2^C X_i + \omega_1^C \theta_{i,t} + \omega_2^C \mu_s + \omega_3^C \sigma_t + \varepsilon_{i,t}^C, \quad (6)$$

where $C_{i,s,t}$ denotes an indicator function equal to 1 if a female CM i residing in SBU s entered a marital relationship at time t, and 0 otherwise. Second, since marriage/cohabitation and fertility may be jointly determined, as a robustness test, we estimate a bivariate probit model whose specification is as follows:

$$CB_{i,s,t}^{*} = \alpha C_{i,s,t-1}^{*} + \sum_{l=1}^{2} \beta_{1,l} DROUGHT_{s,t-l} + \gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t} \quad (7)$$

$$C_{i,s,t}^{*} = \sum_{l=0}^{2} \beta_{1,l}^{C} DROUGHT_{s,t-l} + \gamma_1^C X_{i,t} + \gamma_2^C X_i + \omega_1^C \theta_{i,t} + \omega_2^C \mu_s + \omega_3^C \sigma_t + \varepsilon_{i,t}^C \quad (8)$$

with $cov\left(\varepsilon_{i,t}, \varepsilon_{i,t}^C\right) = \rho$.

Test results are reported in Table 5. For the econometric specification in Eq. (6), both the LPM (column 1) and the probit (column 2) models return a non significant effect of droughts on marriage/cohabitation. The regression coefficients for the one- and two-year lags are both statistically non significant. For the bivariate probit model (Columns 3 and 4), we obtain a similar result. Although cohabitation has a positive causal effect on fertility (column 4), it is not, however, a mechanism through which drought affects the timing of fertility (Column 3). Both specifications thus lead us to reject the hypothesis that cohabitation mediates (either partially or completely) the effect of droughts on the timing of fertility.

5.2 Droughts and Child Mortality

Child mortality may be affected by droughts. Drought-induced deprivation in nutrition is a possible channel of this effect. We test this mechanism using the following regression specification:

$$M_{i,t} = \sum_{l=0}^{2} \beta_{1,l}^{M} DROUGHT_{s,t-l} + \gamma_1^M X_{i,t} + \gamma_2^M X_i + \omega_1^M \theta_{i,t} + \omega_2^M \mu_s + \omega_3^M \sigma_t + \varepsilon_{i,t}^M, \quad (9)$$

where $M_{i,t}$ is an indicator function equal to 1 if a female CM i experienced the death of her child at time t, and 0 otherwise. For this estimation, the probit estimate does not converge. Table 6 reports LPM estimates for this test. Results show no significant effect of droughts on child mortality. Both the one- and two-year lags coefficients are statistically non significant. Therefore we reject the hypothesis that child mortality is the mechanism driving the fertility effects of droughts.

5.3 Drought, the Opportunity Cost of Children, and Fertility

Most communities in sub-Saharan Africa are highly dependent on rainfed agriculture for their livelihoods (FAO, 2017). The World Bank estimates that 96 percent of this region's cropland is rainfed (The World Bank, 2010). With climate change, extreme weather events such as droughts are expected to become a common source of income shocks in this tropical region (Dinkelman, 2017). Against this backdrop, women's high reliance on rainfed agriculture as a source of livelihood is of great concern. Indeed, in sub-Saharan Africa, more than 60 percent of employed women work in agriculture (FAO, 2011). However, there is also evidence that social norms limit women's access to non-agricultural employment, by prescribing unpaid care-labor (including childcare) as their primary responsibility (Budlender, 2008; Doss, 2018). In farming, this lack of spatial and economic mobility would explain why female farmers report lower yields than their male counterparts. This is because, when households have many young children, female farmers likely have to split their time between caring for their children and cultivating their plots (Backiny-Yetna and McGee, 2015; Samman *et al.*, 2016; Doss 2018). Thus, loss of farm productivity represents the opportunity cost of having children in a rural agrarian community.

Therefore, in rural farming communities where agricultural work and family responsibilities are the most important competing claims on a female time, drought, by reducing agricultural TFP, lowers the opportunity cost of having children, making it cheaper for rural households to have more children. If this is the case, then, in urban areas where the range of economic activities to which women have access to is relatively large, droughts should not have a similar effect on the timing and level of fertility as in the rural areas dependent on rainfed agriculture.

We test this hypothesis using the regression specifications in Eq. (1) for urban women. Table 7 reports the regression results for both the LPM and probit model specifications. Both the LPM and the probit models return a negative, but statistically non significant effect of drought, for both the one- and two-year lags coefficients. These results lead us to identify the opportunity cost of having children as the mechanism through which drought affects fertility in communities where women are highly dependent on rainfed agriculture for their livelihoods.

A second exercise we propose to test this mechanism is by looking at the effect of droughts that occur during the non-rainy season. If the effect passes through channels other than the variation (i.e., drop) in the agricultural TFP, one would expect drought to have a significant effect on the timing of fertility if it occurs in the the dry season. The regression equation for this test on the fertility timing thus writes as follows:

$$
\begin{aligned}
CB_{i,s,t} = {} & \sum_{l=1}^{2} \beta_{1,l} DROUGHT^{RS}_{s,t-l} + \sum_{l=1}^{2} \beta_{2,l} DROUGHT^{NRS}_{s,t-l} + \gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} \\
& + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t},
\end{aligned} \tag{10}
$$

where $DROUGHT^{RS}_{s,t-l}$ and $DROUGHT^{NRS}_{s,t-l}$ denote the drought variables for the rainy season (RS) and the non-rainy season (NRS), respectively.

Table 8 reports the results of this test for both the LPM (column 1) and the probit (column 2) specifications, and shows that the coefficient of droughts in the dry season ($DROUGHT^{NRS}_{s,t-l}$) is not statistically significant. These test results reinforce our hypothesis that droughts affect fertility choices by reducing the opportunity cost of having children because of a drop in the agricultural TFP.

5.4 Droughts and Fertility: The Role of Irrigation

We test whether the presence of irrigation facilities mitigates the effect of drought on fertility. For this test, from Eq. (1), we add an interaction term between the irrigation variable, $IRRIG_s$, and the drought variable, $DROUGHT_{s,t-l}$, as a covariate. The econometric specification for this test writes as follows:

$$CB_{i,s,t} = \sum_{l=1}^{2} \beta_{1,l} DROUGHT_{s,t-l} + \sum_{l=1}^{2} \beta_{3,l} DROUGHT_{s,t-l} \times IRRIG_s$$
$$+\gamma_1 X_{i,t} + \gamma_2 X_i + \omega_1 \theta_{i,t} + \omega_2 \mu_s + \omega_3 \sigma_t + \varepsilon_{i,t} \tag{11}$$

where $IRRIG_s$ is an indicator function equal to 1 if commune s has irrigation facilities, and 0 otherwise. One may argue that irrigation is endogenous as being close to a dam or pumping station is not random. However, this variable comes from the Commune data set and was collected in 2001, so before the sampled female CMs had children and droughts occurred; hence, our individual data set is exogenous to the irrigation variable. Furthermore, since the development of irrigation facilities may be correlated with other variables that can also mitigate the effect of drought, in the same vein as in Jayachandran (2006), we also control for the presence of credit institutions and local markets, in addition to the fixed effects at the SBU level (which measure time-invariant development level across SBUs). Also, we assume that all households living in the same community are equally affected by the presence of irrigation. The endogeneity would then be across communities and not households. Henceforth, we argue that our irrigation variable is exogenous, given our controls.

Results of the regression are reported in Table 9. We find that the presence of irrigation facilities mitigates the positive effect of drought on fertility. This result further validates dependence on rainfed agriculture as the mechanism driving the fertility effect of droughts.

6 Income Shocks and Fertility: A Theory

In this section, we demonstrate theoretically, with the fewest possible assumptions, how income shocks affect fertility, in the context where women's participation in economic activities trade-off their primary responsibility as provider of unpaid care-labor. The main idea is that in rural settings where women lack the resources (e.g., education, assets, property rights) needed to engage in non-agricultural employment, rainfed farming is likely to be their only source of livelihoods, apart from their primary responsibility as providers of care-labor to their children and other household members. In this context, the forgone income from taking time away from farming to care for younger children represents the opportunity cost of having children. When extreme weather events such as droughts become common occurrences in such an environment, women's dependence on rainfed farming as a source of livelihood makes them highly vulnerable to negative income shocks, for example, as drought reduces crop yields. This, in turn, lowers the opportunity cost of having children, thus pushing women to raise their fertility. We articulate this idea formally below.

6.1 Fundamentals

Consider a community in which each household is co-headed by a male spouse (m) and a female spouse (f). There are three possible activities in this community: (i) rainfed farming, (ii) non-agricultural employment, and (iii) unpaid care-giving. The first two activities are competing sources of livelihoods for the household, whereas care-giving is a source of marriage surplus. Farming takes place in a family farm operated by both spouses, and include clearing and plowing the field, sowing seeds, weeding, and harvesting, as well as activities involving a minimal transformation of the crop (e.g., the transformation of paddy crop into rice). Non-agricultural activities include making and selling pottery, wood sculptures, jewelry, and other crafts. A key assumption of our model is that care-giving (e.g., caring for children) is the primary responsibility of the woman, reflecting a gendered division of labor prevalent in developing countries, particularly those from sub-Saharan Africa (Budlender, 2008; Doss, 2018).

Each individual is endowed with one unit of labor time. However, whereas a man splits his time between farming and non-agricultural employment, a woman, by contrast, splits hers between unpaid care-labor and farming. This mimics the gendered structure of activities in rural communities of sub-Saharan Africa where opportunities for non-agricultural employment are fewer for women than men, either because of care responsibilities that prevent mothers from traveling long distance in search of lucrative markets, or because of social norms of doing business that undermine women's ability to bargain effectively with male traders for fair prices (Doss, 2018).

Consistent with this gendered structure of activities in rural agrarian communities, a woman works in the family farm while supervising or caring for her children (Doss, 2018). However, working while providing care-labor has an adverse effect on a woman productivity, by reducing her effective labor time. Therefore, if a woman with n children spends l_a^f $\in [0, 1]$ units of labor time working in the family farm while supervising or caring for her younger children, her effective labor in farming is $(1 - \nu n)\, l_a^f$, where $\nu \in (0, \bar{\nu})$ denotes an exogenously given parameter, with $\bar{\nu}$ chosen such that $(1 - \nu n)$ is always non-negative.

As mentioned above, a man in this environment splits his time between farming (l_a^m) and non-agricultural employment (l_c). His labor use constraint thus writes as follows:

$$l_a^m + l_c = 1. \tag{12}$$

Therefore, for the representative household, total household's effective labor supply in agriculture writes as follows:

$$l_a = (1 - \nu n)\, l_a^f + l_a^m. \tag{13}$$

The crop is the *numéraire*. For simplicity, we also assume that all farm output is sold at the farm gate. Let $z \in \mathbb{R}_{++}$ denote the realization of the agricultural TFP at the start of the period. The lower z, the lower agricultural TFP. Thus any factor that lowers z is a negative shock because it decreases agricultural TFP. Denote as $zf\,(l_a)$, the quantity of crop harvested by the representative household, when the realized level of agricultural TFP is z, and the household allocates l_a units of time to farming.

Assumption 1. *The function $f\,(.)$ satisfies the following properties: (i) $f' > 0$; (ii) $f'' < 0$; (iii) $\lim_{l_a \to 0} f' = +\infty$.*

The properties described by Assumption 1 are standard for a production function. We assume that one unit of the crop produced converts into one unit of the *numéraire*, so that $zf\,(l_a)$ is also the quantity of the *numéraire* derived from farming.

Income from non-agricultural employment depends on the quantity of a labor time the male spouse allocates to making and selling crafts, and is measured by $g\,(l_c)$. We also make the following standard assumption:

Assumption 2. *The function $g\,(.)$ satisfies the following properties: (i) $g' > 0$; (ii) $g'' < 0$; (iii) $\lim_{l_c \to 0} F' = +\infty$.*

Each unit of craft made sells at an exogenously given relative price p_c, so that the quantity of the *numéraire* the representative household derives from non-agricultural employment is $p_c g\,(1 - l_a^m)$. Since a woman combines farm work with unpaid care-labor, she always allocates her entire unit of labor time to farming, i.e., $l_a^f = 1$, which yields $1 - \nu n$ units of effective labor. Using (13) and (12), we obtain a realization of the household's total quantity of the *numéraire* as follows:

$$\Phi\left(l_a^m, n, z\right) = zf\left(1 - \nu n + l_a^m\right) + p_c g\left(1 - l_a^m\right), \tag{14}$$

where p_c denotes the relative price of one unit of craft.

6.2 Preferences and Budget Constraints

The representative household derives utility from the joint consumption of the *numéraire* by both spouses (the man and the woman), C, the quantity of children they have, n, and the quality of each child, q:

$$u = U\left(C, n, q\right). \tag{15}$$

The utility function U exhibits the following standard properties:

Assumption 3. *(i)* $U_j > 0$, $j = C, n, q$; *(ii)* $U_{jj} < 0$; *(iii)* $U_{ij} = 0$, $i, j = C, n, q$ *and* $i \neq j$; *(iv)* $\lim_{j \to 0} U_j = +\infty$ *and* $\lim_{j \to +\infty} U_j = 0.$, where $U_j = \partial U / \partial j$.

The representative household allocates the quantity of the *numéraire* obtained between the spouses' joint consumption, C, and their children's nutritional needs, nq, where q denotes the per child quantity of nutrition—a measure of child quality.

As in Becker and Lewis (1973), the cost of an additional child increases with the desired level of child quality, q, while the cost of quality increases with the desired number of children, n. Each new birth thus induces an additional cost, ν, in the form of the woman's loss of labor productivity, due to caring for this additional child while working in the family farm. Thus, the budget constraint faced by the representative household in the rural community writes as follows:

$$C + nq \leqslant \Phi\left(l_a^m, n, z\right), \tag{16}$$

for all i.

Given the properties of the function $U\left(.\right)$, from (15), substituting in (16) yields a realization of household h's wellbeing as follows:

$$U^{*}\left(l_{a}^{m}, n, q\right)=U\left[\Phi\left(l_{a}^{m}, n, z\right)-q n, n, q\right] \tag{17}$$

This reduces the representative household's decision to a choice of the triplet (l_a^m, n, q) specifying the male spouse's time allocated to farming, l_a^m, the quantity of children the couple has, n, and the quality of each child, as measured by the per capita level of nutrition, q.

6.3 Optimal Decisions

The representative household's problem thus is to choose the triplet (l_a^m, n, q) to solve the following decision problem:

$$\max_{\langle l_a^m, n, q\rangle} U^{*}\left(l_{a}^{m}, n, q\right).$$

Using (17), we obtain the first order necessary and sufficient conditions for an interior solution to this problem under Assumptions 1-3 as follows:

$$l_a^m \quad : \qquad z f'\left(1+l_a^m-\nu n\right)=p_c g'\left(1-l_a^m\right) \tag{18}$$

$$n \quad : \qquad U_n=\left[q+\nu z f'\left(1+l_a^m-\nu n\right)\right] U_C \tag{19}$$

$$q \quad : \qquad U_q=n U_C. \tag{20}$$

Condition (18) states that the representative household allocates the male spouse's time between farming and craft-making to equate the value of the marginal productivity of labor in agriculture, $zf'(1+l_a^m-\nu n)$, to its value in craft-making, $p_c g'(1-l_a^m)$.

Condition (19) states that the representative household chooses its desired number of children to equate the utility benefit of having an additional child, U_n, to the opportunity cost of having an additional child, $[q+\nu z f'(1+l_a^m-\nu n)]\,U_C$. We interpret this opportunity cost as the shadow price of a child in this rural community. Inspection of the structure of this shadow price shows that an exogenous increase in child quality (i.e., an increase in q) causes its level to increase, thus making it costlier to have an additional child in this environment. Similarly, an exogenous increase in agricultural TFP (i.e., an increase in z) increases the level of this shadow price. This behavior of the shadow price of a child is key to understanding the effect of droughts on the number of children rural households have.

Finally, condition (20) states that the representative household chooses child quality, q, to equate the (utility) benefit of having a better quality child, U_q, to the opportunity cost of raising child quality by an additional unit, nU_{c_p}. We interpret this opportunity cost as the shadow price of child quality. Inspection of the structure of this shadow price shows that an exogenous increase in the quantity of children (i.e., an increase in n) causes its level to rise, thus making it costlier for the household to invest in child quality.

The representative household optimal allocation plan (l_a^m, n, q) solves the system of three equations in three unknowns defined by (18)-(20). We apply the substitution method to solve this system implicitly.

6.4 Optimal Labor Time Allocation to The Non-Agricultural Activity

We start with the characterization of the household optimal allocation of the male spouse's labor time to the non-agricultural activity. By definition, this labor time allocation writes as follows: $l_c = 1 - l_a^m$, where l_a^m satisfies the first order necessary and sufficient condition in (18), given the triplet (n, q, z). Indeed, under Assumptions 1 and 2, it follows from the *Implicit Function theorem* applied to (18) that, given (n, q, z), the representative household's optimal allocation of the male spouse's labor time in farming is given by:

$$\hat{l}_a^m = L\left(n, z\right), \tag{21}$$

such that

$$zf'\left[1 + L\left(n, z\right) - \nu n\right] - p_c g'\left[1 - L\left(n, z\right)\right] \equiv 0, \tag{22}$$

and the function $L\left(.\right)$ is implicitly defined by the following properties:

$$(i) \quad L_n = \frac{z\nu f''\left(l_a\right)}{zf''\left(l_a\right) + p_c g''\left(1 - l_a^m\right)} \tag{23}$$

$$(ii) \quad L_z = -\frac{f'\left(l_a\right)}{zf''\left(l_a\right) + p_c g''\left(1 - l_a^m\right)}. \tag{24}$$

As the second order condition for an interior maximum, the term $zf''\left(l_a\right) + g''\left(1 - l_a^m\right)$ is strictly negative under Assumptions 1 and 2. Since $f' > 0$ and $f'' < 0$, by Assumption 1, it follows from (23) and (24) that $L_n > 0$ and $L_z > 0$. This, in turn, implies that $\partial\hat{l}_c/\partial n =$

$1 - L_n < 0$ and $\partial \hat{l}_c / \partial z = 1 - L_z < 0$. Hence, the following result:

Proposition 6.1 *Under Assumptions 1-2, the following statements are all true:*
(i) Having more children induces the representative household to reduce the man's labor time allocation to the non-agricultural activity.
(ii) A low TFP in agriculture (i.e., a decrease in z) causes the representative household to increase the man's labor time allocation to the non-agricultural activity.

Proposition 1-(i) stems from the fact that having many children reduces the female spouse's labor productivity in farming. This in turn induces her spouse to compensate for this loss of productivity by increasing his labor time allocation to farming. Hence, the resulting decrease in his labor time allocation to the non-agricultural activity.

6.5 Quantity-Quality Trade-Off

Next, from (19) substitute in (21), and define

$$\Gamma(n, q, z) = U_n - \left[q + \nu z f'\left(1 + L(n, z) - \nu n\right)\right] U_C. \tag{25}$$

Partial differentiation of the function $\Gamma(.)$ with respect to all its three arguments, applying the *envelope theorem*, yields the following effects under Assumptions 1-3:

$$\begin{aligned}
\Gamma_n &= U_{nn} + \nu^2 z f''(l_a) U_C - \left[q + \nu z f'(l_a)\right]^2 U_{CC} < 0 \\
\Gamma_q &= n\left[q + \nu z f'(l_a)\right] U_{CC} - U_C < 0 \\
\Gamma_z &= -\left[\frac{\nu f'(l_a)\, p_c g''(l_o^m)}{z f'' + p_c g''(l_o^m)} U_C + \left[q + \nu z f'(l_a)\right] f(l_a) U_{CC}\right]
\end{aligned}$$

Under Assumptions 1-3, the partial derivative Γ_z has an ambiguous sign. To understand the determinants of this sign, from (19), consider the shadow price of a child defined as

$$p_n = \left[q + \nu z f'\left(1 + L(n, z) - \nu n\right)\right] U_C$$

where $L(n, z) \equiv \hat{l}_a^m$. What effect does an exogenous increase in the level of agricultural TFP have on this price? The answer to this question is obtained by taking the partial derivative of p_n with respect to z. This partial derivative writes as follows, after making use of (24), and applying the *envelope theorem*:

$$\frac{\partial p_n}{\partial z} = \frac{\nu f'(l_a)\, p_c g''(l_o^m)}{z f'' + p_c g''(l_o^m)} U_C + \left[q + \nu z f'(l_a)\right] f(l_a)\, U_{CC} \equiv -\Gamma_z$$

First, observe that an increase in agricultural TFP tends to increase labor productivity in farming. Second, this increase, in turn, has two opposite effects on the shadow price of a child, p_n. One is a positive effect,

$$\frac{\nu f'(l_a)\, g''(l_o^m)}{z f'' + g''(l_o^m)} U_C,$$

resulting from the fact that a higher agricultural TFP increases the woman's forgone labor productivity from providing unpaid care-labor to an additional child while working in the farm. The other is a negative income effect,

$$\left[q + \nu z f'(l_a)\right] f(l_a)\, U_{CC},$$

due to the fact that a higher agricultural TFP tends to raise household income from farming, thus making it more affordable to have an additional child. We assume that the positive effect of a higher agricultural TFP on the shadow price of a child always dominates its negative (income) effect:

$$\frac{\nu f'(l_a)\, g''(l_o^m)}{z f'' + g''(l_o^m)} U_C > -\left[q + \nu z f'(l_a)\right] f(l_a)\, U_{CC}. \tag{26}$$

This condition is motivated alor and Weil (1996) who argue an increase in women's relative wages reduces fertility by raising the cost of children more than household income. In our context, this implies that a higher agricultural TFP increases the shadow price of a child:

$$\Gamma_z = -\frac{\partial p_n}{\partial z} < 0,$$

because it raises the return to farm labor, thus providing the representative household with the incentive to reduce its fertility, to take advantage of the opportunity for earning a high income. Therefore, by the *Implicit Function Theorem*, there exists a function $\widetilde{N}(.)$ defined by

$$\hat{n} = \widetilde{N}(q, z) \tag{27}$$

such that $\Gamma\left[\widetilde{N}(q,z),q,z\right] \equiv 0$. Consequently, under Assumptions 1-3 and condition (26), the function $\widetilde{N}(.)$ is implicitly defined by the following properties: $\widetilde{N}_q = -\Gamma_q/\Gamma_n < 0$ and $\widetilde{N}_z = -\Gamma_z/\Gamma_n < 0$. Hence, the following results:

Proposition 6.2 *Under Assumptions 1-3, the following statements are all true:*
(i) An exogenous increase in child quality, q, induces the representative household to lower its fertility (i.e., $\widetilde{N}_q < 0$).
(ii) Furthermore, if condition (26) also holds, then a lower TFP in agriculture (i.e., a decrease in z) induces this household to increase its fertility.

Proposition 2-(i) is a reformulation of the well-known quantity-quality trade-off (Becker and Lewis, 1973). Proposition 2-(ii) states that rural households' direct response to a negative shock on agricultural TFP is to increase their level of fertility. This results stems from the fact that a lower agricultural TFP decreases the shadow price of a child, under condition (26). However, since child quality is also endogenous, and thus responsive to a TFP shock, this opens up another channel through which such a shock can affect the fertility of rural households namely, through the quantity-quality trade-off (Proposition 2 -(i)).

6.6 Agricultural TFP Shock and Child Quality

Continuing our substitution method for the resolution of the system (18)-(20), we now turn next to equation (20). Substituting expression (21) and (27) yields a reformulation of this condition as follows

$$\Psi(q,z) = 0, \tag{28}$$

where

$$G(q,z) := U_q - \widetilde{N}(q,z)\,U_C. \tag{29}$$

By the application of the *Envelope Theorem*, partial differentiation of $G(.)$ then yields the following effects, under Assumption 3-*(iii)*:

$$G_q = U_{qq} + n^2 U_{CC} - \frac{\left[U_C - n\left[q + zvf'(l_a)\right]U_{CC}\right]^2}{U_{nn} + v^2 z f''(l_a)\,U_C - \left[q + vzf'(l_a)\right]^2 U_{CC}} \tag{30}$$

$$G_z = -nf(l_a)\,U_{CC} - \left(U_C - \left[zvf'(l_a) + q\right]U_{CC}\right)\widetilde{N}_z \tag{31}$$

where $G_j = \partial G / \partial j$, $j = q, z$. The partial derivative, G_q, is certainly negative as a second order condition for an interior maximum. Furthermore, as an implication of Proposition 2-(ii), $G_z > 0$. Therefore, under Assumptions 1- 3, it follows from the *Implicit Function Theorem* applied to (29) that given the realization of the agricultural TFP, z, the optimal level of child quality for the representative household is defined by

$$\hat{q} = Q(z) \tag{32}$$

such that

$$G[Q(z), z] \equiv 0$$

obtains implicitly from the following first derivative:

$$Q'(z) = -\frac{G_z}{G_q} > 0.$$

Hence, the following result:

Proposition 6.3 *Under Assumptions 1-3 and condition (26), a lower agricultural TFP induces the representative household to lower its desired level of child quality (i.e., $Q'(z) < 0$).*

Proposition 3 confirms that an exogenous change in the level of z has an indirect effect on household fertility, working through the quantity-quality trade-off.

Finally, let us turn to the analysis of the total effect of an agricultural TFP shock on the representative household's fertility. From (27), substituting in (32) yields

$$\hat{n}^* = N(z) \equiv \widetilde{N}[Q(z), z].$$

Thus, the total effect of an exogenous change in the level of agricultural TFP obtains as follows:

$$N' = \widetilde{N}_z + \widetilde{N}_q Q'$$

where $\widetilde{N}_z$ denotes its direct effect and $\widetilde{N}_q Q'$ its indirect effect. We know from Proposition 2 that $\widetilde{N}_z < 0$ and $\widetilde{N}_q < 0$, and from Proposition 3 that $Q'(z) > 0$. In other words, the direct and the indirect effects reinforce each other: $N' < 0$. Hence, the following result:

Proposition 6.4 *Let Assumptions 1-3 hold. Suppose, in addition, that condition (26) holds. Then,* *a lower agricultural TFP (i.e., a decrease in z) induces the representative rural household to increase its level of fertility.*

This last proposition formalizes our empirical results, by showing how the occurrence of agricultural droughts lowers the opportunity cost of children, thus raising the level of fertility in communities where women are highly dependent on rainfed agriculture for their livelihoods.

7 Conclusion

The intensity and frequency of extreme weather events, such as droughts, are increasing with climate change. Developing countries are most affected by these adverse shocks due principally to their geographic locations (UN, 2016). The present paper provides new empirical evidence on the causal effect of droughts on fertility in rural communities where women are dependent on rainfed agriculture for their livelihoods. We focus on rural communities of Madagascar—a large Island in the southeastern coast of Africa, in which extreme climatic events, such as droughts, have become a common occurrence.

Combining longitudinal data with information on plausibly exogenous rainfall shocks in Madagascar, we find that droughts have a significant positive effect on both the timing and the level of fertility in agrarian communities where women are dependent on rainfed agriculture for their livelihoods. Our identification strategy relies on the exogenous temporal and spatial yearly variation of droughts in Madagascar between 2004 and 2011. Moreover, we find that the positive effect of drought exposure on fertility is long lasting, as it is not reversed within four years following the occurrence of drought.

The second challenge to identification stems from a concern about temporal displacement of the positive effects of drought in future years, which, if true, would imply that drought has no permanent effect on women's fertility. To test whether drought has a long-lasting effect on fertility, we estimate the effect of contemporaneous and various lagged droughts on both the timing and the quantum of fertility. Test results show that this effect is indeed long-lasting.

With policy implications in mind, we also investigate potential mechanisms driving the positive causal effect of drought on fertility. We consider three potential mechanisms, including family formation through marriage or cohabitation, child mortality, and the opportunity cost of having children. We find no significant effect of drought on either family formation or child mortality, ruling out both of them as potential drivers of the causal effect of drought. By contrast, we find evidence that the opportunity cost of having children is the underlying mechanism of the positive causal effect of drought on fertility in an agrarian communities where women are dependent on rainfed agriculture for their livelihoods. Indeed, given that providing unpaid care-labor is the primary responsibility of women in such communities, the presence of younger children limits these women's ability to cash in on a higher agricultural income. This loss of effective agricultural income represents the opportunity cost of having children in such communities. Thus, any factor that raises (reduces) the agricultural income also increases (lowers) the opportunity cost of having children, with implications for women's fertility. Hence, the positive causal effect of drought on fertility. We formalize this intuition in our theoretical model.

Our results that droughts increase fertility in rural agrarian communities are of particular interest to policymakers in countries affected by slow fertility transitions, such as those from sub-Saharan Africa, where fertility rates remain high, at 4.8 children per woman on average (World Bank, 2016). For these policymakers, as well as for international organizations focusing on development, mitigating factors responsible for the slow fertility transitions in these countries has become a policy priority. Our paper demonstrates that to lower the level of fertility in the slow-transition countries, public policy should aim to increase the opportunity cost to women of having children, rather than relying on family planning initiatives alone. This includes combating the feminization of rainfed agriculture, by expanding the range of economic opportunities to which women have access to, as well as investing in girls' education to enhance their individual agency.

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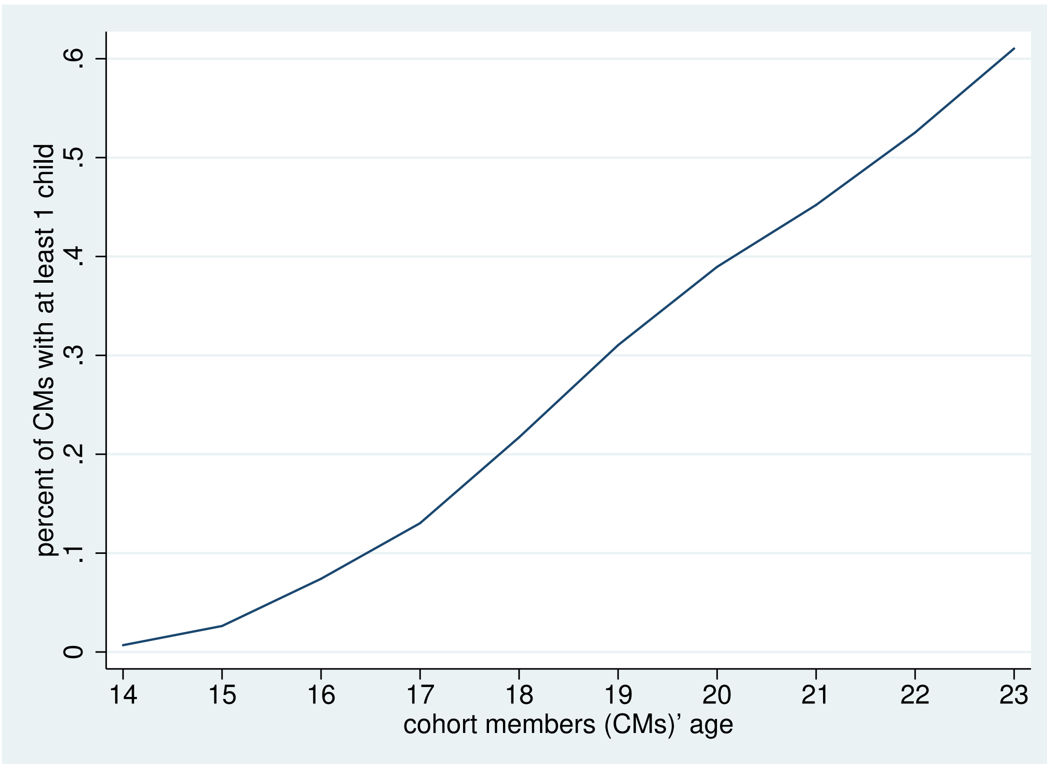
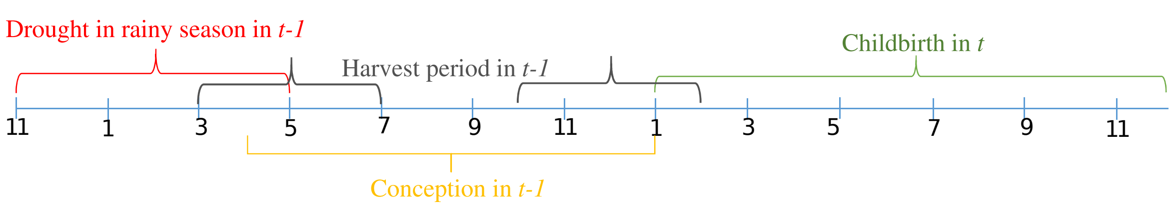
Figures

Figure 1: **Incidence of fertility among female cohort members during the period 2004-2011, by age**



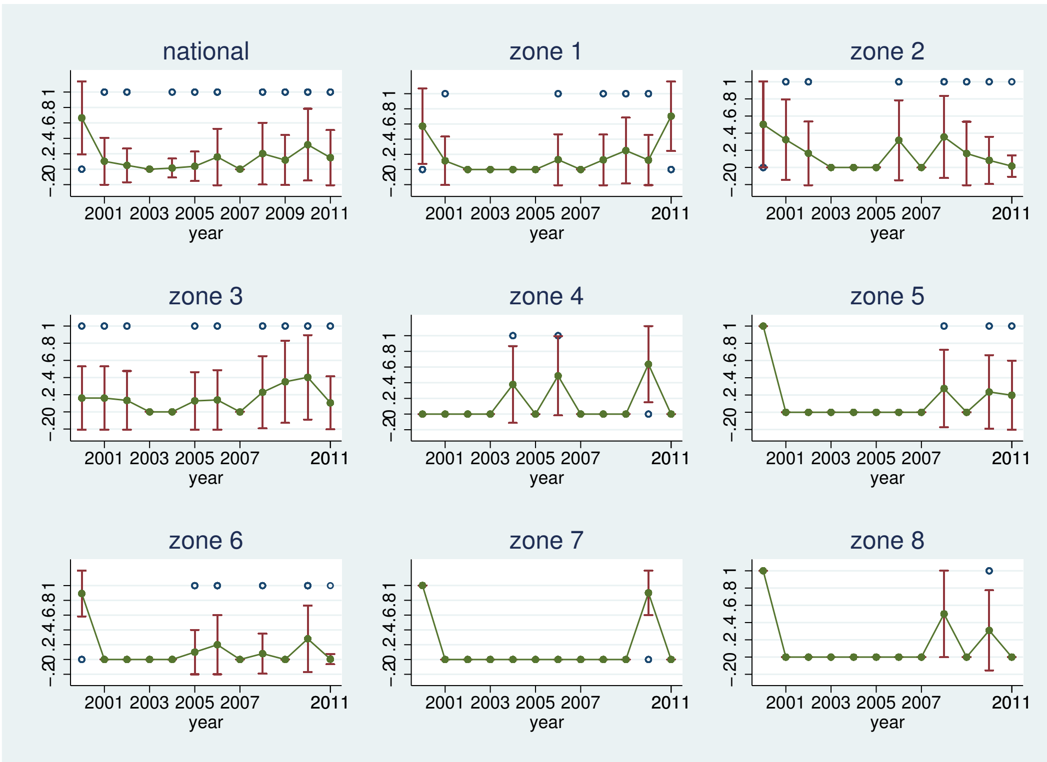
Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Figure 2: **Timing of key variables**



Source: Authors'elaboration.

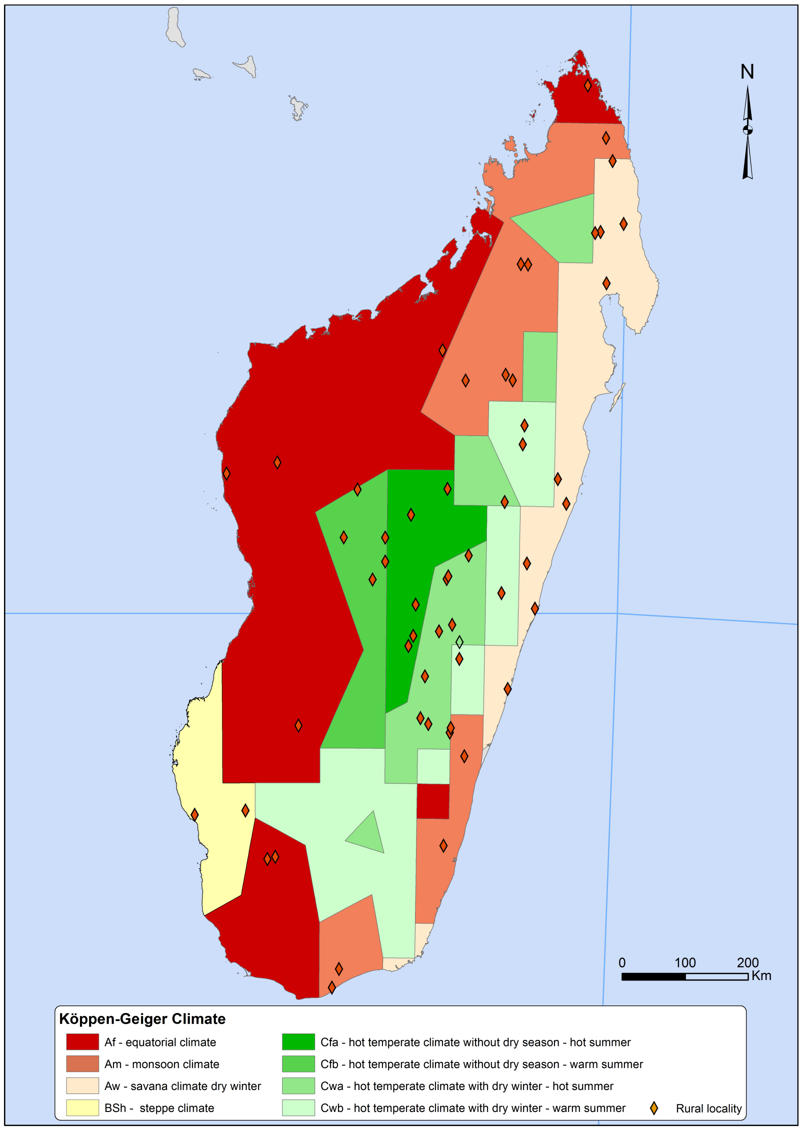
Figure 3: **Incidence of droughts nationally and by climatic zone, by year**



Source: Authors' estimation based on the African Rainfall Climatology, version 2, National Oceanic and Atmospheric Administration.

Notes: The drought variable takes value 1 if the standardized rainfall deviation falls below the 20th rainfall percentile in a district. Climatic zones are defined based on the Köppen–Geiger climate classification system as follows: Zone 1: Equatorial rainforest, fully humid; Zone 2: Equatorial monsoon; Zone 3: Equatorial savannah with dry winter; Zone 4: Steppe climate (hot steppe); Zone 5: Warm temperate, fully humid (hot summer); Zone 6: Warm temperate, fully humid (warm summer); Zone 7: Warm temperate, dry winter (hot summer); Zone 8: Warm temperate, dry winter (warm summer).

Figure 4: **Climatic zones in Madagascar**



Source: Authors' elaboration from Kottek et al. (2006).
Notes: 1. Af. Equatorial rainforest, fully humid; 2. Am. Equatorial monsoon; 3. Aw. Equatorial savannah with dry winter; 4. Bsh. Steppe climate (hot steppe); 5. Cfa. Warm temperate, fully humid (hot summer); 6. Cfb. Warm temperate, fully humid (warm summer); 7. Cwa. Warm temperate, dry winter (hot summer); 8. Cwb. Warm temperate, dry winter (warm summer).

Tables

Table 1: **Descriptive Statistics**

Time-varying characteristics	Mean (2004)	SD	Mean (2011)	SD
Age (years)	14.89	0.81	21.89	0.81
Father ill or dead (%)	8.04	0.27	18.88	0.39
Mother ill of dead (%)	0.42	0.20	12.41	0.33
Enrolled in school (%)	88.46	0.32	16.96	0.38
Highest grade completed (number)	1.02	1.69	5.81	3.55
Number of health centers in the village (%)	1.82	1.32	2.22	1.77
Cohabitation (%)	1.94	0.14	54.29	0.50
Number of children	0.04	0.19	0.85	0.92
Internal migrants (%)	3.32	0.18	29.72	0.46
Time-invariant characteristics (%)	Mean		SD	
Father has no education	51.75		50.01	
Father has completed primary	16.61		38.01	
Father has completed college	31.64		46.26	
Mother has no education	58.74		49.27	
Mother has completed primary	24.65		43.13	
Mother has completed college	16.61		37.24	
Household assets in 2004 (0 to 100)	19.70		16.77	
Household cultivates land in 2004	35.66		48.12	
Ethnicity: Merina	22.52		41.82	
Ethnicity: Betsileo	16.78		37.40	
Ethnicity: Betsimisaraka	9.97		29.97	
Ethnicity: Other	5.70		50.03	
Paved road in village	12.06		0.33	
Paddy fields irrigated by dams or pumping stations	49.74		0.50	
Climatic zone 1	14.33		35.07	
Climatic zone 2	20.45		40.37	
Climatic zone 3	14.86		35.60	
Climatic zone 4	3.32		17.93	
Climatic zone 5	7.86		26.94	
Climatic zone 6	19.58		39.71	
Climatic zone 7	11.36		31.76	
Climatic zone 8	8.21		27.48	
Number of observations	572			

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: All variables are used as explanatory variables in all models, except for those in italics.

Table 2: **Effect of drought on child birth and number of children, linear and non-linear models**

	LPM		**Probit**				**Tobit (Fixed Effect)**	
	Childbirth		**Childbirth**				**Number of children**	
	w/out controls	with controls	w/out controls		with controls		w/out controls	with controls
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
X variables	ME	ME	Coef	ME	Coef	ME	Coef	Coef
Drought (1	0.073**	0.064**	0.199**	0.054**	0.188**	0.047**	0.053	0.085*
year lag)	(0.031)	(0.027)	(0.091)	(0.026)	(0.090)	(0.024)	(0.048)	(0.049)
Drought (2	0.098***	0.085**	0.296***	0.083***	0.267**	0.069**	0.128**	0.138**
years lag)	(0.036)	(0.032)	(0.112)	(0.034)	(0.111)	(0.031)	(0.065)	(0.071)
If CM at school		-0.202***			-0.740***	-0.171***		-0.412***
		(0.027)			(0.093)	(0.022)		(0.098)
Highest grade		-0.017***			-0.075**	-0.017**		-0.083***
		(0.006)			(0.031)	(0.007)		(0.029)
Assets in 2004		-0.001			-0.004	-0.001		-0.002
		(0.001)			(0.006)	(0.001)		(0.006)
If father ill or dead		0.070*			0.283*	0.065*		0.062
		(0.040)			(0.174)	(0.039)		(0.151)
If mother ill or dead		0.052			0.216	0.050		0.146
		(0.047)			(0.191)	(0.044)		(0.133)
If village has access		-			-0.496***	-0.115***		0.096
to a paved road					(0.139)	(0.031)		(0.000)
Number of health		-0.017			0.007	0.002		0.079
centers		(0.021)			(0.945)	(0.022)		(0.075)
If village has access to		-			1.046***	0.241***		0.037
an irrigation system					(0.174)	(0.038)		(0.000)
Ethnicity	no	yes	no	no	yes	yes	no	yes
Father's education	no	yes	no	no	yes	yes	no	yes
Mother's education	no	yes	no	no	yes	yes	no	yes
Age FE	yes	yes	yes	yes	yes	yes	yes	yes
SBUs FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
R2/pseudo R2	0.280	0.348	0.282		0.356			
Observations	3,872	3,862	3,760		3,750		3,872	3,862

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: ME = marginal effects; FE = fixed effects. Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. The binary variables related to the access to paved roads and to irrigation systems at the base year (2004) are collinear with the SBUs fixed effects included in the LPM model, so they are dropped.

Table 3: **Falsification test - Effect of lead drought on child birth and the number of children**

	LPM	Probit	Tobit (fixed effects)
	Childbirth		**Number of children**
	(1)	(2)	(3)
X variables	ME	Coefficient	Coefficient
Drought (1 year lead)	-0.017	-0.054	-0.016
	(0.017)	(0.068)	(0.037)
Drought (2 years lead)	-0.031	-0.118	-0.063
	(0.020)	(0.083)	(0.217)
Additional controls	yes	yes	yes
Age FE	yes	yes	yes
SBUs FE	yes	yes	yes
Year FE	yes	yes	yes
Observations	3,862	3,750	3,862

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 4: **Falsification test - Dynamic Effect of droughts on child birth and the number of children**

	LPM	**Probit**	**Tobit (fixed effects)**
	Childbirth		**Number of children**
	(1)	(2)	(3)
X variables	ME	Coefficient	Coefficient
Drought (1 year lag)	0.045*	0.153*	0.083*
	(0.027)	(0.083)	(0.045)
Drought (2 years lag)	0.107***	0.371***	0.247***
	(0.033)	(0.108)	(0.068)
Drought (3 years lag)	0.095***	0.300***	0.198**
	(0.034)	(0.108)	(0.078)
Drought (4 years lag)	0.062	0.145	0.198**
	(0.042)	(0.130)	(0.086)
Additional controls	yes	yes	yes
Age FE	yes	yes	yes
SBUs FE	yes	yes	yes
Year FE	yes	yes	yes
Observations	2,193	2,129	2,193

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Only female CMs aged 18 or older are included; Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 5: **Mechanism test – Effect of drought on cohabitation**

	LPM	**Probit**	**Bivariate Probit**	
	Cohabitation	**Cohabitation**	**Cohabitation**	**Childbirth**
	(1)	(2)	(3)	(4)
X variables	ME	Coefficient	Coefficient	Coefficient
Cohabitation				1.056***
				(0.136)
Drought	0.010	0.012	-0.024	
	(0.023))	(0.089)	(0.093)	
Drought (1 year lag)	0.021	0.055	0.044	0.301***
	(0.030)	(0.111)	(0.101)	(0.089)
Drought (2 years lag)	0.031	0.166	0.125	0.203
	(0.033)	(0.124)	(0.135)	(0.125)
Additional controls	yes	yes	yes	yes
Age FE	yes	yes	yes	yes
SBUs FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Observations	3,538	3,229	3,035	3,035

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.
Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 6: **Mechanism test – Effect of drought on child mortality**

	LPM
	Mortality
	(1)
X variables	ME
Drought	-0.001
	(0.002)
Drought (1 year lag)	0.003
	(0.003)
Drought (2 years lag)	0.009
	(0.006)
Additional controls	yes
Age FE	yes
SBUs FE	yes
Year FE	yes
Observations	3,570

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 7: **Mechanism test - Effect of drought on child birth and the number of children, in urban areas only**

	LPM	Probit	Tobit (fixed effects)
	Childbirth		**Number of children**
	(1)	(2)	(3)
X variables	ME	Coefficient	Coefficient
Drought (1 year lag)	-0.028	-0.088	-0.238***
	(0.022)	(0.102)	(0.066)
Drought (2 years lag)	-0.016	-0.171	-0.177**
	(0.025)	(0.106)	(0.071)
Additional controls	yes	yes	yes
Age FE	yes	yes	yes
SBUs FE	yes	yes	yes
Year FE	yes	yes	yes
Observations	1,688	1,637	1,450

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 8: **Mechanism test - Effect of drought in non-rainy season on child birth**

	LPM	Probit
	Childbirth	
	(1)	(2)
X variables	ME	Coefficient
Drought (1 year lag; non-rainy season)	-0.010	-0.069
	(0.019)	(0.073)
Drought (2 years lag; non-rainy season)	0.025	0.045
	(0.020)	(0.072)
Drought (1 year lag; rainy season)	0.065**	0.194**
	(0.027)	(0.089)
Drought (2 years lag; rainy season)	0.082**	0.260**
	(0.032)	(0.110)
Additional controls	yes	yes
Age FE	yes	yes
SBUs FE	yes	yes
Year FE	yes	yes
Observations	3,862	3,750

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 9: **Mechanism test and Policy Implications – mitigating effect of irrigation on child birth and the number of children**

	LPM	**Probit**		**Tobit (fixed effects)**
	Childbirth	**Childbirth**		**Number of children**
	(1)	(2)	(3)	(4)
X variables	ME	Coefficient	ME	Coefficient
Drought (1 year lag)	0.100***	0.323***	0.042**	0.127*
	(0.036)	(0.123)	(0.021)	(0.096)
Drought (1 year lag) x	-0.090*	-0.291*	-0.067**	-0.080
Irrigation	(0.047)	(0.165)	(0.033)	(0.100)
Drought (2 year lag)	0.119***	0.371**	0.050*	0.164*
	(0.041)	(0.149)	(0.027)	(0.096)
Drought (2 year lag) x	-0.104*	-0.328*	-0.076*	-0.091
Irrigation	(0.052)	(0.202)	(0.041)	(0.132)
Additional controls	yes	yes	yes	yes
Age FE	yes	yes	yes	yes
SBUs FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Observations	3,862	3,750		3,862

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.
Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.

Table 10: **Robustness check - Effect of drought on migration decision**

	LPM	**Probit**
	Migration	
	(1)	(2)
X variables	ME	Coefficient
Drought (1 year lag)	-0.011	0.056
	(0.008)	(0.138)
Drought (2 years lag)	-0.003	-0.011
	(0.007)	(0.158)
Additional controls	yes	yes
Age FE	yes	yes
SBUs FE	yes	no
Climatic zones FE	no	yes
Year FE	yes	yes
Observations	4,560	4,560

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system. In the probit model, because of the large number of SBUs as effect of migration, we controlled for climatic zones FE and not for SBUs FE.

Table 11: **Robustness check - Effect of drought on fertility, with migrants**

	LPM	**Probit**
	Childbirth	
	(1)	(2)
X variables	ME	Coefficient
Drought (1 year lag)	0.039	0.293***
	(0.025)	(0.099)
Drought (2 years lag)	0.052*	0.378***
	(0.029)	(0.124)
Additional controls	yes	yes
Age FE	yes	yes
SBUs FE	yes	no
Climatic zones FE	no	yes
Year FE	yes	yes
Observations	4,560	4,560

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system. In the probit model, because of the large number of SBUs as effect of migration, we controlled for climatic zones FE and not for SBUs FE.

Table 12: **Robustness check - Effect of drought on child birth and number of children, with CMs individual fixed effects**

	LPM	**Tobit (fixed effects)**
	Childbirth	**Number of children**
	(1)	(2)
X variables	ME	Coefficient
Drought (1 year lag)	0.064**	0.041
	(0.029)	(0.052)
Drought (2 years lag)	0.088**	0.100*
	(0.033)	(0.599)
Additional controls	yes	yes
Age FE	yes	yes
SBUs FE	yes	yes
Year FE	yes	yes
Observations	3,862	3,862

Source: Authors' elaboration from the Madagascar Young Adult Survey and EPSPAM.

Notes: Additional controls are: if CM at school, highest grade, assets in 2004, if father ill or dead, if mother ill or dead, ethnicity, father's education level, mother's education level, if village has access to a paved road, number of health centers in the village, if village has access to an irrigation system.