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Pregnant in haste? Evidence of reproductive behaviours in Uganda

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Masaru Nagashima
Waseda Institute for Advanced Study, Waseda University

Chikako Yamauchi
National Graduate Institute for Policy Studies

Waseda Institute for Advanced Study
早稲田大学 高等研究所

1-21-1 Nishi Waseda, Shinjuku-ku, Tokyo 169-0051, Japan
Tel: 03-5286-2460 ; Fax: 03-5286-2470

Pregnant in haste? Evidence of reproductive behaviours in Uganda*

Masaru Nagashima† and Chikako Yamauchi‡

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Abstract

Appropriate birth spacing improves the outcomes of children and mothers. This paper shows the first evidence that the experience of a pregnancy loss due to miscarriage or stillbirth leads to a (mechanical) increase in the next birth spacing interval and a *decrease* in the intervals for all subsequent births. This shortening effect is mostly explained by mothers' reaction to the subjective probability of pregnancy loss based on their own pregnancy history, which increases substantially after pregnancy loss. These results suggest that pregnancy loss affects birth spacing by changing maternal probabilistic beliefs about losing their unborn children.

JEL Classification Codes: I12, I15, J13, O15.
Keywords: birth spacing, miscarriage and stillbirth, belief updating, family planning, Uganda.

1 Introduction

In many low-income countries, fertility rates as well as maternal and infant mortality rates remain very high: the total fertility rate was 4.9; 541 mothers died per 100,000 live births; and 56.4 infants died per 1,000 live births.[1] One of the factors contributing to this situation is short birth spacing. Appropriate spacing of births can reduce the total fertility rate by decreasing the number of children a female can have during her reproductive period. It can also decrease the burden on fatigued uterus, thereby increasing nutrition and protection for a foetus. As a result, longer birth spacing intervals are associated with lower infant mortality, preterm delivery and pregnancy-related complications (Conde-Agudelo et al., 2006; Dadi, 2015; Norton, 2005; Pimentel et al., 2020; Rutstein, 2005). Furthermore, longer intervals are shown to improve educational achievement, mental health and marriage outcomes (Buckles and Munnich, 2012; Smits et al., 2004; Vogl, 2013) as well as mothers' wage growth paths (Karimi, 2014).[2]

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†Waseda Institute for Advanced Study, Tokyo, Japan. Email: mnagashima@aoni.waseda.jp.
‡National Graduate Institute for Policy Studies, Tokyo, Japan. Email: c-yamauchi@grips.ac.jp.

[1] World Development Indicators by World Bank, retrieved on the 30th of August 2017, at http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators.

[2] One of the pathways through which birth spacing affects subsequent outcomes is birth weight. Appropriate birth spacing is shown to increase birth weight (e.g. Rosenzweig and Wolpin, 1988), which in turn improves socioeconomic outcomes throughout one's life (Behrman and Rosenzweig, 2004; Bharadwaj et al., 2018; Black et al., 2007; Fletcher, 2011).

This study investigates whether the birth spacing interval is affected by the experience of miscarriage/stillbirth or pregnancy (foetal) loss. Existing studies indicate that infant death shortens subsequent birth spacing, and this is interpreted as the replacement effect (Maitra and Pal, 2008; Whitworth and Stephenson, 2002).[3] This effect is robustly confirmed by Bhalotra and van Soest (2008) and van Soest and Saha (2018) even after accounting for the reverse effect of short birth spacing intervals on infant mortality. However, the effects of past pregnancy loss have not yet been fully examined. This is unfortunate because pregnancy loss, which is mainly due to genetic anomalies, as discussed below, is unlikely to be reduced in a similar manner as infant mortality, which can be reduced by public health improvement. Rather, it is likely to increase as maternal age of pregnancy increases.

Available evidence suggests that pregnancy loss similarly shortens pregnancy loss. For instance, past studies on the impact of birth spacing have instrumented it with pregnancy loss (Buckles and Munnich, 2012; Karimi, 2014).[4] However, it is unclear whether the effect remains or dissipates as females experience many more pregnancies. Such long-term consequences matter in determining reproductive behaviours in settings where females give many births and face high infant and maternal mortality. This issue, however, has not been examined since existing studies on pregnancy loss have focused on developed countries with relatively low fertility. Thus, the analysis of longer-term reproductive behaviour in high-fertility settings is called for (Bhalotra, 2010). We fill this research gap by providing evidence on the longer-term effects of pregnancy loss and further explore the mechanism behind them.

Identifying the impact of pregnancy loss requires pregnancy loss to occur at random. Medical studies suggest that it indeed does after controlling for unobserved heterogeneity across individuals. The most common cause of miscarriage and stillbirth is chromosomal abnormality of the foetus, accounting for 50% to 80% of all cases (Simpson, 2007). The abnormalities are due to mal-separation of chromosomes during meiotic division, which is likely to be unpredictable conditional on a few factors, such as age and genetic attributes (Brown, 2008; Larsen et al., 2013; Silver et al., 2007; Simpson, 2007).[5] These strands of literature suggest that pregnancy loss can be considered exogenous once individual-level unobserved heterogeneity is controlled. Based on this idea, we utilise a maternal fixed effects model to estimate the impact of pregnancy loss on birth spacing. Intuitively, this amounts to comparing pregnancy intervals before and after the experience of pregnancy loss.

As a result, we find first that women with a pregnancy loss lengthen their birth spacing intervals immediately after the loss—consistent with the literature utilising miscarriage to instrument birth spacing. Second, the intervals for all subsequent pregnancies are significantly shorter by four to eight months, similar to the results in the literature on the impact of infant mortality on birth spacing. Third, the shortening effect gradually diminishes as women experience more live births, but it persists for the entire fertility after pregnancy loss. Fourth, we find suggestive evidence for the mechanism of the shortening effects, where females react to their subjective probability of losing a foetus given their fertility history. This is analogous to the framework put forward by Mira (2007), where the perceived probability of infant death departs from its true probability and females update their beliefs every time they observe whether the newborn child survives the neonatal period. By defining a proxy for the belief as the share of a lost pregnancy out of all the pregnancies before each conception, we show that the larger the share of pregnancy loss, the shorter their subsequent birth spacing intervals. These results sug-

[3]Other previous studies have shown that birth spacing and more general fertility patterns are explained by socioeconomic factors such as female education, wages, contraception, macroeconomic conditions, and the gender of the previous child (Bhalotra, 2010; Heckman and Walker, 1990; Kim, 2010; Pimentel et al., 2020).

[4]Hotz et al. (2005) and Miller (2011) also use the first-pregnancy miscarriage that endogenously reduces teenage motherhood and find its positive impact on females' subsequent careers.

[5]Human reproduction is said to be very inefficient in the sense that approximately 60% of all fertile eggs miscarry without being ever recognised, and 15% to 20% of the recognised pregnancies also end up miscarrying (Brown, 2008; Larsen et al., 2013).

gest that one's own fertility experience affects birth spacing through its impact on the subjective probability of pregnancy loss. These are one of the first pieces of evidence for the long-term shortening effect of pregnancy loss and the mechanism behind it, which channels through beliefs on the probability of foetal loss. These findings are consistent with general behavioural theory, which posits that the realisation of an event with a small probability may change one's belief about the chance that it occurs again, and it may lead to a behavioural change thereafter (Hertwig et al., 2004).

The rest of the paper is organised as follows. Section 2 reviews the relevant literature, followed by a description of the data used. Sections 3 and 4 explain the data and estimation strategy, followed by Sections 5 and 6, where our main results and discussion on the underlying mechanism are presented. The last section concludes.

2 Medical Literature on Miscarriage and Stillbirth

Miscarriage refers to the loss of pregnancy before 20 to 23 gestational weeks, and the loss that occurs later is termed stillbirth (Brown, 2008; Larsen et al., 2013). Pregnancy loss, such as these, is also referred to as spontaneous abortion and sporadic pregnancy loss. Such a loss is not uncommon, accounting for 10% to 15% of all clinically recognized pregnancies (van den Berg et al., 2012). Since the cut-off length of gestation that divides miscarriage and stillbirth varies across studies even in the literature of obstetrics and gynaecology,[6] and since our data (explained in more details later) do not distinguish the two, we refer to terminated pregnancies as spontaneous pregnancy losses, or simply pregnancy loss, throughout the paper.[7]

Among many potential causes of pregnancy loss, the most important is genetic factors (Brown, 2008; Ford and Schust, 2009; Larsen et al., 2013; Silver et al., 2007). This type of pregnancy loss originates from meiotic division, which may involve malsegregation of the pairs of chromosomes[8] and result in chromosomal abnormalities of the foetus, such as sex chromosomal polysomies. Approximately 50% (Brown, 2008) to 80% (Simpson, 2007) of all pregnancy losses are estimated to be associated with genetic problems. Chromosomal abnormalities are more likely observed for older mothers, but no other factors are reported to be consistently associated. Another genetic cause for pregnancy loss is said to be parental karyotype abnormality (Ford and Schust, 2009), although this is considered much less frequent (accounting for 3% to 6% of pregnancy loss cases, Larsen et al. 2013).

Nongenetic factors are also associated with pregnancy loss, while their causal impact on pregnancy loss is debated. For example, anatomic factors such as uterine malformation and uterine fibroid are observed more frequently among those who have experienced pregnancy loss (Brown, 2008; Larsen et al., 2013). Immunologic causes[9] and endocrine aetiologies[10] are associated with pregnancy loss as well (Ford and Schust, 2009). Thrombophilia is also suspected to be associated with miscarriage and stillbirth, though it is considered to be caused by genetic attributes, and its causal impact on pregnancy loss has not been clarified (Tomer, 2014).

Infectious diseases are also said to increase the likelihood of pregnancy loss (Silver et al., 2007). In developed countries where clinical data are available, approximately 10% to 25% of

[6]For instance, Brown (2008) uses 23 gestational weeks, whereas Larsen et al. (2013) seems to use 22 weeks. Silver et al. (2007) used 20 weeks but made clear the cut-off every time they cited other studies.

[7]Another issue is the number of losses a female experiences. Recurrent losses are relatively rarer but more likely to be caused by nongenetic factors (Ford and Schust, 2009). We consider the robustness of our results to recurrent losses (see Appendix Figure A.1 and Appendix Section C).

[8]Chromosomal abnormalities, therefore, can be caused by both males and females. However, the extra chromosome, one of the most commonly reported causes of chromosomal abnormality, is mostly of maternal origin (Larsen et al., 2013). Therefore, although not strictly perfect, it may be enough to control for maternal characteristics in our particular context.

[9]Examples include antiphospholipid, antinuclear, and antithyroid antibodies.

[10]Examples include hypothyroidism.

stillbirths are reported to be caused by infection. Some infectious diseases have seasonality, and other infections may be related to sanitary conditions. In particular, infection due to bacteria is likely to be more common in developing countries.

Lifestyle factors, such as smoking and alcohol, are suspected to risk pregnancy losses, yet the evidence seems to be quite mixed and unclear. For instance, Brown (2008) cite several studies that found an association between cigarette smoking and pregnancy loss, but Larsen et al. (2013) and Ford and Schust (2009) note that past evidence is based on mere correlations. Regarding coffee intake, while coffee drinking is accepted in many countries (Larsen et al., 2013), Ford and Schust (2009) drew a study showing that caffeine has a dose-dependent relationship with pregnancy loss. Alcohol consumption seems an exception such that many studies agree upon its adverse effect (Brown, 2008; Ford and Schust, 2009; Larsen et al., 2013; Silver et al., 2007). Obesity is associated with pregnancy losses only for extreme cases with a body mass index larger than thirty (Larsen et al., 2013).

To summarize, by far, the most important cause of pregnancy loss is genetic abnormality, which depends in part upon age but is otherwise likely to be unpredictable. While the causal relationship has not been firmly established, anatomic factors are also large in proportion, and there could be other factors related to immunity, endocrine function, and thrombosis. However, these factors are likely to be time-invariant. Thus, in our analyses, we control for individual fixed effects, which purge any potential bias that may emerge due to unobserved differences in health across individuals. Similarly, behavioural risk factors such as smoking and drinking are usually persistent, and they are unlikely to cause a bias in our fixed effects estimates. One potential cause of bias may be infectious diseases. In particular, seasonal infection is likely to affect only children born in certain months. To address this issue, we control for month dummies, which can effectively capture the impact of seasonality.

3 Data

3.1 Demographic and Health Survey in Uganda in 2011

We primarily use the data of the Demographic and Health Surveys (DHS) in Uganda conducted in 2011. The data were collected by the Uganda Bureau of Statistics and ICF International Inc. in May through December in 2011. The survey covered a nationally representative sample of 10,086 households from which 9,247 females aged 15-49 years were found. These females were asked about household characteristics, socioeconomic activities, and reproductive behaviours. They also reported pregnancy history and, for each live birth, further information such as the year and month of the birth and place of delivery.

One of the variables of interest in this study is the experience of miscarriage and stillbirth. The DHS first asks 'Have you ever had a pregnancy that miscarried, was [aborted] or ended in a stillbirth? '[11] If the respondent answers yes to this question, it further asks the year and month when the *last* such pregnancy ended. There are two issues about this measurement that are worth discussing here. First, it is possible that a female experiences multiple and/or consecutive miscarriages or stillbirths, although the probability is small (Ford and Schust, 2009). The DHS asks about whether respondents had more than one pregnancy loss but does not record when the losses except for the last one occurred. As a result, the data do not represent all pregnancy losses. Second, this measurement does not separate abortion from miscarriage or stillbirth. If abortion is selectively performed, our analysis using the DHS data may be biased in any arbitrary way. However, we show the results based on a different data set that measures miscarriage and

[11]The DHS Uganda 2011 questionnaire has the following question: 'Have you ever had a pregnancy that miscarried, was or ended in a stillbirth?' However, the recode manual (Demographic and Health Surveys, 2013) describes the variable as '[w]hether the respondent ever had a pregnancy that terminated in a miscarriage, abortion, or still birth, *i.e.*, did not result in a live birth.' Therefore, we inserted the seemingly missing 'abortion' and enclosed it with square brackets.

stillbirth separately from abortion are qualitatively unchanged. For details, see Section 5.2 and Appendix C.

Another important variable, birth spacing, is defined as the interval months between the end of the last pregnancy and that of the current pregnancy. This means that birth spacing is undefined for the first pregnancy. Thus, our analysis focuses on females with at least two pregnancies at the time of the survey. It is possible to measure the birth spacing interval for the birth immediately following a miscarriage or stillbirth from the timing of the pregnancy loss. However, for comparability with previous studies, we define the interval as discussed above.[12]

3.2 Descriptive analyses

Tables 1 and 2 show the summary statistics of major variables defined at the birth and mother levels, respectively. In the data, there are approximately 4,400 females with at least three live births and 21,200 children born to them.[13] In Table 1, we find that our sample females have 31.6 months of birth spacing intervals on average. Approximately two-thirds of the intervals are shorter than the WHO recommendation.[14] Among births given by females who have ever lost pregnancy, 35% were conceived after their loss experience. Approximately 11% were the first pregnancies immediately after pregnancy loss; 8% were the second after pregnancy loss; another 6% were the third after the loss. In our analysis, the fourth and subsequent postloss pregnancies are put into one category, as they each account for less than one percent. Table 2 shows that the sample females had given 5.7 births on average. This number is likely to be censored from the right for younger females who are unlikely to have completed fertility. For instance, females older than 40 years who are likely to be closer to their fertility completion reported 7.5 births. Additionally, slightly more than a quarter of females were shown to have experienced pregnancy loss. Other variables suggest that our sample females are 34 years old on average with 5.7 years of education and mostly married or cohabitating (more than 80% in total). Note that these socioeconomic characteristics are controlled for in the regression analysis.

4 Empirical Strategy

4.1 Estimation model

We investigate the impact of pregnancy loss on birth spacing based on the following linear model:

$$y_{ij} = \phi_j + \delta_1 D_{ij}^{\text{post}} + \delta_2 x_{ij} + v_{ij} \tag{1}$$

where ϕ_j represents female fixed effects (FEs), D_{ij}^{post} takes the value of one if pregnancy i for female j follows pregnancy loss (*i.e.*, if any preceding pregnancy was terminated due to miscarriage, stillbirth, or abortion), and x_{ij} denotes control covariates, including the female's age at the termination of pregnancy i, the month and year of pregnancy i, the indicator for whether the pregnancy ended in a single or multiple births, and the sexes of children born at her

[12]The WHO defines birth spacing as the interval between the end of a pregnancy and the conception of the next pregnancy (World Health Organization, 2007). Since our DHS data do not contain information about the length of gestation, we cannot compute a birth spacing measure consistent with the WHO definition. This difference is, however, unlikely to invalidate our econometric analysis, unless the length of gestation for pregnancies conceived after pregnancy loss systematically differs from that of pregnancies before the loss. To date, we have not found convincing literature that suggests a systematic increase or decrease in premature births after losing a pregnancy.

[13]The statistics in Table 1 are calculated such that every child is counted as one observation regardless of the number of children born together. Noting the possible selection of females who carry multiple births to term (Bhalotra and Clarke, 2016), we primarily focus on birth (multiple births are counted as one observation) in our main analysis, while we confirm the robustness of our conclusion when we count each child as one observation.

[14]Since the WHO recommends at least two years of the pregnancy interval (between the onset of a pregnancy and the end of its previous one), we compute the recommendation as equivalent to two years plus nine months or 33 months.

i-th and its previous births. We treat the data as an unbalanced panel where the time dimension is defined by the number of pregnancies. In equation (1), the parameter of interest is δ_1, which measures the average difference in the birth spacing intervals before and after pregnancy loss experience. The inclusion of female FEs is likely to address the potential bias arising from unobserved heterogeneity, such as preferences and social norms, pointed out by Heckman et al. (1985). It is also likely to account for potential confounding factors such as physical conditions and genetic attributes of females identified in Section 2. With further controls for pregnancy-specific characteristics, δ_1 is likely to capture the causal impact of pregnancy loss on the interval.

It is possible that the effect of pregnancy loss changes in the course of pregnancy history. For example, the effect may be large when the memory of a pregnancy loss is still fresh in the female's mind, and it may diminish as she experiences several successful live births. To examine this heterogeneity, we modify equation (1) as

$$y_{ij} = \phi'_j + \sum_{l \in L} \delta_1^l D_{ij}^{\text{post},l} + x_{ij}\delta'_2 + v'_{ij} \tag{2}$$

where $D_{ij}^{\text{post},l}$ equals one if pregnancy i of female j is her l-th pregnancy since her last pregnancy loss episode and zero otherwise.[15] The set L denotes the decomposition of postloss pregnancies and is either $\{1, 2+\}$, $\{1, 2, 3+\}$, or $\{1, 2, 3, 4+\}$, where $l+$ denotes the l-th and all the subsequent postloss pregnancies.[16] That is, we group postloss pregnancies into the first one and the rest, or the first, second, and the rest, or the first, second, third, and the rest. In this modified specification, we are interested in the parameters δ_1^l, which represent the change in birth spacing at the l-th pregnancy after loss. This specification allows us to examine the persistence of the impact of pregnancy loss.

4.2 Validity of the Identifying Assumptions

The above specification is essentially a fixed-effects difference-in-difference regression. The parameters of interest can thus be identified under the assumption of no correlation between pregnancy loss and the error term conditional on the included covariates. This is likely to hold given the discussion in Section 2. Nonetheless, we show evidence for the implications of the assumption, namely, no significant difference in the pretrend of the outcome (Section 4.2.1) and no correlation of pregnancy loss with predetermined covariates (Section 4.2.2). Additionally, if females with pregnancy loss stop conceiving after their loss experience, it can result in selective attrition associated with pregnancy loss. We test whether this is the case (Section 4.2.3).

4.2.1 Pretrend of the Birth Spacing

A potential concern for identification is that pre-existing differences in birth spacing behaviours between females with and without pregnancy loss may bias our estimates.[17] To see this, we examine whether the trend in birth spacing interval is systematically correlated with the experience of pregnancy loss by regressing the intervals on whether the female has ever had pregnancy loss, linear parity, and their interaction. The results are presented in Table 3.[18] They show that

[15] For example, consider female j who experienced a pregnancy loss after two live births but never afterwards. For this female, we have $D_{3,j}^{\text{post},1} = 1$ since her third live birth (subscript $i = 3$) is her 1st live birth after her loss experience (superscript $l = 1$). Similarly, we have $D_{4,j}^{\text{post},2} = 1$ since her fourth live birth ($i = 4$) is her 2nd live birth after her loss experience ($l = 2$).

[16] When we present estimation results, we write $L_1 \equiv \{1\}$, $L_2 \equiv \{1, 2+\}$, $L_3 \equiv \{1, 2, 3+\}$, and $L_4 \equiv \{1, 2, 3, 4+\}$.

[17] For instance, if females whose birth spacing intervals become shorter over time are more likely to lose pregnancy, the interval can spuriously appear shorter after the loss.

[18] In column (1), we compare the spacing interval between their first and second live births of females who have given three live births in a row and those who lost their third pregnancy after their first two live births. Likewise, column (2) compares intervals between the first and second, as well as the second and third, births of

there is no prior difference in birth spacing behaviours in terms of its level and trend between females with and without pregnancy loss experience. The estimates for loss experience and differential trends are generally small and statistically insignificant. A few significant estimates are unstable and found for small samples. These results suggest that if birth spacing intervals are estimated to be different for pregnancies conceived before and after loss experience, it is unlikely because females with such experience have differential pre-existing trends.

The absence of differential pretrends can be graphically confirmed by plotting the average birth spacing intervals of females with pregnancy loss before they experience one and comparing them with those without pregnancy loss. Figure 1 shows that birth spacing intervals prior to pregnancy loss are close to the intervals of females with no such experience. Average intervals are noisier for females with pregnancy loss, particularly at higher-order parities, due to the small sample size shown at the bottom of the figure. However, the average intervals for the two groups are statistically indistinguishable at each parity.[19] These results suggest that the two groups of females are unlikely to be different on average in birth spacing intervals before pregnancy loss.

4.2.2 Pre-determined characteristics and pregnancy loss

We then checked that pregnancy loss was uncorrelated with predetermined characteristics. Available characteristics in our data that are typically considered predetermined include religion, ethnicity,[20] and native languages. Figure 2 shows that the linear projection coefficients from the regression of whether the female has ever experienced a pregnancy loss on these predetermined covariates are generally statistically insignificant. Some coefficient estimates turn out to be statistically significant at conventional levels, such as Baganda for ethnicity. However, these significant estimates do not occur more frequently than would by random chance, and the multiple hypothesis testing corrected p- and q-values corroborate this observation.[21] These results suggest that pregnancy loss experience is likely to be orthogonal to the observable predetermined covariates.

4.2.3 Selection into Higher-Order Parities

Finally, we examine the possibility of selective attrition by comparing the likelihood of giving the $(k+t)$-th live birth between females who have given k live births in a row followed by a loss of the pregnancy that would have made her $(k+1)$-st live birth and the females who have given at least $k+1$ live births.[22] We regress the dummy variable, B_j^{k+t}, which equals one if female j gives birth to her $(k+t)$-th child on the indicator for whether having lost the pregnancy that

females with four live births in a row and those with pregnancy loss at the fourth pregnancy after the first three live births.

[19] In Appendix Table B.1, we further decompose the preloss trend into each parity and confirm that systematic differences do not seem to exist between females with and without pregnancy loss experience. In addition, we add to equations (1) and (2) a dummy for whether pregnancy i of female j is the last one that precedes her lost pregnancy. The results, presented and discussed in Section 5.1, confirm our above findings that females before a pregnancy loss episode are similar to females with no such experience in terms of birth spacing. The results, presented and discussed in Section 5.1, confirm our above findings that females before a pregnancy loss episode are similar to females with no such experience in terms of birth spacing.

[20] While we note the recent finding by Rademakers and van Hoorn (2021) suggesting that ethnicity reporting may be time-variant, pregnancy loss and birth spacing intervals may not be the most likely to correlate with a change in reported ethnicity.

[21] Specifically, we use the Westfall and Young (1993) method to control the familywise error rate and the Anderson (2008) method to control the false discovery rate.

[22] The first comparison is based on the idea that females with k live births only are similar in terms of the realised number of live births prior to the pregnancy loss, while the second comparison is intended to compare females who have revealed desire for the same number of pregnancies at least up to the $(k+1)$-st pregnancy.

would have become her $(k+1)$-st live birth, D_j^{k+1}, and background characteristics as follows:[23]

$$B_j^{k+t} = \beta_0 + D_j^{k+1}\beta_1 + X_j\beta_2 + e_j. \tag{3}$$

We conduct this exercise for $k = \{1, ..., 7\}$[24] and $t = \{1, 2, 3, 4\}$.[25]

The results are presented in Appendix Table B.2. They reveal two patterns. First, females with a pregnancy loss are less likely to progress to higher-order births. Second, the decline narrows down the higher the postloss parity. These findings suggest the influence of right censoring: although females who lost their foetuses progress more slowly, they catch up with those without the loss as time goes.

When we regress Equation (3) by separating females with a pregnancy loss into those for whom years since the loss are less than the median and those for whom the years since the loss are equal to or larger than the median, we find the selection effect only for the former (Appendix Table B.3). Therefore, pregnancy loss is unlikely to induce fertility discontinuation except through right censoring. The bias due to right censoring is unlikely in our setting because we show later that the main results do not change qualitatively depending on the period of time elapsed since pregnancy loss (Appendix Figure A.2).

5 Results

5.1 The effects of a pregnancy loss on spacing intervals

Our main results for the effect of pregnancy loss on spacing interval are presented in Table 4. Each column shows the results based on equations (1) and (2), with different sets of D^{post} dummies (denoted by L_1 through L_4). In a specification with only one dummy variable indicating births conceived after a loss, we find no significant change in birth spacing (column 1). However, once the first postloss birth is separated from the other subsequent births, we find that the first postloss pregnancy has a longer spacing interval, whereas the subsequent pregnancies have shorter intervals (columns 2 to 4). Point estimates in column (4) suggest that the first live birth after a loss has a 5.2 month longer interval, but the subsequent intervals are shorter by 5.6 to 8.2 months. The positive effect for the first postloss birth is mechanical, as the birth spacing interval in our analysis is defined as the interval between the previous and current live births. While this positive effect has been reported in previous studies on the impact of pregnancy loss, the negative effects for all subsequent births have not been reported. The point estimates for the second, third, and all the subsequent postloss pregnancies suggest that the negative effects diminish as females experience successful live births after pregnancy loss but do not disappear over the course of their pregnancy history. These effects correspond to approximately 18-26% of the mean spacing interval of 31.4 months for females with no pregnancy loss (Table 1).[26]

We test the pretrend assumption by adding a prepregnancy loss dummy, $D^{\text{pre},1}$, which equals one if the pregnancy precedes the loss (Column 5). Estimated coefficients for postloss dummies are essentially unchanged, while the preloss dummy has a small coefficient that is far from statistically significant. This suggests that the pretrend assumption is likely to hold, corroborating our findings from Section 4.2.1.

While the reduction in birth spacing interval by several months may not sound substantial, this exposes mothers and children at greater risk. That is, foetal loss reduces the share of pregnancies whose intervals are at least as long as the WHO standard of 33 months. The

[23]The covariates include age and age squared, years of education, region, religion, and ethnicity.

[24]The average number of births for females aged over 40 or 45 years is between seven and eight; see Table 2.

[25]In the main analyses, we decompose the changes in birth spacing intervals for the first, second, third, and all the subsequent births after the loss episode.

[26]The interval between the loss and the birth of the next child is likely to be shortened as well, although it is obscured by the mechanical lengthening effect on the birth spacing interval that encompasses the loss.

results for this outcome (column 6) suggest that while pregnancies that immediately follow a pregnancy loss are more likely to satisfy the WHO standard, the subsequent pregnancies are 9-14 percentage points more likely to fall below the standard, with the tendency tapered a little for the fourth or later pregnancies after the loss. Given the adverse impact of short birth spacing intervals on maternal and child outcomes, these results imply that pregnancy loss triggers a series of harms to herself and her children.

5.2 Measurement of the pregnancy loss

The results thus far have shown that pregnancy loss lengthens the current birth spacing interval but shortens subsequent intervals. However, these are based on DHS data, which contain the timing of the most recent pregnancy loss only and do not differentiate miscarriage/stillbirth from induced abortion. We show that these measurement issues do not change our conclusion by using our secondary data collected from the RePEAT survey. These data contain the timing information for each pregnancy loss and distinguish abortion from miscarriage/stillbirth. Furthermore, since the history of miscarriages and stillbirths were asked first, before asking that of abortion, it is unlikely that respondents falsely reported abortion as miscarriage, which is said to be one of the sources of measurement errors in low-income countries (Singh et al., 2018). The details of the RePEAT survey are provided in Appendix C.

Appendix Table B.4 shows the results. In columns (1) and (2), we compare the results from the DHS and RePEAT data, restricting the sample females to only those who live in the districts covered by the RePEAT data, and using the same set of covariates available in both data sets. Although less precise, most likely due to the smaller sample size, the RePEAT data are found to produce similar results where the first birth spacing interval after a pregnancy loss lengthens and the subsequent intervals shorten.

We then conducted three exercises to examine the sensitivity of the main results to the measurement of pregnancy loss. In column (3), we exclude abortion from the pregnancy loss measurement and re-estimate the main model. In column (4), for females with more than one pregnancy loss experience, we use the timing of their first experience, rather than the last (as in the DHS data), to code the postpregnancy loss dummies. In column (5), we reset the postpregnancy loss dummies every time females experience losses. With all these coding rules, the estimated results remain similar at least qualitatively. These findings suggest that our main findings are likely to be robust to different definitions of postpregnancy loss indicators.

5.3 Robustness checks and additional analyses

Another concern might be that our main findings are driven by older females whose pregnancies are observed more frequently than younger females whose pregnancy data are likely to be right censored. We address this concern by using weights that correct for the potential oversampling of females with more births. This may be of particular importance given our unbalanced panel setting. The results using the inverse of the number of times that a female appears in the estimation sample (Appendix Table B.5) show that the estimates are virtually unchanged. These results suggest that the unbalanced nature of our panel estimation is unlikely to bias our estimates.

We then explore how widely the behavioural response is observed by extending the estimation sample to females in all DHS data sets in Sub-Saharan African (SSA) countries. These countries generally suffer from short birth spacing intervals, high fertility and high infant and maternal mortality rates. The consequence of pregnancy loss therefore can be severe and long-lasting.[27] We pool the data from all DHS surveys listed in Appendix Table B.6 as long as they

[27] The main analysis uses data from Uganda as another data set, RePEAT, allowing us to conduct the above robustness check.

come from SSA and possess pregnancy loss information.[28] The results in Appendix Table B.7 reveal that the birth spacing response to pregnancy loss is found in these augmented data. Our findings from Ugandan data are thus likely to be externally valid to other SSA countries.

6 Belief Updating Mechanism for the Change in Birth Spacing Behaviours

We now consider a possible explanation for our main findings that pregnancy loss makes females pregnant quickly. This might be because females with such experiences worry about recurrence of pregnancy loss in the future or even their infecundity thereafter. As a result, they may overly react to the loss by shortening their subsequent spacing intervals. Updating a probabilistic expectation of an event with a small probability and changing a behaviour afterwards has been examined in several contexts (Hertwig et al., 2004).[29] Indeed, the growing body of literature on probabilistic beliefs suggests that people in developing countries form subjective beliefs according to their past outcomes (Delavande, 2014).

To take this perspective into the context of fertility behaviours, consider a female who attempts to achieve a certain number of children during her reproductive years.[30] She starts reproduction with a small perceived probability of losing a pregnancy due to miscarriage or stillbirth. At some point in time, she loses a pregnancy and updates the perceived loss probability to a higher percentage. Given the years of reproduction left for her and the remaining number of children to give birth to, she adjusts her fertility schedule with her updated belief. This reoptimization shortens birth spacing intervals for all subsequent pregnancies.

We investigate this hypothesis using the constructed indicator for *realized probability* of a pregnancy loss at the beginning of pregnancy that can lead to the i-th live birth for female j, z_{ij}. More specifically,

$$z_{ij} = \frac{D_{ij}^{\text{post}}}{i - 1 + D_{ij}^{\text{post}}} \tag{4}$$

where $i-1$ is the number of live births that female j had before the pregnancy that can make her i-th live birth if born alive. The fraction measures the proportion of pregnancy losses out of the pregnancies that she has ever conceived prior to her i-th pregnancy. If all the pregnancies before the i-th one ended in a live birth, then $z_{ij} = 0$ as $D_{ij}^{\text{post}} = 0$. If there was a pregnancy loss prior to her i-th pregnancy, then $D_{ij}^{\text{post}} = 1$, and the denominator is the number of total pregnancies, including live births and a loss prior to pregnancy i.[31] In addition, we allow the effect of z_{ij} to differ over the subsequent fertility history, similar to allowing $D_{ij}^{\text{post},l}$ to affect the spacing interval differently for the postloss live birth group $l \in L_1$, L_2, L_3, or L_4. The interaction term between z_{ij} and $D_{ij}^{\text{post},l}$ is denoted as z_{ij}^l. If the effect of the realized probability is significant and that of the dummy for pregnancy loss is insignificant, it suggests that females do not respond to the fact that they lost a pregnancy but change birth spacing intervals according

[28]The DHS data have information about pregnancy loss since version four (used since the late 1990s). We exclude purpose-specific waves of the DHS, such as the Malaria Indicators Survey and AIDS Indicator Surveys.

[29]For example, Lybbert et al. (2007) report that herders in eastern Africa are found to update their expectations when they obtain a low-rainfall forecast; Oster (2018) shows evidence of and examines the mechanism for the increase in pertussis vaccination following local outbreaks; and Some scholars (e.g., Ando et al., 2017; Fink and Stratmann, 2015) investigate whether housing prices near nuclear power plants in countries such as Sweden and the U.S. changed after the nuclear plant blast in Fukushima in 2011.

[30]See Supplementary Appendix D for a more formal discussion.

[31]As an illustration, consider that female j experiences two live births, a loss, and another two live births in this order. For her, the realized probabilities of pregnancy loss before the second, third and fourth live births are $z_{2,j} = 0$, $z_{3,j} = 1/3$, and $z_{4,j} = 1/4$, respectively (note that the third live birth realizes at her fourth pregnancy). z_{ij} corresponds to the prior belief with an assumption that the prior is formed as the mean of a Beta distribution $\mathcal{B}(a_{ij}, b_{ij})$, where $a_{ij} = D_{ij}^{\text{post}}$ and $b_{ij} = i - 1$.

to the realized loss probability. This is likely the case when belief updating takes place and explains the behavioural change in birth spacing. In contrast, if the effect of realized probability is insignificant and that of the dummy for pregnancy loss is significant, it implies that females do not respond to the probability but instead respond to the fact that they lost a pregnancy. In this case, belief updating may not take place, and other factors such as psychic shock and trauma may trigger shortening of the subsequent spacing intervals.

The estimation results are presented in Table 5. First, the results demonstrate that the estimated effects of the subjective loss probability are very significant. Once the first postloss pregnancy and the subsequent pregnancies are separated, the shortened intervals for the latter pregnancies are explained by the reaction to increased subjective probability, as the coefficients for z^{2+}, z^{3+}, z^3 and z^{4+} are significant (columns 2-4). For example, the estimated coefficient of -27.79 for the probability interacted with the third postloss pregnancy, z^3, implies that a 1 percentage point increase in the probability of a pregnancy loss leads to a .26 month decrease in the birth spacing interval (column 4). To see the magnitude of the effect, let us take an example of a female who had had had two live pregnancies before her loss (two is the median of the number of preloss live births), followed by three more live births. For this female, the realized probability of pregnancy loss at her third postloss pregnancy (which is her sixth pregnancy and fifth live birth) is $z^3_{5,j} = 1/5$. That is, she experienced five pregnancies before the third postloss pregnancy, out of which one was lost without resulting in a live birth. Compared to the case without such a loss, the birth spacing interval for the third postloss pregnancy is predicted to be shorter by $|-27.79 \times (1/5)| = 5.56$ months. Observe that this is very close to the change at the third postloss pregnancy reported in Table 4 and to the effects of infant mortality on birth spacing intervals found in Bhalotra and van Soest (2008).[32]

Second, even when the subjective probability is simultaneously controlled, the effects of the dummy for postloss pregnancy still suggest that a pregnancy loss shortens the interval for the second post-loss pregnancy (columns 2-4). However, the loss experience no longer affects the birth spacing interval for the third and subsequent births (columns 3-4). These results suggest that females' reaction to pregnancy loss is explained by their adjustment of reproduction schedule according to the updated pregnancy loss probability. The only exception is the particularly short interval at the second post-pregnancy, which is not fully explained by such belief update and rescheduling. This is consistent with the hypothesis that pregnancy loss can change females' subjective belief on its probability and birth spacing behaviour.

The supported hypothesis also implies that females who have had fewer births prior to pregnancy loss are likely to face a larger change in their subjective probability of pregnancy loss. These in turn mean that the impact of subjective belief on subsequent birth spacing intervals is more pronounced. This implication is confirmed in Figure 3, which plots the heterogeneous effect estimates of pregnancy loss for females with a different number of live births given by the time they had the loss. We found that females with two or fewer live births at pregnancy loss exhibited larger shortening effects.

7 Conclusion

This study examined the impact of pregnancy loss, namely, miscarriage and stillbirth, on the birth spacing behaviour. The gynaecology and obstetrics literature suggests that these types of pregnancy losses can occur in any woman at any time due to a random genetic reason after controlling for individual heterogeneity. We have shown that postloss birth spacing intervals are first lengthened for a mechanical reason but are later shortened persistently. This shortening effect of pregnancy loss is mostly explained by the past empirical probability of pregnancy loss each female experienced. This is consistent with the belief updating hypothesis, where females

[32]Using their estimates and the mean log interval, their reported impact of postnatal death of the previous child is approximately -5.7 months.

adjust their perceived probability of pregnancy loss and birth spacing behaviours based on their own experience. To the best of our knowledge, this is the first empirical evidence suggesting that beliefs on reproductive outcomes are formed based on one's own past experiences and that such beliefs affect future behaviours.

Our results provide an important policy implication for countries with high fertility and short birth spacing. That is, it may be effective to inform females who have lost pregnancy of the true probability of pregnancy loss, which is generally smaller than their beliefs that are usually overestimated immediately after the loss. It has not yet been clear, however, whether belief updating occurs at the same magnitude when new information is provided by someone else and is not based on her own experience. Indeed, it is argued that the success of information intervention crucially hinges upon not only the contents of information but also who provides it to whom and how (Dupas, 2011). Investigating the effectiveness of information provision is thus an interesting avenue for future studies.

This study is not, however, free of limitations. First, one could obtain more rigorous evidence if the data were large enough and successful in measuring miscarriage and stillbirth separately from induced abortion. Second, to further understand the decision making of birth spacing relating to the beliefs on the pregnancy loss probability, it is crucial to collect probabilistic expectations, which has been increasingly demonstrated to be effective in the developing world (Delavande, 2014). Third, there can be other competing theories than the belief updating that can provide empirically consistent predictions on birth spacing behaviours, and thus a more detailed investigation will be needed. These are unaddressed questions left for future studies.

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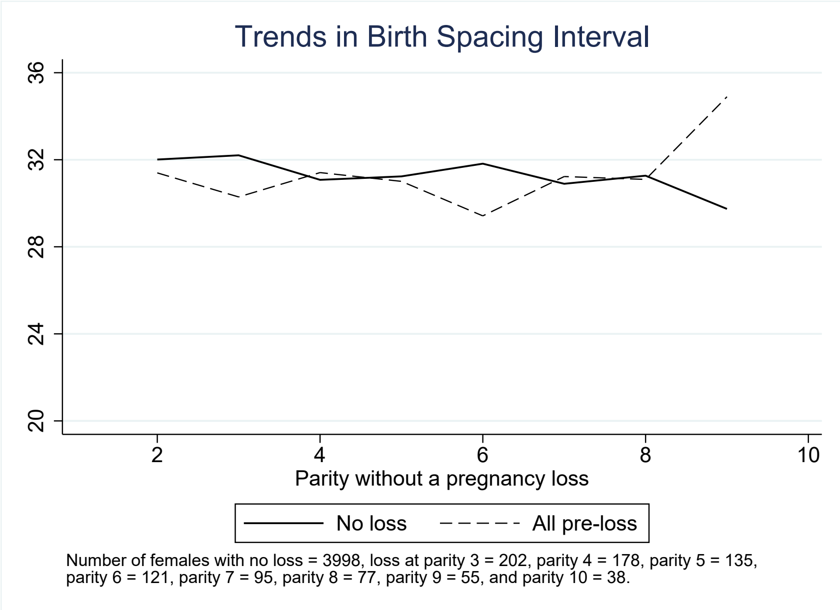
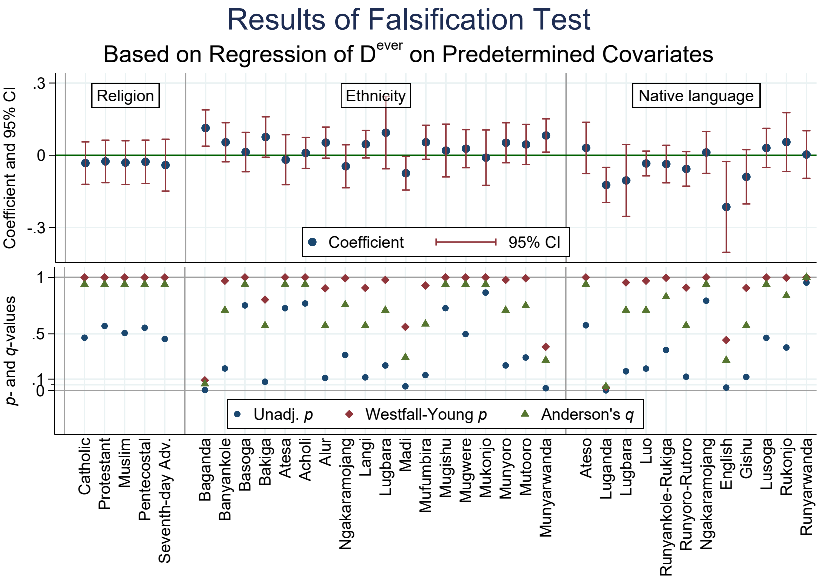
8 Figures and Tables.



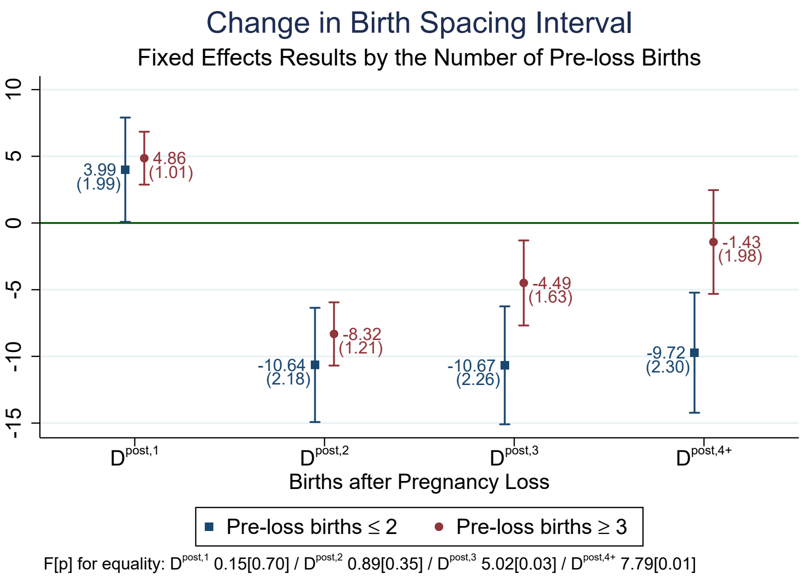
Source: DHS Uganda 2011. *Notes*: This figure shows average birth spacing intervals for females with no pregnancy loss experience and preloss intervals for females with a loss at parities three through ten.

Figure 1: Preloss Birth Spacing Interval by Loss Experience.



Source: DHS Uganda 2011. *Notes*: This figure shows the estimates and 95% confidence intervals, in the upper half, for coefficients of predetermined covariates from the regression of the indicator for having ever had a pregnancy loss. The lower half of the figure shows the unadjusted p-values, familywise error rate corrected p-values (Westfall and Young, 1993), and false discovery rate corrected q-values (Anderson, 2008). Base categories are '*other*' for all three variables.

Figure 2: Results of the Falsification Test.



Source: DHS Uganda 2011. *Notes*: This figure shows the point estimates and 95% confidence intervals of the changes in birth spacing intervals after pregnancy loss for those with two or fewer births before the loss and those with more births before the loss.

Figure 3: Regression Results for Birth Spacing Interval by Live Births Delivered Prior to Pregnancy Loss.

Table 1: Summary Statistics of Major Variables Observed at the Pregnancy Level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All Females			No pregnancy loss			Ever lost pregnancy		
	N	mean	sd	N	mean	sd	N	mean	sd
Birth spacing interval	21155	31.57	18.22	14698	31.37	18.22	6410	32.07	18.19
1 if interval < 33 months	21155	0.662	0.473	14698	0.671	0.470	6410	0.639	0.480
Age at giving birth	25622	24.68	6.41	17925	24.44	6.30	7642	25.23	6.62
1 if single birth	25622	0.969	0.172	17925	0.967	0.178	7642	0.974	0.158
1 if child is male	25622	0.507	0.500	17925	0.506	0.500	7642	0.512	0.500
1 if birth after pregnancy loss	25020	0.100	0.300	17925	0.000	0.000	7095	0.353	0.478
1 if 1st birth after loss	25020	0.032	0.175	17925	0.000	0.000	7095	0.112	0.315
1 if 2nd birth after loss	25020	0.022	0.147	17925	0.000	0.000	7095	0.078	0.269
1 if 3rd birth after loss	25020	0.016	0.127	17925	0.000	0.000	7095	0.057	0.233
1 if +4th birth after loss	25020	0.030	0.171	17925	0.000	0.000	7095	0.106	0.308

Source: DHS Uganda 2011. *Notes*: This table shows the summary statistics of major variables for all females aged 15 to 49 years with 3 births or more (columns 1 to 3), those who had never had pregnancy loss (4 to 6), and those who had ever lost a pregnancy (7 to 9).

Table 2: Summary Statistics of Major Variables Observed at the Female Level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All Females			No Pregnancy Loss			Ever Lost Pregnancy		
	N	mean	sd	N	mean	sd	N	mean	sd
No. live births	4406	5.72	2.30	3178	5.54	2.23	1220	6.18	2.41
No. live births, aged 40+	1182	7.49	2.44	747	7.35	2.46	432	7.71	2.37
No. live births, aged 45+	512	7.80	2.59	328	7.68	2.64	182	7.99	2.50
1 if ever lost pregnancy	4398	0.277	0.448	3178	0.000	0.000	1220	1.000	0.000
1 if lost >1 pregnancy	4398	0.016	0.127	3178	0.000	0.000	1220	0.059	0.236
Age	4406	34.21	7.43	3178	33.46	7.40	1220	36.16	7.16
Years of education	3382	5.700	3.285	2441	5.853	3.319	938	5.296	3.152
Marital status: Never married	4403	0.007	0.082	3176	0.008	0.088	1219	0.004	0.064
Marital status: Married	4403	0.516	0.500	3176	0.505	0.500	1219	0.545	0.498
Marital status: Cohabiting	4403	0.308	0.462	3176	0.315	0.465	1219	0.290	0.454
Marital status: Widowed	4403	0.063	0.243	3176	0.066	0.248	1219	0.056	0.230
Marital status: Divorced	4403	0.010	0.099	3176	0.009	0.095	1219	0.012	0.110
Marital status: Separated	4403	0.096	0.295	3176	0.097	0.296	1219	0.094	0.291

Source: DHS Uganda 2011. *Notes*: This table shows the summary statistics of major variables for women who were as old as 15 to 49 years and had at least three births.

Table 3: Regression-Based Test for Differential Trends in Birth Spacing Interval Before Pregnancy Loss.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Birth Spacing Interval							
Loss at Parity	3	4	5	6	7	8	9	10
Ever lost pregnancy	5.928***	3.248	0.982	-3.139	1.445	0.219	-0.669	-4.365*
	(1.626)	(4.567)	(3.619)	(2.395)	(1.790)	(2.156)	(1.880)	(1.774)
Ever lost pregnancy		-0.694	0.866	1.537*	0.000	0.609	0.769*	0.955**
× Parity		(1.812)	(1.160)	(0.733)	(0.414)	(0.474)	(0.360)	(0.336)
Adj. R^2	0.006	0.001	0.003	0.002	0.001	0.004	0.008	0.006
N	3401	5466	6147	6243	5510	4360	3080	2067
Females with no loss	3199	2556	1915	1440	1007	651	386	221
Females with loss	202	178	135	121	95	77	55	38

Source: DHS Uganda 2011. *Notes*: This table shows selected estimates from the regression of birth spacing interval. Reported in parentheses are the standard errors robust to heteroscedasticity. Statistical significance is denoted by *** if $p<0.01$, ** if $p<0.05$, and * if $p<0.1$. Along with the estimates, we report the F-statistic for the joint test for the loss indicator and its interaction with parity. The regressions use the sample of females who have made at least as many pregnancy attempts as indicated in the column title.

Table 4: Regression Results for the Effect of Pregnancy Loss on Birth Spacing Intervals.

	(1)	(2)	(3)	(4)	(5)	(6)
	Interval in Months					1 if $\geq$ 33 Months
Loss Dummies	L_1	L_2	L_3	L_4	L_4	L_4
D^{post}	-0.124					
	(0.786)					
$D^{post,1}$		5.087***	5.169***	5.203***	4.638***	0.181***
		(0.885)	(0.887)	(0.888)	(1.023)	(0.022)
$D^{post,2+}$		-7.315***				
		(1.033)				
$D^{post,2}$			-8.215***	-8.161***	-8.769***	-0.135***
			(1.034)	(1.035)	(1.131)	(0.028)
$D^{post,3+}$			-6.259***			
			(1.170)			
$D^{post,3}$				-6.849***	-7.486***	-0.144***
				(1.188)	(1.293)	(0.031)
$D^{post,4+}$				-5.613***	-6.297***	-0.094**
				(1.324)	(1.417)	(0.034)
$D^{pre,1}$					-1.321	
					(0.887)	
N	20955	20955	20955	20955	20955	20955
Adj. R^2	0.314	0.325	0.325	0.325	0.325	0.160

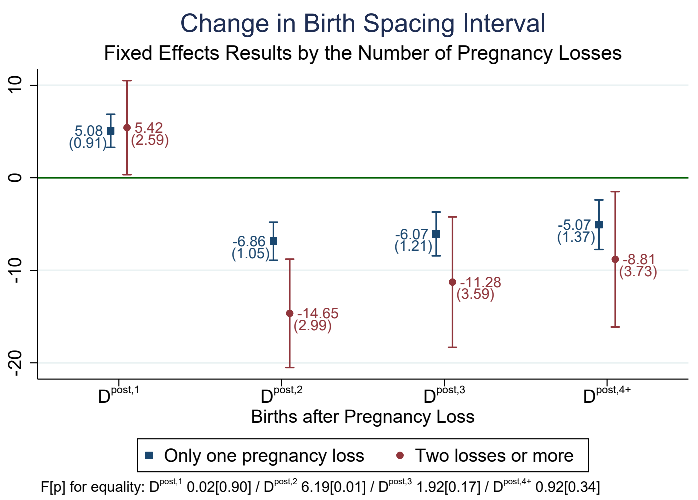
Source: DHS Uganda 2011. *Notes*: This table shows selected estimates from the regression of birth spacing intervals. Standard errors are reported in parentheses and clustered at the female level. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1. Sets of pregnancy loss dummy subscripts are $L_1 = \{1+\}$, $L_2 = \{1, 2+\}$, $L_3 = \{1, 2, 3+\}$, and $L_4 = \{1, 2, 3, 4+\}$.

Table 5: Estimated Effects of Pregnancy Loss and Loss Probabilities on Birth Spacing Intervals.

	(1)	(2)	(3)	(4)
Loss Dummies	L_1	L_2	L_3	L_4
D^{post}	-3.637**			
	(1.179)			
$D^{post,1}$		4.843*	4.755*	5.108*
		(1.954)	(1.970)	(1.996)
$D^{post,2+}$		-5.096***		
		(1.367)		
$D^{post,2}$			-8.360***	-7.740***
			(1.731)	(1.849)
$D^{post,3+}$			-1.023	
			(1.929)	
$D^{post,3}$				-1.437
				(2.781)
$D^{post,4+}$				3.415
				(2.779)
z	18.466***			
	(4.197)			
z^1		0.633	1.484	-0.267
		(7.279)	(7.401)	(7.581)
z^{2+}		-11.941**		
		(4.364)		
z^2			-1.147	-4.656
			(6.044)	(7.098)
z^{3+}			-29.616***	
			(8.559)	
z^3				-27.787*
				(12.982)
z^{4+}				-62.560***
				(15.311)
N	20955	20955	20955	20955
Adj. R^2	0.315	0.325	0.326	0.326

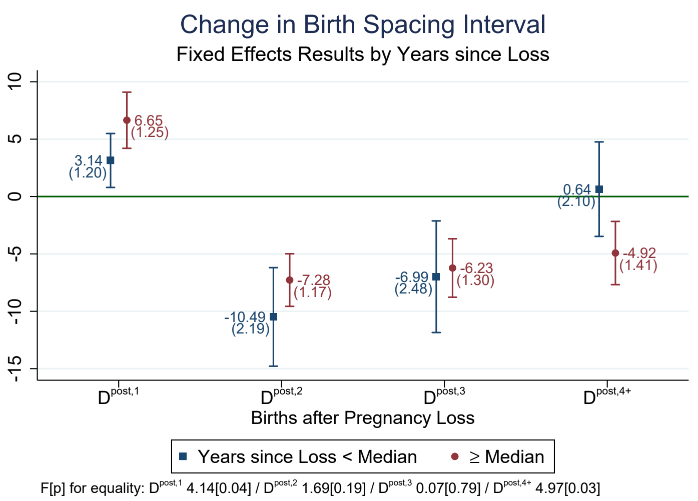
Source: DHS Uganda 2011. *Notes*: This table shows estimated impacts of pregnancy loss and loss probabilities on birth spacing intervals. Reported in parentheses are the standard errors clustered at the woman level. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1. Sets of pregnancy loss dummies are $L_1 = \{1+\}$, $L_2 = \{1, 2+\}$, $L_3 = \{1, 2, 3+\}$, and $L_4 = \{1, 2, 3, 4+\}$.

Appendix A Appendix Figures.



Source: DHS Uganda 2011. *Notes*: This figure shows the point estimates and 95% confidence intervals of the changes in birth spacing after pregnancy loss for those with only one pregnancy loss and those with more losses.

Figure A.1: Effect Heterogeneity by the Number of Pregnancy Loss.



Source: DHS Uganda 2011. *Notes*: This figure shows the point estimates and 95% confidence intervals of the changes in birth spacing after pregnancy loss for those for whom the years since the pregnancy loss are shorter than the median and those for whom they are equal to or longer than the median.

Figure A.2: Effect Heterogeneity by Years Elapsed since Pregnancy Loss.

Appendix B Appendix Tables.

Table B.1: Regression-Based Test for Differential Trend in Birth Spacing Interval before Pregnancy Loss.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Loss at Parity	3	4	5	6	7	8	9	10
Ever lost pregnancy	5.928***	1.861	2.694	0.362	-0.902	1.018	0.067	-3.191*
	(1.626)	(1.243)	(1.655)	(1.226)	(1.287)	(1.898)	(1.840)	(1.552)
Ever lost pregnancy		-0.694	0.922	0.388	3.865*	-0.222	0.514	1.491
× (Parity=3)		(1.812)	(2.338)	(1.828)	(1.910)	(2.440)	(2.447)	(2.161)
Ever lost pregnancy			1.731	2.810	5.167*	3.881	3.477	4.561
× (Parity=4)			(2.320)	(2.200)	(2.229)	(2.447)	(2.682)	(2.992)
Ever lost pregnancy				4.316	1.555	3.090	5.055	3.647
× (Parity=5)				(2.320)	(1.865)	(2.654)	(2.936)	(2.318)
Ever lost pregnancy					1.156	1.565	3.805	5.208*
× (Parity=6)					(1.816)	(2.491)	(2.744)	(2.466)
Ever lost pregnancy						3.343	4.544	4.982
× (Parity=7)						(2.997)	(2.677)	(3.062)
Ever lost pregnancy							4.367	2.099
× (Parity=8)							(2.748)	(2.708)
Ever lost pregnancy								10.609***
× (Parity=9)								(3.092)
Adj. R^2	0.006	0.001	0.002	0.003	0.003	0.006	0.013	0.008
N	3401	5466	6147	6243	5510	4360	3080	2067
Females with no loss	3199	2556	1915	1440	1007	651	386	221
Females with loss	202	178	135	121	95	77	55	38

Source: DHS Uganda 2011. *Notes*: This table shows estimated differences in birth spacing intervals between females with and without pregnancy loss. Standard errors are reported in parentheses and robust to heteroskedasticity. Statistical significance is denoted by *** if $p<0.01$, ** if $p<0.05$, and * if $p<0.1$. The regression includes females who have at least as many pregnancies as indicated in the column title—including those who only have live births and those who lost the last pregnancy—and compares the spacing intervals of births excluding the most recent one.

Table B.2: Estimated Results for Selection into Higher-Order Births.

	(1)	(2)	(3)	(4)
Regressand	Give Birth to the $(k+t)$-th Child.			
Control Females	With $k+1$ Live Births			
	$t=1$	$t=2$	$t=3$	$t=4$
	Panel A. $k=1$.			
Pregnancy loss	-0.285***	-0.231***	-0.169***	-0.098***
	(0.029)	(0.028)	(0.026)	(0.024)
N	3401	3401	3401	3401
Adj. R^2	0.282	0.339	0.427	0.432
	Panel B. $k=2$.			
Pregnancy loss	-0.359***	-0.277***	-0.164***	-0.091***
	(0.035)	(0.033)	(0.030)	(0.027)
N	2620	2620	2620	2620
Adj. R^2	0.352	0.302	0.377	0.366
	Panel C. $k=3$.			
Pregnancy loss	-0.313***	-0.224***	-0.138***	-0.080**
	(0.035)	(0.035)	(0.032)	(0.029)
N	2036	2036	2036	2036
Adj. R^2	0.311	0.290	0.332	0.278
	Panel D. $k=4$.			
Pregnancy loss	-0.391***	-0.288***	-0.196***	-0.114***
	(0.044)	(0.045)	(0.039)	(0.033)
N	1438	1438	1438	1438
Adj. R^2	0.389	0.228	0.222	0.207
	Panel E. $k=5$.			
Pregnancy loss	-0.445***	-0.302***	-0.228***	-0.085*
	(0.049)	(0.048)	(0.038)	(0.034)
N	1055	1055	1055	1055
Adj. R^2	0.430	0.137	0.179	0.162
	Panel F. $k=6$.			
Pregnancy loss	-0.444***	-0.369***	-0.193***	-0.110***
	(0.057)	(0.051)	(0.043)	(0.033)
N	700	700	700	700
Adj. R^2	0.438	0.166	0.167	0.108
	Panel G. $k=7$.			
Pregnancy loss	-0.394***	-0.358***	-0.243***	-0.117***
	(0.066)	(0.066)	(0.050)	(0.030)
N	439	439	439	439
Adj. R^2	0.360	0.143	0.094	0.062

Source: DHS Uganda 2011. *Notes*: This table shows the estimated results of the regression of giving birth on pregnancy loss status and female characteristics among females with at least $k+1$ live births and no pregnancy loss and others with at least as many live births and a pregnancy loss at parity k. Standard errors are reported in parentheses and robust to heteroskedasticity. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1.

Table B.3: Heterogeneity in the Selection into Higher-Order Births by Years since Pregnancy Loss.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Give birth to the $(k+t)$-th child							
	Years since Loss < Median				Years since Loss ≥ Median			
	$t=1$	$t=2$	$t=3$	$t=4$	$t=1$	$t=2$	$t=3$	$t=4$
Panel A. $k=1$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel B. $k=2$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel C. $k=3$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel D. $k=4$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel E. $k=5$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel F. $k=6$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479
Panel G. $k=7$.								
Pregnancy loss	-0.087	-0.259***	-0.256***	-0.177***	0.001	-0.007	-0.031	-0.037
	(0.047)	(0.034)	(0.023)	(0.013)	(0.029)	(0.038)	(0.042)	(0.043)
N	6151	6151	6151	6151	6141	6141	6141	6141
Adj. R^2	0.587	0.586	0.545	0.482	0.600	0.590	0.544	0.479

Source: DHS Uganda 2011. *Notes*: This table shows the estimated results of the regression of giving birth on pregnancy loss status and female characteristics among females with at least $k+1$ live births and no pregnancy loss and others with at least k live births and a pregnancy loss at parity k. Standard errors are reported in parentheses and robust to heteroskedasticity. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1.

Table B.4: Regression Results for the Effect of Pregnancy Loss on Birth Spacing Intervals.

	(1)	(2)	(3)	(4)	(5)
Data	DHS	RePEAT			
Abortion	Incl.	Incl.	Excl.	Incl.	Incl.
Loss	Last	Last	Last	First	Reset
$D^{post,1}$	0.404***	0.513***	0.540***	0.574***	0.537***
	(0.094)	(0.100)	(0.099)	(0.105)	(0.100)
$D^{post,2}$	-0.630***	-0.374***	-0.314***	-0.332**	-0.319**
	(0.103)	(0.060)	(0.063)	(0.114)	(0.113)
$D^{post,3}$	-0.529***	-0.443*	-0.369	-0.370	-0.335
	(0.122)	(0.175)	(0.192)	(0.199)	(0.175)
$D^{post,4+}$	-0.520***	-0.108	-0.064	-0.196	-0.255
	(0.139)	(0.139)	(0.145)	(0.129)	(0.142)
N	12324	4880	4880	4880	4880
Adj. R^2	0.316	0.303	0.303	0.304	0.304

Source: DHS Uganda 2011 and RePEAT Uganda 2015. *Notes*: This table shows selected estimates from the regression of birth spacing intervals measured in years. Standard errors are reported in parentheses and clustered at the female level. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1. In columns (1) and (2), the birth is regressed using the same set of covariates and the same outcome measurement but different data sets. In column (3), the pregnancy loss variable excludes abortion. In column (4), the timing of the first, rather than the last, pregnancy loss is used. In column (5), the post-pregnancy loss counter is reset every time a female experiences a loss.

Table B.5: Robustness Check by Using Probability Weights.

	(1)	(2)	(3)	(4)
Loss Dummies	L_1	L_2	L_3	L_4
D^{post}	0.034			
	(0.829)			
$D^{post,1}$		4.879***	4.959***	4.992***
		(0.932)	(0.934)	(0.935)
$D^{post,2+}$		-8.362***		
		(1.138)		
$D^{post,2}$			-9.335***	-9.291***
			(1.176)	(1.176)
$D^{post,3+}$			-6.920***	
			(1.243)	
$D^{post,3}$				-7.551***
				(1.295)
$D^{post,4+}$				-6.043***
				(1.374)
N	20955	20955	20955	20955
Adj. R^2	0.354	0.366	0.366	0.366

Source: DHS Uganda 2011. *Notes*: This table shows the estimated impact of pregnancy loss on birth spacing intervals. Estimation is adjusted for the probability weights where females with fewer births are assigned larger weights inverse to the number of their interval observations. Standard errors are reported in parentheses and clustered at the female level. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1. Sets of pregnancy loss dummies are $L_1 = \{1+\}$, $L_2 = \{1, 2+\}$, $L_3 = \{1, 2, 3+\}$, and $L_4 = \{1, 2, 3, 4+\}$.

Table B.6: Countries and Years of Data Sets Used for the Analysis for the Entire Sub-Saharan Africa.

(1) Country	(2) Year of survey
Angola	2015-16
Benin	2001, 2006, 2011-12, 2017-18
Burkina Faso	2003, 2010
Burundi	2010, 2016-17
Cameroon	2004, 2011
Chad	2004, 2014-15
Comoros	2012
Côte d'Ivoire	2011-12
Ethiopia	2000, 2005, 2011, 2016
Gabon	2012
Gambia	2013
Ghana	1998, 2003, 2008, 2014
Guinea	2005, 2012
Kenya	2003, 2008-09, 2014
Lesotho	2004, 2009, 2014
Liberia	2007, 2013
Madagascar	2003-04, 2008-09
Malawi	2000, 2004, 2010, 2015-16
Mali	2001, 2006, 2012-13
Mozambique	2003, 2011
Namibia	2000, 2006-07, 2013
Niger	2006, 2012
Nigeria	2003, 2008, 2013
Rwanda	2000, 2005, 2010, 2014-15
Sao Tome & Principe	2008-09
Senegal	2005, 2010-11, 2012-13, 2014, 2015, 2016, 2017
Sierra Leone	2008, 2013
Swaziland (Eswatini)	2006-07
Tanzania	1999, 2004-05, 2010, 2015-16
Togo	2013-14
Uganda	2000-01, 2006, 2011, 2016
Zambia	2001-02, 2007, 2013-14
Zimbabwe	1999, 2005-06, 2010-11, 2015

Notes. This table lists the data sets used for the robustness check of the main estimates for the entire Sub-Saharan Africa. The DHS data include information on pregnancy loss from its version 4. The analysis uses all the available DHS data with this information.

Table B.7: Robustness Check by Using All Available Data from Sub-Saharan Africa.

	(1)	(2)	(3)	(4)
	Birth Spacing Interval			
Loss Dummies	L_1	L_2	L_3	L_4
D^{post}	1.278***			
	(0.099)			
$D^{post,1}$		6.444***	6.499***	6.520***
		(0.105)	(0.105)	(0.105)
$D^{post,2+}$		-6.238***		
		(0.131)		
$D^{post,2}$			-7.042***	-7.005***
			(0.133)	(0.133)
$D^{post,3+}$			-5.185***	
			(0.148)	
$D^{post,3}$				-5.674***
				(0.151)
$D^{post,4+}$				-4.610***
				(0.169)
N	2059626	2059626	2059626	2059626
Adj. R^2	0.368	0.375	0.375	0.375

Source: DHS. See Appendix Table B.6 for included countries. *Notes.* This table shows estimated effects of pregnancy loss on birth spacing intervals. Reported in parentheses are standard errors clustered at the female level. Statistical significance is denoted by *** if p<0.01, ** if p<0.05, and * if p<0.1. Sets of pregnancy loss dummies are $L_1 = \{1+\}$, $L_2 = \{1, 2+\}$, $L_3 = \{1, 2, 3+\}$, and $L_4 = \{1, 2, 3, 4+\}$. All regressions include as covariates female age and its square, birth order, birth year and month of the child.

Appendix C Research on Poverty, Environment, Agriculture, and Technology Survey in Uganda in 2015

The DHS data provide detailed information to analyse the relationship between birth spacing and pregnancy loss. However, their survey question does not separate abortion from miscarriage and stillbirth.[33] In addition, the DHS data do not have the precise measure of the history of pregnancy losses.[34] These features suggest that the measurement of miscarriage and stillbirth in the DHS data may be imperfect for the purpose of our analysis. Therefore, we use secondary data that allow us to analyse the effect of miscarriage and stillbirth separately from induced abortion. The data were collected from the Research on Poverty, Environment, Agriculture, and Technology (RePEAT) survey conducted in Uganda in 2015 by the National Graduate Institute for Policy Studies and Makerere University. Its sample is not nationally representative, but it covers 1,755 households from 117 villages in 39 districts, where random sampling was done at the village level, as well as the household level in each village. The RePEAT survey collected information about reproductive behaviours of females who were 15 to 59 years old, whereas we use the subsample of them aged 15 to 49 years to be consistent with the DHS data.

The oral interview of the RePEAT survey first asked the respondents to report the years in which they had given live births.[35] It then asked them whether they had ever had a stillbirth, and if so, the years of their stillbirths (if they had experienced more than one stillbirth, they were asked to list the years of all of their stillbirths). Once the list of years of stillbirths was completed, the survey asked about miscarriage experiences and then induced abortions in the same manner. Key in this interview survey is that while being asked orally about stillbirth experiences, respondents did not know that the next questions were going to be about miscarriages, and similarly, while being asked about miscarriage experiences, they did not know that they would be asked about abortions next. This survey and questionnaire design made it fairly difficult, if not impossible, for the respondents to falsely report induced abortion experiences as miscarriages.[36] As we show soon below, the ratio of unclear responses ('Do not know', 'Refuse to answer', and 'Do not recall') to valid responses is much higher with the history of abortion than that of miscarriage or stillbirth, indicating that respondents who wanted to keep secret their abortion experiences may have had to choose these unclear responses since miscarriage questions were already finished, while we still do find a few abortion cases. In addition to the measurement that separates miscarriage and stillbirth from abortion, we can observe more than one pregnancy loss per person if any. Using thus collected data from the RePEAT survey, we examine the extent to which the measurement of pregnancy loss alters the major findings.

Table C.1 also shows the share of females for whom the survey response to the question on the year of pregnancy loss includes at least one 'Do not know (DNK),' 'Refuse to answer (RTA),' and 'Do not recall (DNR),' separately for miscarriage and stillbirth, as well as for abortion.[37] When we take the ratio of those who accurately report the year of pregnancy loss to those who report one of DNK, RTA, and DNR, The ratio is .0607/.267 = .227 for miscarriage and stillbirth, while it is .0124/.0086 = 1.442 for abortion. That is, we find that a larger ratio of females made an unclear response to the question on the exact year of abortion given having at

[33]Since induced abortion is illegitimate in Uganda except for the case in which the mother is physically threatened to death (Singh et al., 2018), the number of abortions should not be so large. However, some females may perform unsafe abortions on their own or fail to report their abortion experience truthfully.

[34]Although they had information on whether the women had more than one pregnancy loss, they did not ask when the losses occurred except for the latest experience.

[35]This implies that the birth spacing variable is measured in years in the RePEAT survey, not in months as in the DHS data.

[36]Singh et al. (2018) presents a summary of field studies that suggest that many women do not report abortion experiences when directly asked, and that women tend to report miscarriages, whereas they actually had abortions.

[37]There is another response category, 'Not applicable (NA).' However, NA was used during the survey mainly to mark those who were not supposed to answer the question.

least one experience. This is likely to suggest that the pregnancy loss variable does effectively exclude abortion from its measurement in our RePEAT data.

Table C.1: Pregnancy Loss Variables in the RePEAT Data.

	(1) N	(2) mean	(3) sd
Ever had pregnancy loss	9545	0.273	0.446
More than one pregnancy loss	9545	0.024	0.153
Ever had miscarrige or stillbirth	9545	0.267	0.442
More than one miscarriage or stillbirth	9545	0.024	0.153
Ever had abortion	9545	0.0086	0.0923
Unclear about miscarriage or stillbirth timing	9545	0.0607	0.2387
Unclear about abortion timing	9545	0.0124	0.1105

Source: RePEAT Uganda 2015. *Notes*: This table shows the summary statistics of pregnancy loss variables for females aged 15 to 49 years. Unclear responses include 'do not know,' 'refuse to answer,' and 'do not remember.'

Appendix D Model of Pregnancy Timing with Subjective Belief for Loss Probability

In this section, we present a simple microeconomic model of analysing the timing of pregnancy that incorporates the subjective belief of the probability of pregnancy loss. Consider a female who just gave a live birth at period 0, chooses consumption and pregnancy status for periods 1 and 2 to maximise her utility, and receives terminal utility at period 3. One condition for her lifetime fertility is to achieve at least $\bar{N}$ children. Let her utility function at period t be written as

$$U_t = \lambda X_t + \kappa N_t,$$

where X_t represents consumption at period t, N_t the number of children, $\lambda > 0$ and $\kappa > 0$ the marginal utility from consumption and children, respectively. Only in period 3, we assume a slightly different utility of the form:

$$U_3 = \lambda X_3 + \kappa N_3 - C\mathbf{I}\{N_3 < \bar{N}\}$$

with $C > 0$ representing the social punishment or psychic cost for failing to achieve the desired number of children while she is reproductive, where $\mathbf{I}\{\cdot\}$ denotes the indicator function that equals one if the condition in the brackets holds and zero otherwise. She faces the budget constraint:

$$Y_t = X_t + \nu N_t,$$

where $\nu > 0$ denotes the cost of raising N_t children relative to the price of consumption goods that is normalised to unity.[38] The only state variable in this model, N_t, evolves such that

$$N_{t+1} = N_t + (1 - \mu_t)P_t,$$

where $P_t = 1$ if the female becomes pregnant at period t and 0 otherwise, $\mu_t = 1$ if the pregnancy at period t ends in a loss and 0 otherwise.

We consider $\bar{N} = N_0 + 1$, which implies that the female has to give at least one live birth during periods 1 and 2. In other words, she chooses whether to become pregnant and attempts to give a live birth at period 1, period 2, or both to achieve her total fertility equal to or larger than $\bar{N}$. To make the model more realistic and consistent with the African context, we impose the following assumption on the utility from the number of children.

Assumption 1*. The marginal utility of children is positive but its marginal benefit is smaller than that from consumption. That is,*

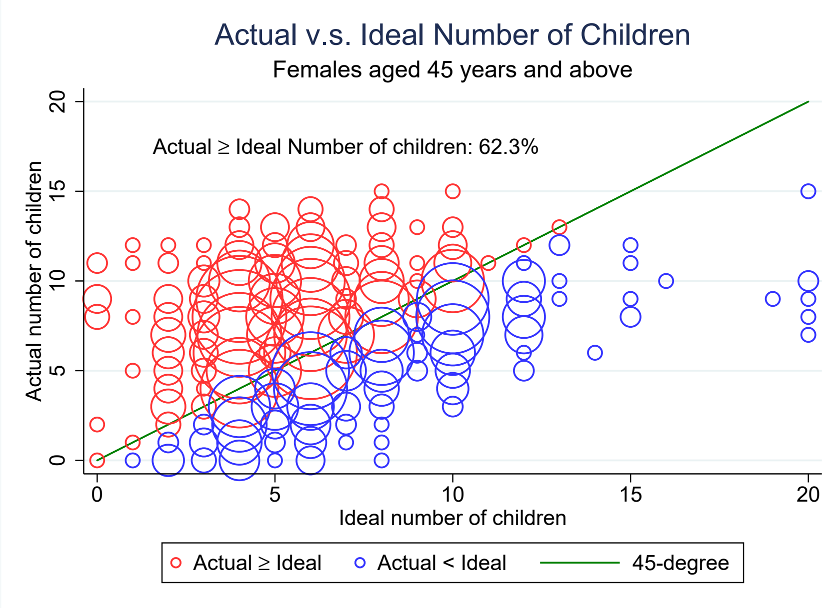
$$\lambda > \frac{\kappa}{\nu}.$$

This condition is consistent with the fertility literature using data from sub-Saharan Africa, which finds that the number of children that females want to have in their lifetime is generally smaller than that desired by their partners and that females actually end up making in their lifetime (Ashraf et al., 2014). In our data, we find that approximately two-thirds of females end up having at least their desired number of children (for details, see Appendix Figure D.1). This feature can be incorporated into our model herein by Assumption 1.

At period $t = 3$, the female chooses only consumption, where her optimisation problem is written as:

$$\max_{X_3} U_3 = \lambda X_3 + \kappa N_3 - C\mathbf{I}\{N_3 < \bar{N}\} \quad \text{subject to} \quad Y_3 \geq X_3 + \nu N_3.$$

[38] We assume that getting pregnant in period t is costless, but this is not too unrealistic, particularly when the female is just one child to completion of her desired lifetime fertility with larger $\bar{N}$, since other older children can help her with chore work and other household activities.



Source: DHS Uganda 2011. *Notes*: This figure shows the distribution of the actual and ideal number of children of females aged 45 years and above, where the size of circles corresponds to the share of females at the actual and ideal numbers of children on the vertical and horizontal axes, respectively.

Figure D.1: Actual v.s. Ideal Number of Children of Females Aged 45 Years and Above.

Since she has only one choice variable, X_3, the solution is $X_3^* = Y_3 - \nu N_3$, and her value function is $V_3(N_3) = \lambda X_3^* + \kappa N_3 = \lambda Y_3 + (-\lambda\nu + \kappa)N_3$. In the case $N_3 < \bar{N}$, the value is $V_3(N_3) = \lambda Y_3 + (-\lambda\nu + \kappa)N_3 - C$.

At period $t = 2$, she faces the optimisation problem:

$$\max_{X_2, P_2} U_2 + \beta V_3(N_3)$$

subject to

$$Y_2 = \lambda X_2 + \nu N_2 \quad \text{and} \quad N_3 = N_2 + (1 - \mu_2)P_2$$

where β represents the time discount rate between 0 and 1. To solve for the solutions, we substitute $X_2 = Y_2 - \nu N_2$ and consider the two cases below.

Case 1. If $N_2 = \bar{N}$, take the utility difference when $P_2 = 1$ and 0:

$$\begin{aligned} Q_2(\bar{N}) &\equiv U_2(P_2 = 1, N_2 = \bar{N}) + \beta[(1-\mu_2)V_3(\bar{N}+1) + \mu_2 V_3(\bar{N})] \\ &\quad - [U_2(P_2 = 0, N_2 = \bar{N}) + \beta V_3(\bar{N})] \\ &= \beta(1-\mu_2)(-\lambda\nu + \kappa) \end{aligned}$$

With Assumption 1, we have that $(-\lambda\nu + \kappa) < 0$, so the solution is

$$P_2^*(\bar{N}) \equiv \mathbf{I}\{Q_2(\bar{N}) > 0\} = 0.$$

Case 2. If $N_2 = \bar{N} - 1$, again take the utility difference:

$$\begin{aligned} Q_2(\bar{N}-1) &\equiv U_2(P_2 = 1, N_2 = \bar{N}-1) + \beta[(1-\mu_2)V_3(\bar{N}) + \mu_2 V_3(\bar{N}-1)] \\ &\quad - [U_2(P_2 = 0, N_2 = \bar{N}-1) + \beta V_3(\bar{N}-1)] \\ &= \beta(1-\mu_2)(-\lambda\nu + \kappa + C). \end{aligned}$$

We assume that the female attempts to become pregnant to avoid the terminal utility loss of C at any cost. In other words, we assume that C is so large that any female with $N_2 \leq \bar{N}$ attempts to avoid it by becoming pregnant at period 2. The following formally states this condition:

Assumption 2. *The utility loss when the number of pregnancies does not reach the desired number, $\bar{N}$, is large enough to induce any female to become pregnant at period 2 and attempt to avoid incurring it at period 3. That is,*

$$C > \lambda\nu - \kappa.$$

By Assumption 2, we have that $Q_2(\bar{N}-1) > 0$, so the solution is

$$P_2^*(\bar{N}-1) \equiv \mathbf{I}\{Q_2(\bar{N}-1) > 0\} = 1.$$

The value functions at period 2 depend on the number of children at the beginning of period 2 such that

$$\begin{aligned}
V_2(\bar{N}) &= U_2(P_2 = 0, N_2 = \bar{N}) + \beta V_3(\bar{N}) \\
&= \lambda Y_2 + (-\lambda\nu + \kappa)\bar{N} + \beta V_3(\bar{N}) \\
V_2(\bar{N}-1) &= U_2(P_2 = 1, N_2 = \bar{N}-1) + \beta\left[(1-\mu_2)V_3(\bar{N}) + \mu_2 V_3(\bar{N}-1)\right] \\
&= \lambda Y_2 + (-\lambda\nu + \kappa)(\bar{N}-1) + \beta\left[(1-\mu_2)V_3(\bar{N}) + \mu_2 V_3(\bar{N}-1)\right].
\end{aligned}$$

Define the differences in the value functions as:

$$\begin{aligned}
\Delta V_3 \equiv& V_3(\bar{N}) - V_3(\bar{N}-1) = -\lambda\nu + \kappa + C \\
\Delta V_2 \equiv& V_2(\bar{N}) - V_2(\bar{N}-1) = -\lambda\nu + \kappa + \beta\mu_2\Delta V_3.
\end{aligned}$$

At period 1, she faces the optimisation problem of the form:

$$\max_{X_1, P_1} U_1 + \beta V_2(N_2) = U_1 + \beta\left[P_1(1-\mu_1)V_2(\bar{N}) + (1 - P_1(1-\mu_1))V_2(\bar{N}-1)\right]$$

subject to

$$\begin{aligned}
Y_1 &= X_1 + \nu N_1 \\
N_2 &= N_1 + (1-\mu_1)P_1
\end{aligned}$$

Substitute $X_1 = Y_1 - \nu N_1$ to reduce the choice variables and consider the utility difference if the female becomes pregnant and if not:

$$\begin{aligned}
Q_1 \equiv& U_1(P_1 = 1) + \beta[(1-\mu_1)V_2(\bar{N}) + \mu_1 V_2(\bar{N}-1)] - U_1(P_1 = 0) - \beta V_2(\bar{N}-1) \\
=& U_1(P_1 = 1) - U_1(P_1 = 0) + \beta(1-\mu_1)\Delta V_2.
\end{aligned}$$

The female gets pregnant at period 1 if $Q_1 > 0$, *i.e.*,

$$P_1^* = \mathbf{I}\{Q_1 > 0\}.$$

For the female making the pregnancy decision at period 1, $\tilde{\mu} = \mu_1 = \mu_2$ denotes her perceived probability of pregnancy loss, which takes the same value for all the periods ahead. Consider the derivative of Q_1 with respect to $\tilde{\mu}$:

$$\begin{aligned}
\frac{\partial Q_1}{\partial \tilde{\mu}} =& -\beta\Delta V_2 + \beta(1-\tilde{\mu})\frac{\partial \Delta V_2}{\partial \tilde{\mu}} \\
=& \beta(\lambda\nu - \kappa) + \beta^2(1 - 2\tilde{\mu})(-\lambda\nu + \kappa + C)
\end{aligned}$$

Here, the first term is positive by Assumption 1, and Assumption 2 implies that the second term can be positive and negative depending upon the value of $\tilde{\mu}$, as in the two cases below.

Case 1. If $0 \leq \tilde{\mu} \leq 1/2$, $\partial Q_1/\partial\tilde{\mu} > 0$. This suggests that females who perceive the probability of pregnancy loss to be not too high always attempt to become pregnant and give birth in period 1 rather than period 2.

That is, as long as the perceived probability of pregnancy loss is at most one half, an increase in the perceived probability always makes the female more likely to become pregnant in period 1, which leads to a shorter birth spacing interval from period 0.

Case 2. If $1/2 < \tilde{\mu} \leq 1$, the sign of $\partial Q_1/\partial\tilde{\mu}$ is ambiguous and depends upon which of the positive and negative parts is larger, the marginal utility from an additional child at period 2 $(\lambda\nu - \kappa)$, or the difference in the value functions at period 3 (ΔV_3).

Note that in our definition of perceived probability computed as a function of pregnancy history the perceived probability can become larger than half only if a female experiences a loss at her first pregnancy. In addition, since the spacing interval can only be defined for the second and subsequent pregnancies that lead to a live birth, a perceived probability larger than half does not affect birth spacing behaviours for pregnancies that are used for our estimation. This suggests that although it is theoretically possible that the perceived probability exceeds half, such a case is precluded in our estimation analysis.

Even if the perceived probability is larger than half $(1/2 < \tilde{\mu} \leq 1)$, we can further show that $\partial Q_1/\partial\tilde{\mu} > 0$ is equivalent to:

$$C < \frac{1-\beta(1-2\tilde{\mu})}{-\beta(1-2\tilde{\mu})}(\lambda\nu-\kappa) = \frac{1+\beta\tilde{\gamma}}{\beta\tilde{\gamma}}(\lambda\nu-\kappa)$$

where $\tilde{\gamma} \equiv -(1-2\tilde{\mu}) > 0$ for $1/2 < \tilde{\mu} \leq 1$. This implies that the smaller the perceived probability of pregnancy loss is, the larger the value of $\tilde{\gamma}$, and the more likely this inequality is to hold. In other words, as long as the social punishment C is not too large or as long as the perceived probability of pregnancy loss is not too large, an increase in perceived probability of pregnancy loss can still lead to a larger likelihood of pregnancy in period 1, i.e., shorter birth spacing.