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Original Research Article

Fertility, Parental Investment, and the Early Adoption of Modern Contraception in Rural Ethiopia

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Objectives: What triggers initial shifts to fertility limitation as populations undergo socioeconomic development remains poorly understood. Alternative models emphasize the social contagion of low fertility ideals, or the individual perception of economic and/or fitness benefits to fertility limitation. Few micro-level studies in communities experiencing the earliest stages of the demographic transition are available. In a previous study, we found little support for the role of social transmission through friendships and spatial networks in explaining contraceptive uptake in rural Ethiopia, where contraceptive prevalence is low (<20%). Here, using data from the same population, we investigate the possibility that early contraceptive uptake is best understood as a manipulation of parental investment in response to local environmental change.

Methods: We used data on >800 women which recorded fertility, birth spacing and offspring survivorship. We first investigated whether ever-users and non-users differ in their reproductive behavior and success prior to contraception use. We then conducted a within-women analysis to investigate the impact of contraceptive uptake on reproduction and child survivorship.

Results: Women who have experienced higher fertility and higher child survival adopt modern contraception sooner rather than later, and contraceptive use among early adopters is predictive of greater birth spacing. However, contraceptive uptake does not have an impact on offspring survivorship.

Conclusions: Our data provide support for the idea that preferences for low fertility emerge in response to increasing competition between offspring. The study has implications for our understanding of the emergence of local fertility norms and the spread of modern birth control. Am. J. Hum. Biol. 00:000–000, 2012.

Understanding change in human reproductive decisions, and in particular the transition from high to low fertility rates as populations undergo socioeconomic development (i.e., the demographic transition), has wide social, economic, and public health implications (Mason, 1997). However, current literature provides little consensus on what factors account for fertility decline, with alternative models emphasizing cultural shifts vs. the emergence of new economic benefits to fertility limitation (Bongaarts and Watkins, 1996; Borgerhoff-Mulder, 1998; Coale and Watkins, 1986). Evolutionary anthropological models of fertility decline parallel nonevolutionary demographic perspectives in this regard. For instance, models of cultural evolution argue that low fertility in industrialized populations results from the social transmission of maladaptive beliefs (Kendal et al., 2005; Richerson and Boyd, 2005), while life-history theory posits that shifts to low fertility rates results from psychological dispositions evolved to optimize parental investment per child (Goodman et al., in press; Kaplan and Lancaster, 2000). Classic macro-level studies on the European demographic transition have been used to support the view that low fertility results from social contagion. Coale and Waktins (1986) for example found that neighboring European regions initiated fertility decline at similar time, independently of economic factors. However, few studies at the micro-level have been able to show that the decision to limit family size is initiated through social influence. For instance, using data from a high fertility population where the demographic transition is just starting (i.e., rural Ethiopia), we found that the decision to adopt modern contraception, a proxy for fertility regulation, is poorly predicted by social transmission through friendships and spatial networks (Alvergne et al., 2011). Here, using data from the same population, we test the alternative hypothesis that the initial use of contraception allows women to regulate fertility so as to increase parental investment per child.

According to life-history theory, individuals face fundamental resource allocations trade-offs between investing in fertility and other domains, such as growth, survival and care of offspring (Mace, 2000; Stearns, 1992). These life history trade-offs are proposed to explain why the upper limit of fertility observed in high fertility populations is much lower than the maximum number of children a woman can have in her entire reproductive career (Lawson and Mace, 2011; Kaplan, 1996). In humans there is evidence that fertility is associated with costs, in terms of maternal longevity (Helle et al., 2002) but also in terms of competition between offspring for survival and/or later success (Lawson and Mace, 2011). For instance, short birth intervals are generally associated with a higher risk of infant mortality (Blurton Jones, 1986; Bongaarts, 1987; Hobcraft et al., 1985), and both total family size and birth

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order influence competition for financial and time investment in offspring (Gibson and Gurmu, 2011; Lawson and Mace, 2009). In turn, life-history models posit that psychological mechanisms detecting the fitness returns of parental investment would have allowed individuals to regulate their fertility optimally across human evolutionary history (Kaplan and Lancaster, 2000), and therefore should have been favored. In particular, if environmental change is associated with an increase (or perceived increase) in the fitness return of parental investment per child, then the incentive to reduce family size might be triggered.

Several observations suggest that the modernization and socioeconomic development of populations might fit a life-history framework. First, socioeconomic development leads to a decrease in child mortality. If child mortality drops, and fertility initially remains the same, individuals achieve a higher family size than otherwise expected, which might in turn increase sibling competition for parental resources (Gibson and Mace, 2006). Second, socioeconomic development is associated with improvements in sanitation and health care access, and reduced vulnerability to subsistence failure, natural disaster, and violent conflict. These changes decrease exposure to extrinsic environmental risks to offspring survival and later success, and thus increase the relative importance of parental investment (Lawson et al., in press). Finally, modernization is associated with a transition from subsistence to skills-based economy, which increases the value of parental investment in education in obtaining wealth (Kaplan and Lancaster, 2000). Interestingly, in both developed and developing populations there is some evidence of increasing benefits to fertility limitation in wealthier families, with regard to child survival, health, and socioeconomic outcomes (Gibson and Sear, 2010; Goodman et al., in press; Lawson and Mace, 2011; Lawson et al., in press). Overall, this suggests that the initial development of populations is associated with an increased sibling competition for parental investment, which might trigger the initial spread of low fertility norms. However, whether individuals initially (i.e., early in the transition) control reproductive scheduling so as to increase parental investment per child remains to be investigated.

The adoption of modern contraception in populations not previously using it can be used as a proxy to track the early spread of low family size. Contraceptive uptake is indeed negatively associated with fertility in developing countries: for each 15% point increase in contraceptive prevalence at the national level, the total fertility rate decreases by one child (Tsui, 2001). Contraception might be used for several purposes however. For instance, a study in rural Gambia found that contraception is not used to stop reproduction but to manage the length of birth intervals. In particular, it is associated with the need to avoid postpartum sexual abstinence, which is a traditional way to maintain long birth intervals (Bledsoe et al., 1994). In populations undergoing a demographic transition, contraceptives might initially be used to increase birth intervals, which might in turn increase reproductive success through improved child survival or other child fitness-related outcomes. While contraceptive use has been associated with improved mother survival through the reduction of high risk pregnancies (e.g., teenage pregnancies) (Fortney, 1987), it is less clear whether change in family building pattern also improve the survival of children (Bongaarts, 1987) and overall reproductive success. Recent studies comparing the reproductive success (i.e., completed family size) of contraceptive users and non-users have found either no difference (Borgerhoff Mulder, 2009), or higher initial reproductive success among contraceptive users [4.9 vs. 4.2 offspring, completed fertility (Mace et al., 2006)]. That contraceptive ever-users do not have fewer children than others in those two sub-Saharan populations is puzzling. These studies cannot distinguish between a selection effect (i.e., that women with higher fertility are more likely to adopt contraceptives) and/or the impact of contraceptive use on child survival. It thus remains unclear whether early contraceptives users differ in their reproductive strategies in the first place and whether the use of contraception positively impacts on child fitness-related outcomes.

In this article, we investigate whether the adoption of modern contraception at the early stages of the demographic transition can be understood as a strategic decision allowing increased parental investment per child. We use longitudinal data from a population of rural Ethiopia where the prevalence of contraceptive uptake is still low (<20%; http://www.pathfind.org/). This allows us to investigate why individuals in a high-fertility setting decide to shift their reproductive scheduling towards lower fertility, a prerequisite if we are to explain what triggers fertility decline in the first place. Our aim is twofold. First, we investigate whether contraceptive ever-users and non-users show pre-existing differences (i.e., independent from contraceptive use) in their fertility and offspring survivorship. Models proposing that the spread of a low fertility norm results from social influence do not predict that contraceptive ever-users differ from non-users in the first place in terms of reproductive effort, i.e. resources attributed to fertility vs. parental investment. Life-history models, however, predict that women using contraception might be those who face the highest offspring competition with modernization, such as those with the highest fertility or the highest child survival. Second, we investigate whether the adoption of modern contraception has a positive impact on parental investment per child (as quantified by the length of birth intervals) and child outcomes (as quantified by child mortality risk). The length of birth intervals can be considered a proxy for how much resources are devoted to fertility as compared with parental investment, with short births intervals indicating an emphasis on fertility rather than on parental investment (Blurton Jones, 1986). We predict that the use of modern contraception allows women to lengthen birth intervals, i.e., increase parental investment, and subsequently increase offspring survivorship.

METHODS

Study site

The study is based on a community of agro-pastoralists living in four villages of the Arsi Administrative zone, Oromia Regional State, South Central Ethiopia. In this rural area, resources are limited, and the community suffers from periodic shortages of both water and food. Access to basic health service and schooling is restricted: the nearest health care services and high schools are over 20 km distance from the villages (See Gibson, 2002, for more information on the study site). In the studied population, the rate of mortality during the first year of life for offspring born before 1990 is 13.4% and decreases to 5.6%

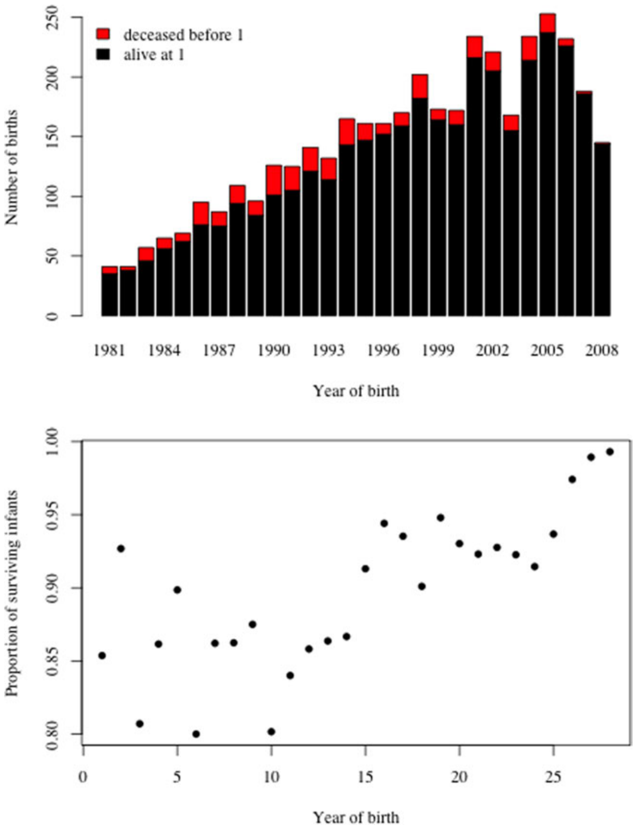

Fig. 1. Number of infants dead and alive (top panel) and proportion of surviving infants (bottom panel) as a function of the year of birth. Only mortality during the 1st year of life is depicted, as it represents most of the deaths in the population (in the period covered, 54% of deaths under the age of 5 are under the age of 1). Mortality decreases with time, and especially after the 90s, where the government adopted a policy to improve reproductive health and access to modern contraception. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

for those born after (Fig. 1). The prevalence of contraceptive uptake is of 19.6% in 2008, which is representative of the country (15% between 2006 and 2010; www.unesco.org). In the studied population, the first event of contraceptive uptake is recorded in 1990, and in 2008, 19% of the sample has ever-used modern contraception. In the studied population, 22.9% of women are formally educated. Note that by 2008, 96% of women have heard about modern contraception (Alvergne et al., 2011). The preferred methods are injection (70%) and the pill (30%).

DATA COLLECTION

A total of 943 ever-married women of reproductive age (15–52 years; mean = 31.7; s.d. = 8.8) residing in the four villages were interviewed in 2008/9 about their birth and contraceptive histories. This includes all women living in the villages at the time of the survey as identified by a census of the four villages in 2008. Only women for whom age and birth history were recorded were included in the analysis. This reduced the sample to 936 women (among which >99.0% were married at the time of the survey). Clearance was obtained from the University College London Research Ethics Committee and the Ethiopian Science and Technology Agency. Signed consent was obtained from all participants.

The survey included questions on whether women had ever heard about modern contraception, and whether they had ever used it in the past (binary variable: yes or no) and when they first used it (i.e., before their first birth, or after which birth). The variable describing contraceptive uptake within women takes two values, 0 for years in which adoption has not occurred yet, and 1 from the year after the first year of adoption. The quality of the data on contraceptive uptake has been checked using previous surveys conducted since 1999, a date at which the process of contraceptive uptake was at an early stage. Each woman was also asked about her marital history, education (binary variable: has ever attended formal school or not), wealth (as quantified by cattle possessions, an index of social status in this population) and religion [e.g., Muslims (90.9%) or Orthodox Christians (9.1%)]. A cohort variable was calculated based on the date of birth (4 quartiles). Finally, mother's age at birth of each child was computed as a categorical variable (<20 years; 20–36 years; +36 years, mean = 25.4, s.d. = 5.5).

STATISTICAL ANALYSIS

The analyses aim to investigate whether contraceptive ever-users and non-users show pre-existing differences in their fertility, birth spacing and offspring survival (between-women analysis), and whether the adoption of modern contraception has an impact on those traits (within-women analysis). In each case, we used discrete-time event history analyses to predict women's risk of birth and risk of child mortality depending on contraceptive behavior (section 3.1.). To infer effect size estimates and their confidence intervals, we used information theoretic methods (section 3.2.). All analyses were carried out using the R software (version 2.11.0). We used the R packages lme4 (Bates et al., 2011) and AICcmodavg (Mazerolle, 2011).

Discrete-time event history analysis

Discrete-time hazard models predict the probability of an event occurrence (e.g., child death) in a given time period D (e.g., from 1- to 2-year-old) conditional that the event has not occurred yet and as a function of predictors X. The conditional probability, or risk, of an event occurrence for a particular time period is calculated using data from all those who are eligible to experience the event during that time period (the risk set). To do so, the original data are expanded into a person-period dataset tracking, for each individual, the event history from the beginning until the end of time of exposure to the risk. When an individual i experiences an event or is censored during the period D, the individual drops out of the risk set in all future time periods. The structure of the model, predicting the logit hazard (i.e., the log odds) of event occurrence for individual i in period j is detailed below (Singer and Willet, 2003). Each alpha (intercept) represents the value of the logit hazard of event occurrence in the particular time period D. The alphas act as multiple intercepts, one per period, and represent the baseline logit hazard function, i.e., the value of logit hazard when all predictors X are 0. The betas (slopes) assess the effect of one unit of variation in the value of predictors X (Singer and Willet, 2003).

$$\operatorname{logit} h(t_{ij}) = [\alpha_1 D_{1ij} + \alpha_2 D_{2ij} + \cdots + \alpha_J D_{Jij}] + [\beta_1 X_{1ij} + \beta_2 X_{2ij} + \cdots + \beta_p X_{pij}]$$

For each analysis, we ran a logistic regression including multiple intercepts for the time indicator (i.e., a step function) on a person–period dataset. First, we investigated the relationship between contraceptive use and women's risk of birth (i.e., reproductive scheduling). We used a multiple event-history analysis on a person–period data set where the event indicator is a birth and the time indicator is a birth interval. Second, we investigated the relationship between contraceptive use and child risk of death under age 5. A single event history analysis was run on a person–period data set where the event indicator is a death and the time indicator is child's age (from 0- to 5-year-old). To take into account time-invariant unobserved heterogeneity between mothers, we used a mixed model in which a random intercept was considered for the identity of the mother.

Statistical inference

Over the last 10 years, biologists and anthropologists have increasingly promoted the use of information theoretic approaches for statistical inference (Anderson et al., 2000; Burnham and Anderson, 2010; Towner and Luttbeg, 2007). As compared with the classical null hypothesis significance testing approach according to which data provide absolute support for a single hypothesis, these methods are based on the assumption that competing models could describe the data equally well. They also present the advantage to take into account model uncertainty when computing effect sizes estimates and their confidence interval. We proceeded through the following steps: for each question, a set of a priori candidate models is assumed (section 3.3.), for which a measure of each model's fit scaling to its complexity is derived [e.g., Akaike information criterion (Akaike, 1974)]. The model for which AIC is minimized is selected as the best for the empirical data at hand. The evidence for each alternative model is calculated by rescaling AIC values relative to the model with the minimum AIC, which subsequently allows models to be ranked according to their ability to account for the data. Inferences are thus conditional of the data and on the models a priori considered. In addition, a measure of weight of the evidence that a given model is the best approximating model in the set considered is calculated [Akaike weight (ω)], which ultimately allow to derive model-averaged based estimators for all variables (see Anderson et al., 2000 for details on the calculus). The use of model based average estimators allows better precision and reduced bias compared with the estimator of that parameter only for the best-approximating model.

Candidate model sets

Women's risk of birth: for each analysis (i.e., between-women or within-women), we first considered a null model (M1) taking into account the structure of the data, i.e., a step function describing the length of the interval since the last reproduction (multiple intercepts). We then considered a control model (M2), including covariates known or likely to influence reproductive scheduling, such as age, economic resources, cohort (based on quartiles for each sample) and whether or not the previous child has survived to age 1 (to control for replacement effects). To investigate whether women show pre-existing differences in their reproductive scheduling, we considered a model including both control predictors and a variable describing the contraceptive behavior of women (i.e., ever-users vs. non-users in the between-women analysis; before vs. after contraceptive uptake in the within-women analysis). In particular, we investigated whether women are differing in their overall risk of birth after any birth interval (M3; no interaction between contraceptive behavior and birth interval), or if they differ in their birth spacing patterns (M4; interaction between contraceptive behavior and birth interval).

Mortality under age 5: for each analysis (i.e. between-women and within-women), we first considered a null model (M1) taking into account the structure of the data, i.e., a step function describing the period of exposure to the risk of death (i.e., age, multiple intercepts). We then considered control models, including covariates known to influence child mortality, i.e. age of the mother at birth, wealth, length of preceding and succeeding birth intervals, child sex and child cohort. Birth interval variables (length of preceding interval; length of succeeding interval) were transformed into categorical variables with 3 levels: short (<2 years); long (>1 year); first/last born (0). Note that twins were excluded as they suffer from higher mortality (data not shown). Models were run either including birth intervals variables (M2a) or including birth order (M2b) as a continuous variable. We then considered models (M3a and M3b) including control variables and investigating the possibility that children differ in their risk of mortality depending on their mother's contraceptive behavior (i.e., ever-users vs. non-users in the between-women-analysis; before versus after contraceptive uptake in the within-women analysis).

RESULTS

Pre-existing differences between early adopters of modern contraception and others

In the following analyses, we considered births occurring before women have ever adopted modern contraception, so that any differences between ever-users and non-users in terms of fertility or offspring survival could not be the result of contraceptive uptake. We found that women who will adopt contraception by 2008, i.e., among the first 20% of adopters, are more likely to experience higher fertility and higher offspring survival in the first place, independently of wealth and level of education.

Fertility and reproductive scheduling. We investigated reproductive differences between non-users and ever-users prior their first use. The analysis is based on 809 women and 8524 birth intervals. Among those women, 21% (N = 170) were ever-users by 2008. Non-users are less likely to reproduce than ever-users before they first adopt modern contraception (Fig. 2). The most likely model in the set is the one considering that women do not differ in the spacing of their births but in their overall risk of birth (weight = 0.78; AIC = 9224.3; K (number of parameters) = 13; LL (log likelihood) = −4599.2), but there is some uncertainty, and the alternative model assuming a difference in reproductive scheduling has a weight of

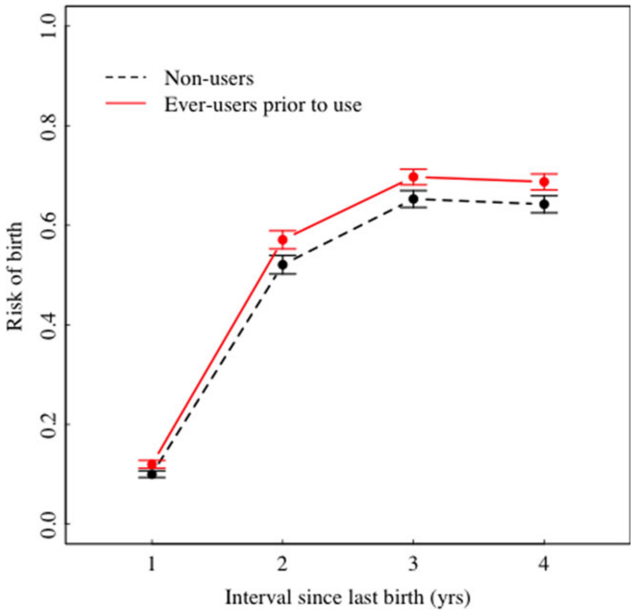

Fig. 2. Pre-existing differences in reproductive scheduling between contraceptive ever-users and non-users. Predicted risk of birth as a function of birth interval. Early adopters are 23% more likely to reproduce than others (weight of the model = 0.78). The values are depicted for women born between 1965 and 1971; of age > 19 and < 37; of minimum wealth, and whose previous birth has survived. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 1. Risk of birth: pre-existing differences between ever-users and non-users

Variables	Estimate	Std. error	*z*-Value	Pr(>|*z*|)
Birth Interval (1 year)	−2.02	0.10	−21.21	0.00
Birth Interval (2 years)	0.27	0.09	3.10	0.00
Birth Interval (3 years)	0.81	0.09	8.60	0.00
Birth Interval (4 years)	0.77	0.12	6.36	0.00
Ever-users (Yes)	**0.20**	**0.07**	**2.72**	**0.01**
Wealth	−0.03	0.06	−0.56	0.58
Cohort (<1970 and >1963)	**−0.18**	**0.08**	**−2.25**	**0.02**
Cohort (<1964 and >1957)	**−0.32**	**0.08**	**−3.84**	**0.00**
Cohort (<1958)	**−0.25**	**0.08**	**−2.94**	**0.00**
Age of the mother at birth (< 20 yrs)	0.15	0.08	1.83	0.07
Age of the mother at birth (> 36 yrs)	0.14	0.14	1.00	0.32
Replacement birth (Yes)	0.26	0.15	1.75	0.08

Estimates and standard errors for the model best approximating the data within the model set (Model's weight = 0.78). Women who will be ever-users by 2008 are more likely to give birth, after any length of birth interval. Note that for ever-users, only births occurring prior to the first use are considered, thus excluding that the lower child mortality risk among ever-users result from the effect of contraceptive uptake. The risk of birth is predicted for each time period of exposure to the risk, here birth interval (multiple intercepts); Brackets indicate the category for categorical variables. The reference categories are: age of the mother at birth (>19 and <37 years); cohort (born after 1969); ever-users (No); replacement birth (No). Lines in bold indicate salient deviations from the reference categories.

0.17 (AIC = 9227.4; K = 16; LL = −4597.7). The averaged estimates taking into account model uncertainty indicate that the risk of birth after any birth interval is 23% higher for future contraceptive users (Hazard Ratio (HR) = 1.23 [1.03; 1.46]; Table 1). Overall, the results indicate that ever-users are more fertile than non-users before they even adopt modern contraception. This relationship is independent of the fact that women are more likely to resume reproduction after the death of a child, women's cohort, women's age at birth and wealth.

TABLE 2. Risk of under-5 mortality: pre-existing differences between ever-users and non-users

Variables	Estimate	Std. error	*z*-Value	Pr(>|*z*|)
Age (Birth)	−3.56	0.21	−16.96	0.00
Age (1 year)	−4.62	0.22	−20.62	0.00
Age (2 years)	−5.14	0.24	−21.53	0.00
Age (3 years)	−5.25	0.24	−21.56	0.00
Age (4 years)	−6.26	0.30	−20.68	0.00
Age (5 years)	−6.66	0.34	−19.47	0.00
Ever-Users (Yes)	**−0.28**	**0.13**	**−2.22**	**0.03**
Child cohort (>1990 and <1996)	**0.50**	**0.19**	**2.63**	**0.01**
Child cohort (>1984 and <1991)	**0.75**	**0.18**	**4.13**	**0.00**
Child cohort (<1985)	**1.38**	**0.17**	**7.94**	**0.00**
Wealth	**−0.08**	**0.04**	**−2.35**	**0.02**
Interval until next birth (< 3 years)	**0.63**	**0.11**	**5.65**	**0.00**
Last Born	**−0.58**	**0.24**	**−2.41**	**0.02**
Interval since last birth (< 3 years)	**0.38**	**0.11**	**3.45**	**0.00**
First Born	**1.12**	**0.26**	**4.25**	**0.00**
Child sex (female)	−0.11	0.09	−1.27	0.20
Age of the mother at birth (< 20 yrs)	**0.27**	**0.12**	**2.29**	**0.02**
Age of the mother at birth (> 36 yrs)	0.39	0.31	1.26	0.21

Estimates and standard errors for the model best approximating the data within the model set (Model's weight = 0.84). Children born of mothers who will become ever-users by 2008 (i.e., where the prevalence of contraceptive uptake is c.a. 20%) are exposed to a lower risk of mortality. The risk of mortality is predicted for each time period of exposure to the risk, here age in years (multiple intercepts). Brackets indicate the category for categorical variables. The reference categories are: age of the mother at birth (>19 and <37 years); child cohort (born after 1995); interval until next birth (>2 years); interval since last birth (>2 years); child sex (male); ever-users (no). Lines in bold indicate salient deviations from the reference categories.

Under five mortality. We investigated differences in offspring mortality between non-users and ever-users prior to their first use. The analysis is based on 4,067 children and 871 mothers, among which c.a. 20% (N = 178) are ever-users by 2008. The results suggest that children born before their mothers adopt contraception are 25% (HR= 0.75 [0.58; 0.98]; Table 2; Fig. 3) less likely to die before they reach the age 5 as compared with children born of mothers who are non-users. This is furthermore supported by the weight of the model considering mother's contraceptive behavior (weight = 0.84; K = 19; AIC = 4827.4; LL = −2394.7) as compared with that of a model excluding this variable (weight = 0.16; K = 18; AIC = 4830.63; LL = −2397.31). The analysis is controlled for age of the mother at birth, wealth, child sex, and cohort of the child, as well as the length of birth interval before and after the birth of the child (<3 years, > 2 years, firstborn/lastborn). Risk of mortality is strongly influenced by birth order and birth interval. Risk of mortality is 3.2 times higher (95CI [1.82; 5.15]) for first born and 44% lower (95CI [0.34; 0.92]) for last-born. When the birth follows or is followed by an interval shorter than 3 years, the risk of mortality is increased by 46 and 88%, respectively. Risk of mortality also decreases with increasing economic possessions (i.e., cattle). Overall, the results suggest that contraceptives ever-users experience lower offspring mortality in the first place, independently of wealth or the length of birth interval.

The impact of the adoption of modern contraception on fertility, birth spacing, and child mortality

In the following analyses, we investigated whether uptake of modern contraception is associated with a change in overall fertility, birth spacing and child mortality. We compared women's risks of reproduction and child mortality before and after they have ever used modern contraception (within-women analysis). Birth spacing is longer after the adoption of modern contraception. However, although we found that birth spacing < 3 years is associated with a higher risk of child mortality early in life (see previous section), contraceptive uptake is not associated with a decrease in the risk of child mortality. Child mortality is mainly predicted by time of birth.

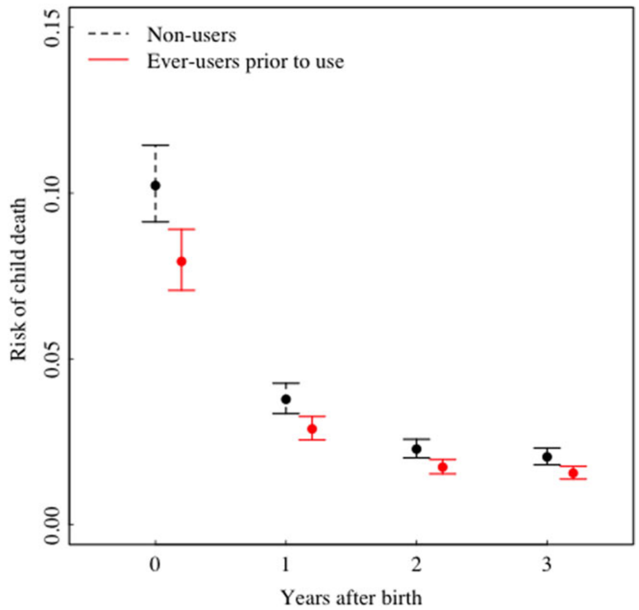

Fig. 3. Pre-existing differences in child mortality between contraceptive ever-users and non-users. Predicted risk of child death as a function of age. The risk of mortality under the age of 5 for children whose mothers will be ever-users by the time of the survey but who are born before their mothers first adopt contraception is 25% lower than for children whose mothers are not early adopters. Values are depicted for male offspring born before 1993; born before and after an interval < 3 years; of mothers aged between 20 and 36 and of minimum wealth. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Fertility and birth intervals. We investigated differences in risk of birth before and after women have ever-used contraception. The analysis is based on 172 women and 1,808 birth intervals. The results suggest that women are less likely to reproduce after short birth intervals once they have adopted modern contraception (Fig. 4), controlling for wealth, women's age, women's cohort, and whether or not the previous child has survived. In particular, averaged estimates indicate that after the adoption of modern contraception, the risk to reproduce after an birth interval of 2 years is decreased by 62% (HR = 0.38; 95CI[0.46; 0.86]; Table 3). However, for other intervals lengths, the risk of birth is similar before and after the adoption of modern contraception (HR 1 year IBI = 0.71; 95CI[0.36; 1.41]; HR 3 years = 1.15; 95CI[0.49; 2.69], HR 4 years = 1.39; 95CI[0.44; 4.35]). That contraception is used to manipulate birth interval is furthermore supported by the weight of the model considering this possibility (weight = 0.98; K = 16: AIC = 1989.38; LL = −978.7). Overall, the results indicate that the adoption of modern contraception allows women to change their reproductive scheduling towards longer births intervals.

Under five mortality. We investigated differences in the risk of child death before and after mothers have ever used contraception. The analysis is based on 178 women and 871 children. The results suggest that contraceptive

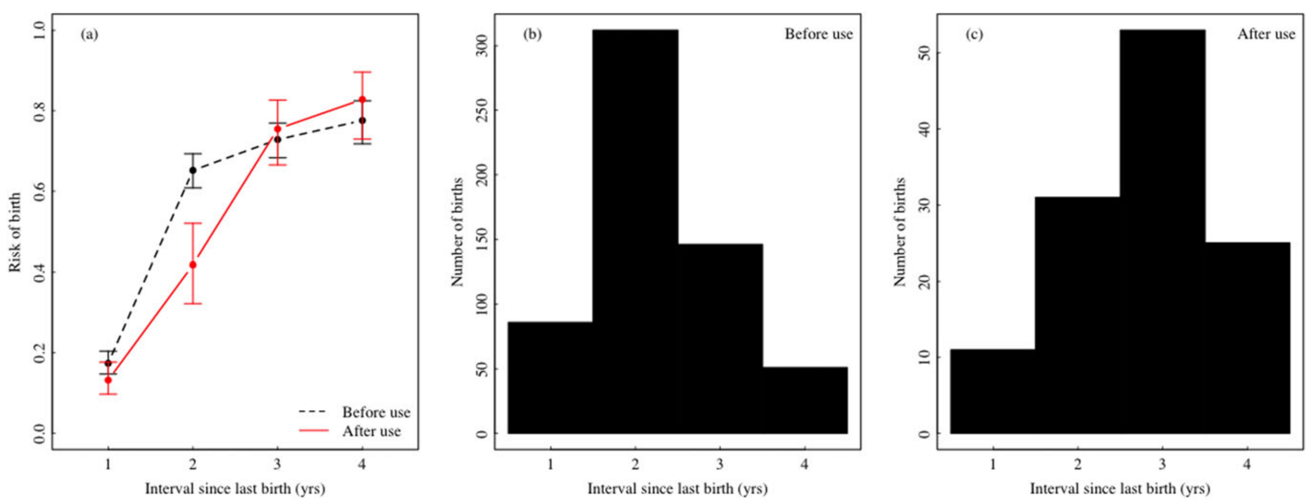

Fig. 4. Reproductive scheduling before and after the adoption of modern contraception. (a) Predicted risk of birth (±s.e) before and after use. After the first ever-use of modern contraception, the risk of birth after a 2 years birth interval is decreased by 62% (plain line). Values are depicted for women born after 1970, of minimum wealth, of age > 19; and < 37; and whose previous birth has survived. (b) Number of births before the use of modern contraception as a function of birth interval: raw data (N = 595 births). (c) Number of births after the use of modern contraception as a function of birth interval: raw data (N = 120 births). After the adoption of modern contraception, women tend to reproduce at longer birth intervals. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 3. Risk of birth before and after the adoption of modern contraception

Variables	Estimate	Std. error	z-Value	Pr(>|z|)
Birth interval (1 year)	−1.45	0.20	−7.36	0.00
Birth interval (2 years)	0.73	0.19	3.92	0.00
Birth interval (3 years)	1.09	0.22	5.00	0.00
Birth interval (4 years)	1.35	0.31	4.39	0.00
Adoption (after)	−0.32	0.34	−0.94	0.35
Wealth	−0.14	0.12	−1.17	0.24
Cohort (<1970 and >1963)	−0.11	0.16	−0.65	0.51
Cohort (<1964 and >1957)	**−0.41**	**0.17**	**−2.45**	**0.01**
Cohort (<1958)	**−0.52**	**0.17**	**−3.05**	**0.00**
Age of the mother at birth (< 20 yrs)	−0.13	0.18	−0.71	0.48
Age of the mother at birth (> 36 yrs)	0.34	0.30	1.13	0.26
Replacement birth (Yes)	−0.16	0.29	−0.56	0.58
Birth Interval (2 years): Adoption (after)	**−0.96**	**0.41**	**−2.32**	**0.02**
Birth Interval (3 years): Adoption (after)	0.14	0.44	0.32	0.75
Birth Interval (4 years): Adoption (after)	0.33	0.58	0.57	0.57

Estimates and standard errors for the model best approximating the data within the model set (Model's weight = 0.98). The adoption of modern contraception is associated with a decreased risk of birth after a birth interval of 2 years. The risk of birth is predicted for each time period of exposure to the risk, here duration since last birth in years (multiple intercepts); Brackets indicate the category for categorical variables. The reference categories are: age of the mother at birth (>19 and <37 years); cohort (born after 1969); adoption (before); replacement birth (No). ":" denotes an interaction between 2 variables. Lines in bold indicate salient deviations from the reference categories.

TABLE 4. Risk of under-5 child mortality before and after the adoption of modern contraception

	Estimate	Std. error	z-Value	Pr(>|z|)
Age (Birth)	−4.43	0.69	−6.41	0.00
Age (1 year)	−5.11	0.71	−7.18	0.00
Age (2 years)	−6.28	0.78	−8.06	0.00
Age (3 years)	−6.04	0.77	−7.87	0.00
Age (4 years)	−7.25	0.92	−7.92	0.00
Age (5 years)	−7.66	1.01	−7.57	0.00
Adoption (after)	0.20	0.34	0.60	0.55
Child cohort (>1990 and <1996)	0.71	0.57	1.25	0.21
Child cohort (>1984 and <1991)	**1.31**	**0.62**	**2.12**	**0.03**
Child cohort (<1985)	**2.03**	**0.61**	**3.33**	**0.00**
Wealth	0.00	0.08	0.01	0.99
Interval until next birth (<3 years)	0.37	0.26	1.43	0.15
Last Born	−0.13	0.59	−0.22	0.83
Interval since last birth (<3 years)	0.45	0.26	1.73	0.08
First Born	1.03	0.65	1.57	0.12
Child sex (female)	−0.06	0.21	−0.27	0.79
Age of the mother at birth (<20 yrs)	−0.48	0.33	−1.49	0.14
Age of the mother at birth (>36 yrs)	0.46	0.64	0.72	0.47

Estimates and standard errors for the model including contraceptive behavior (Model's weight = 0.16). The adoption of modern contraception is not associated with a decrease in child mortality risk. Rather, time of birth (child cohort) is the most important predictor. The risk of mortality is predicted for each time period of exposure to the risk here age in years (multiple intercepts). Brackets indicate the category for categorical variables. The reference categories are: age of the mother at birth (>19 and <37 years); child cohort (born after 1995); interval until next birth (>2 years); interval since the previous birth (>2 years); child sex (male); ever-users (No). Lines in bold indicate salient deviations from the reference categories.

use has no impact on child mortality risk (β ± s.e. = 0.06 ± 0.33; Table 4). This implies that while contraceptive use is associated with an increase in birth spacing, it does not have an impact on child survival among early adopters. However, the results do not rule out that women perceive a decrease in offspring mortality following the adoption of modern contraception. Time is associated with both an increase in contraceptive prevalence and a decrease in offspring mortality risk. This may create an apparent relationship between the risk of child death and the use of contraception. Child mortality risk is indeed lower after than before the adoption of contraception if child's cohort is not controlled for (β ± s.e. = −1.02 ± 0.26).

DISCUSSION

In this article, we investigate the hypothesis that the early adoption of modern contraception can be understood as part of a strategy to reduce competition between offspring for parental investment. Using respective data from a site in rural Ethiopia where fertility is high (>5 births per woman) and contraceptive prevalence is low (<20% have ever used contraception), we examine both pre-existing differences between users and non-users in their fertility and offspring survivorship and the impact of contraceptive use on these traits. We demonstrate that women who experience relatively high fertility and low child mortality, and consequently the highest levels of competition between offspring, are most likely to engage with novel contraceptive technologies. We also present evidence that contraceptive use is associated with avoidance of specifically short birth intervals, which during the early study period are strongly associated with increased risk of offspring death. However, since the uptake of contraception coincides with dramatic improvements in child survival brought about by development in the region, short birth intervals associated with contraceptive use did not further reduce the risk of child mortality. These findings are consistent with the idea that contraceptive use may be motivated by a parental desire to reduce reproductive effort and concentrate investment in relatively few offspring. They also highlight the difficulties that both parents in developing rural communities such as this one, and analysts of demographic data, may face in ascribing the causes of local declines in child mortality.

Over the last 20 years, socioeconomic development in the study population has brought about dramatic reductions in child mortality (Gibson and Mace, 2006). In this context, continuing high fertility leads to a higher number of surviving offspring (i.e., completed fertility) than might otherwise be expected in the absence of changes in their environment. Assuming that parental resource constraints remain similar, this higher completed fertility may have negative consequences for offspring as parental investment is diluted across more children. Gibson and Mace (2006) for example, present evidence that the installation of water taps in the region has reduced child mortality, but is also associated with overall reductions in child health as parents struggle to feed and care for additional surviving offspring. Gibson and Lawson (2011) also associate these changes with more discriminative parental investment in child education. Our results suggest that this extra competition between offspring motivates contraceptive uptake, with women in this population using contraception to space births and stop reproduction once a sufficient number of children are produced (See also Alvergne et al., 2011). This interpretation also implies that while fertility decline is often envisaged as a shift in cultural norms (Newson et al., 2005), in populations undergoing mortality decline, contraceptive use, and the consequent decline in fertility, can also be interpreted as the adherence to stable cultural norms for the production of intermediate levels of completed fertility (See also Carey and Lopreato, 1995).

Short birth intervals have been associated with increased risk of child mortality across many traditional communities (Blurton Jones, 1986; Bongaarts, 1987; Hobcraft et al., 1985) and we show that the same relationship also characterizes the rural Ethiopian population under current study. That contraception use is associated with the specific avoidance of such short birth intervals, while mothers were equally likely to have births at longer intervals, suggests that when contraceptive users do decide to have more children they aim to do so in a way that minimizes investment competition between vulnerable young offspring. Interestingly, however, we found no evidence that contraceptive use improved child survival as overall child mortality risks had already substantially declined by the time contraceptive use became common. Other benefits to increasing birth spacing, both for maternal and child health are perhaps likely, but this result raises the possibility that using contraceptives to space births does not lead to the benefits parents may normally anticipate, and thus motivations for contraceptive use may be out-of-sync with current environmental conditions. Yet individual inference of the causality of local shifts in mortality risk is unlikely to be accurate or immediate in such contexts, particularly where levels of education are low (Montgomery, 2000).

Our previous work on this study population found little evidence for the role of social transmission of modern contraceptives through either spatial and friendship networks. Among early adopters, most were the first to adopt modern contraception within their friendships networks (i.e., 86%). Similarly, spatial proximity to a contraceptive ever-user was not associated with an increased risk of adopting modern contraception (Alvergne et al., 2011). Altogether, the results are consistent with the view that the initial uptake of novel behaviors relies on individual learning, rather than social contagion. Theories of fertility decline based on the social diffusion of low fertility norms also make no prediction that the uptake of such norms (here assessed through contraceptive use) will vary according to the reproductive history of mothers. A life history perspective, accounts for this pattern and argues that contraceptive uptake is motivated at the individual-level by a desire to limit competition between offspring as socioeconomic development increases the pay-offs to parental investment (Kaplan, 1996; Kaplan and Lancaster, 2000). Previous literature on the demographic transition has emphasized heterogeneity in the causes of fertility decline in different populations (Mason, 1997) and we do not suggest that our findings here can be generalized to all contexts. We also note that while our investigations into contraceptive uptake in rural Ethiopia suggest that parental investment models are most consistent with the pattern of initial contraception uptake, it remains possible that alternative processes motivate further reductions in fertility and its maintenance at low levels at later stages of the demographic transition (Borgerhoff-Mulder, 1998). We hope this study will stimulate future researchers to test competing theoretical accounts of the demographic transition using data from the same study population and at different stages of fertility decline.

To conclude, we found that the early adopters of modern contraception in rural Ethiopia are more likely to be those experiencing the highest level of offspring competition, i.e., women experiencing the highest fertility and the lowest child mortality. This suggests that individual effects trigger the adoption of modern contraception early in the demographic transition. We also found that while the adoption of modern contraception increases the length of birth interval, it does not translate into higher child survival. This does not exclude that women use contraception for that purpose, however, as the concomitant decrease in child mortality risk with the increase of contraceptive users in the population over time may create an apparent causal positive relationship between contraceptive use and child survival. Alternatively, women might adopt contraception to reduce offspring competition later in life, perhaps most notably in relation to child education, and so further research on the perceived benefits of contraception is warranted. Overall, we hope that this study will have implications for family planning programs, in stressing the role of child mortality, parental investment, and individual decision in initiating shifts to low fertility.

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LITERATURE CITED

Akaike H. 1974. A new look at the statistical model identification. IEEE Trans Autom Control 19:716–723.

Alvergne A, Gurmu E, Gibson M, Mace R. 2011. Social transmission and the spread of modern contraception in rural Ethiopia. PLoS One 6:7.

Anderson DR, Burnham KP, Thompson WL. 2000. Null hypothesis testing: problems, prevalence and an alternative. J Wildl Manage 64: 912–923.

Bates D, Maechler M, Bolker B. 2011. lme4: linear mixed-effects models using S4 classes. R package version 0.999375–40.

Bledsoe C, Hill AG, D'Allessandro U, Langerok P. 1994. Constructing natural fertility: the use of Western contraceptives in rural Gambia. Pop Dev Rev 20:81–114.

Blurton Jones NG. 1986. Bushman birth spacing: a test for optimal inter–birth intervals. Ethol Sociobiol 7:91–105.

Bongaarts J. 1987. Does family planning reduce infant mortality rates? Pop Dev Rev 13:323–334.

Bongaarts J, Watkins SC. 1996. Social interactions and contemporary fertility transitions. Pop Dev Rev 22:639–682.

Borgerhoff Mulder M. 2009. Tradeoffs and sexual conflict over women's fertility preferences in Mpimbwe. Am J Hum Biol 21:478–487.

Borgerhoff Mulder M. 1998. The demographic transition: are we any closer to an evolutionary explanation? TREE 13:266–270.

Burnam KP, Anderson DR. 2010. Model selection and multi-model inference: a practical information-theoretic approach, 2nd ed. New York: Springer.

Carey AD, Lopreato J. 1995. The evolutionary demography of the fertility-mortality quasi-equilibrium. Pop Dev Rev 21:613–630.

Coale AJ, Watkins SC. 1986. The decline of fertility in Europe. Princeton: Princeton University Press.

Fortney J. 1987. The importance of family planning in reducing maternal mortality. Stud Fam Plan 18:109–114.

Gibson M, Gurmu E. 2011. Land inheritance establishes sibling competition for marriage and reproduction in rural Ethiopia Proc Natl Acad Sci USA 108:2200–2220.

Gibson M, Mace R. 2006. An energy saving development increases birth rate and childhood malnutrition in rural Ethiopia. PLoS Med 3:e87.

Gibson MA. 2002. Development and demographic change; the reproductive ecology of a rural Ethiopian Oromo population. London: University College London.

Gibson MA, Lawson DW. 2011. 'Modernization' increases parental investment and sibling resource competition: evidence from a rural development initiative in Ethiopia. Evol Hum Behav 32:97–105.

Gibson MA, Sear R. 2010. Does wealth increase parental investment biases in child education? Evidence from two African populations on the cusp of the fertility transition. Curr Anth 51:693–701.

Goodman A, Koupil I, Lawson DW. 2012. Low fertility increases descendant socioeconomic position but reduces long-term fitness in a modern post-industrial society. Proc Roy Soc B: Biol Sci 279:4342–4351.

Helle S, Lummaa V, Jokela J. 2002. Effect of producing sons on maternal longevity in premodern populations. Science 298:5592.
Hobcraft JN, McDonald JW, Rutstein SO. 1985. Demographic determinants of infant and early child mortality: a comparative analysis. Popul Stud 39:363–385.
Kaplan H. 1996. A theory of fertility and parental investment in traditional and modern human societies. Yearb Phys Anth 39:91–135.
Kaplan HS, Lancaster JB. 2000. The evolutionary economics and psychology of the demographic transition to low fertility. In: Cronk WI, Chagnon N, editors. Human behavior and adaptation: an anthropological perspective: Aldine de Gruyter. p 238–322.
Kendal JR, Ihara Y, Feldman MW. 2005. Cultural niche construction with application to fertility control: a model for education and social transmission of contraceptive use. Morrison Institute Working Paper Series 102.
Lawson D, Mace R. 2009. Trade-offs in modern parenting: a longitudinal study of sibling competition for parental care. Evol Hum Behav 30:170–183.
Lawson DW, Alvergne A, Gibson MA. 2012. The life history trade-off between fertility and child survival. Proc Roy Soc B: Biol Sci 279:4755–4764.
Lawson DW, Mace R. 2011. Parental investment and the optimization of human family size. Phil Trans R Soc B 366:333–343.
Mace R. 2000. Evolutionary ecology of human life history. Anim Behav 59:1–10.
Mace R, Allal N, Sear R, Prentice A. 2006. The uptake of modern contraception in a Gambian community: the diffusion of an innovation over 25 years. In: Wells JCK, Strickland S, Laland K, editors. Social information transmission and human biology. Boca Raton: CRC Press.
Mason KO. 1997. Explaining fertility transitions. Demography 34:443–454.
Mazerolle MJ. 2011. AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 1.20.
Montgomery MR. 2000. Perceiving mortality decline. Pop Dev Rev 26:795–819.
Newson L, Postmes T, Lea SE, Webley P. 2005. Why are modern families small towards an evolutionary and cultural explanation for the demographic transition. Pers Soc Psy Rev 9:360–375.
Richerson PJ, Boyd R. 2005. Not by genes alone: how culture transformed human evolution. Chicago: The University Of Chicago Press.
Singer JD, Willet JB. 2003. Applied longitudinal data analysis: modeling change and event occurrence. New York: Oxford University Press.
Stearns SC. 1992. The evolution of life histories. Oxford: Oxford University Press.
Towner MC, Luttbeg B. 2007. Alternative statistical approaches to the use of data as evidence for hypotheses in human behavioral ecology. Evol Anthr 16:107–118.
Tsui AO. 2001. Population policies, family programs, and fertility: the record. Pop Dev Rev 27:184–204.