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Konrad-Zuse-Strasse 1 · D-18057 Rostock · Germany · Tel +49 (0) 3 81 20 81 - 0 · Fax +49 (0) 3 81 20 81 - 202 · www.demogr.mpg.de

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The effects of birth spacing on health and socioeconomic outcomes across the life course: evidence from the Utah Population Database

Kieron J. Barclay I barclay@demogr.mpg.de
Ken R. Smith

This working paper has been approved for release by: Maarten J. Bijlsma (bijlsma@demogr.mpg.de),
Deputy Head of the Laboratory of Population Health.

THE EFFECTS OF BIRTH SPACING ON HEALTH AND SOCIOECONOMIC OUTCOMES ACROSS THE LIFE COURSE: EVIDENCE FROM THE UTAH POPULATION DATABASE

ABSTRACT. The relationship between the length of birth intervals and child outcomes has received increased attention in recent years, but few studies have examined offspring outcomes across the life course in North America. In this study we examine the relationship between birth intervals and a range of short- and long-term outcomes, including preterm birth, low birth weight, infant mortality, college graduation, occupational attainment, and adult mortality, using data from the Utah Population Database (UPDB). To study infant outcomes we use data on cohorts born 1947–2016, to study educational and occupational outcomes we use data on cohorts born 1950–1980, and to study adult mortality we use data on cohorts born 1900–1949, with mortality outcomes followed until 2016. We use linear regression, linear probability models, and survival analysis, and compare the results from models with and without sibling comparisons. Children born after a birth interval of 9-12 months have a higher probability of low birth weight, preterm birth, and infant mortality both with and without sibling comparisons; longer intervals are further protective, but to a much less dramatic extent, and the protective effect of longer intervals against low birth weight and preterm birth was clearer in cohorts born before the 1990s. Based upon sibling comparison analyses, even the very shortest birth intervals do not negatively influence educational or occupational outcomes, nor long-term mortality. These findings suggest that extremely short birth intervals can increase the probability of poor perinatal outcomes, but that any such disadvantages disappear over the extended life course.

INTRODUCTION

The timing and spacing of births are of core interest to demographers, and many researchers have examined whether the spacing between siblings has consequences for a child's health and development. We define birth spacing as the time in months between two live births. There is a long tradition of research examining how spacing is related to infant and child mortality in both historical contexts and contemporary low- and middle-income countries (Bean et al., 1992; Lynch and Greenhouse, 1994; Conde-Agudelo et al., 2006; Molitoris, 2017; Molitoris et al., 2019). Many studies have also examined whether birth spacing is associated with perinatal outcomes, such as low birth weight, and long-term educational and socioeconomic outcomes in high-income countries (Powell and Steelman, 1990; Buckles and Munnich, 2012; Ball et al., 2014; Barclay and Kolk, 2017). Recent years have seen a resurgence of interest in this topic as researchers began to use instrumental variables and fixed effects in an attempt to isolate the net effect of birth spacing on child outcomes. The prevailing consensus that short birth intervals have a negative effect on offspring outcomes in high-income countries has been called into question by a series of studies reporting null associations after adjusting for unobserved confounding (e.g. see Ball et al., 2014; Hanley et al., 2017; Barclay and Kolk, 2017, 2018; Ahrens et al., 2019).

Although it is clear that that short birth intervals are associated with a higher risk of poor perinatal outcomes and infant mortality in low- and middle-income countries even after adjusting for unobserved confounding (Conde-Agudelo et al., 2006; Molitoris, 2018; Molitoris et al., 2019), in high-income countries the association between birth interval length and offspring outcomes remains contested. For example, the association between short birth intervals and the probability of preterm birth and low birth weight seems to vary between different high-income countries (Klebanoff, 2017). For long-term outcomes, some studies suggest that short birth intervals are associated with worse educational outcomes (Powell and Steelman, 1990, 1993; Buckles and Munnich, 2012), while others suggest that birth spacing has no long-term educational, socioeconomic, or health consequences (Nguyen, 2014; Barclay and Kolk, 2017, 2018; Grätz, 2018).

Part of the challenge about drawing conclusions from the existing literature on the association between birth intervals and offspring outcomes is uncertainty about the relative importance of the social and public health context, as well as the application of different statistical methods. For example, in Sweden there is no association between birth interval length and educational outcomes (Barclay and Kolk, 2017), while short intervals are associated with worse educational outcomes for some children in the United States (Buckles and Munnich, 2012). However, the extent to which these different patterns can be explained by considerable differences between the Swedish and American welfare and health care systems, or different research designs, remains unclear.

The goal of this study is to examine whether birth intervals are associated with long-term outcomes in the United States when using a population-based dataset and applying statistical methods that compare siblings in order to reduce residual confounding. To do so, we use data from the Utah Population Database (UPDB) to examine how birth intervals are associated with offspring outcomes over the life course. We examine perinatal outcomes, educational and occupational attainment, and mortality in adulthood in relation to birth spacing, and use a within-family sibling comparison design that allows us to minimise residual confounding and to isolate the net effect of birth interval length on offspring outcomes. To preview our results, we find that very short birth intervals are strongly associated with the probability of low birth weight (LBW), preterm birth, and infant mortality. However, the negative effects disappear over the long-term. In contrast to the results that ignore unadjusted confounding due to family-specific effects, we find no disadvantages in educational or occupational attainment, or adult mortality, for those born even after very short birth intervals after accounting for unobserved differences between families.

Previous Research on Birth Spacing and Perinatal Outcomes in High-income Countries. Until recently, research had consistently shown that especially short and especially long birth intervals were both associated with poor perinatal outcomes. For example, a meta-analysis of 67 studies published up to 2006 showed that there is a J-shaped curve in the relationship between the length of birth intervals and peri-natal and child health outcomes, with interpregnancy intervals (IPIs) shorter than 18 months, and longer than 59 months significantly associated with poor perinatal outcomes (Conde-Agudelo et al., 2006). Based on this body of evidence, the World Health Organization has recommended that women avoid pregnancy until at least 24 months after the birth of the previous child (WHO, 2005). For their part, the American College of Obstetricians and Gynecologists (ACOG) recommends an IPI of at least 6 months (ACOG, 2019). Despite this, research suggests that many prospective mothers do not recall ever having been advised about IPI length, and are not aware of the potential importance of IPIs for pregnancy outcomes (Yang et al., 2019).

However, since 2014 this long held consensus about the negative effects of short birth intervals was shaken by a study using Australian data and sibling fixed effects to study the relationship between interpregnancy intervals and the probability of preterm birth, LBW, and being small for gestational age (SGA) (Ball et al., 2014). By comparing siblings born to the same mother, they were able to hold constant unobserved factors shared by siblings that are correlated both with the length of birth intervals as well as perinatal outcomes. Ball et al. (2014)

found that the association between short IPIs (0-5 months) and preterm birth, LBW, and SGA reduced to almost zero after adjusting for unobserved heterogeneity at the maternal level. These results suggested that the length of birth intervals may not actually have a causal effect on the risk of poor peri-natal outcomes, and that the long documented association might result from omitted variable bias. Birth intervals are not randomly distribution across families, and it might be the case that children born after short birth intervals are more likely to be born to mothers with worse health, for example.

This surprising finding triggered a number of follow-up studies using the same research design. A study using data from Canada (Hanley et al., 2017) reached the same conclusions as the paper by Ball et al. (2014). Studies using data from Sweden also found that short IPIs were no longer associated with the risk of LBW or SGA when using a fixed effects analysis (Class et al., 2017; Barclay et al., 2020). However, some follow-up studies have reached different conclusions, particularly when examining preterm birth. Studies using data from the United States (Shachar et al., 2016; Mayo et al., 2017; Lonhart et al., 2019) have shown that short IPIs (variously defined as 0-5 months or 0-18 months) are associated with the risk of preterm birth even when comparing siblings born to the same mother, as has research using data from Sweden (Class et al., 2017) and the Netherlands (Koullali et al., 2017), though the latter study conditioned on the mother having had a preterm birth at parity one. A recent review of the evidence in high-income countries has concluded that the findings are mixed and further research that carefully takes potential confounding into consideration is needed (Ahrens et al., 2019).

Previous Research on Birth Spacing and Long-term Outcomes in High-income Countries. In comparison to the voluminous literature on birth spacing and perinatal outcomes, there is far less research on the long-term consequences of birth intervals (Steelman et al., 2002). Research using standard regression approaches has consistently found that short birth spacing and higher overall sibling density are associated with worse long-term outcomes, such as lower test scores, or a lower likelihood of making educational transitions (Dandes and Dow, 1969; Pfouts, 1980; Powell and Steelman, 1990, 1993). Recent studies that have attempted to identify the net effect of birth spacing on educational and cognitive outcomes using instrumental variables and sibling fixed effects have, however, come to differing conclusions.

Using data from the National Longitudinal Survey of Youth (NLSY79), Buckles and Munnich (2012) applied miscarriage as an instrument for birth spacing (a miscarriage induces a longer birth interval than would otherwise be expected) and found that a 12 month increase in spacing increased test scores for the older sibling in a sibling-pair by approximately 0.17 standard deviations, and spacing less than 2 years negatively affected both math and reading scores significantly. However, they did not find that spacing affected the younger sibling of the pair.

Using Swedish population data, Pettersson-Lidbom and Skogman Thoursie (2009) leveraged a 1980 policy reform that encouraged women to have shorter birth intervals in order to increase the value of their parental leave benefits as an instrument for birth interval length. They found that longer birth intervals were associated with a higher probability of completing the academic track of upper secondary education: a one-month decrease in spacing decreased the probability of this very specific educational outcome by 2 percentage points, which is an enormous effect if extrapolated to longer intervals (Pettersson-Lidbom and Skogman Thoursie, 2009). Pettersson-Lidbom and Skogman Thoursie (2009) did not examine any other measures of educational achievement or attainment.

A study by Nguyen (2014, Chapter 4), using data on 800 sibling pairs from the National Longitudinal Study of Adolescent to Adult Health (Add Health), found that birth spacing was no longer associated with test scores, educational attainment, or earnings after applying the sibling comparison design. Further studies based on Swedish population registers and sibling comparisons found that birth intervals were not substantively or significantly associated with high school GPA, cognitive scores, educational attainment, earnings, unemployment, receiving welfare support, or multiple dimensions or health and mortality after comparing siblings sharing the same mother and father (Barclay and Kolk, 2017, 2018). Consistent with Barclay and Kolk (2017, 2018), Grätz (2018) reported that birth spacing has no effect on cognitive scores or upper secondary attendance (*Gymnasium*) in Germany after applying sibling fixed effects.

Although the findings from these studies examining long-term outcomes in relation to birth intervals are mixed, the divide seems to be primarily along methodological lines. Studies that have use instrumental variables to estimate the effects of birth intervals have found that shorter intervals are associated with worse educational outcomes (Buckles and Munnich, 2012; Pettersson-Lidbom and Skogman Thoursie, 2009), while studies that have applied a sibling comparison approach do not find any association between the length of birth intervals and long-term outcomes (Nguyen, 2014; Barclay and Kolk, 2017, 2018; Grätz, 2018).

Nevertheless, it is certainly possible that birth spacing could affect long-term outcomes in the United States; research on the link between IPIs and perinatal outcomes suggests a persistent association in the US, but less elsewhere (Shachar et al., 2016; Mayo et al., 2017; Lonhart et al., 2019), and there is a large body of literature showing that preterm birth and LBW are associated with lower test scores, and lower educational and socioeconomic attainment (Conley and Bennett, 2000; Behrman and Rosenzweig, 2004; Black et al., 2007; D'Onofrio et al., 2013; Baranowska-Rataj et al., 2019).

Birth Intervals and Offspring Outcomes: Potential Explanatory Mechanisms. Before turning to our empirical analysis, we briefly review the literature concerning the potential mechanisms by which birth interval length could affect child outcomes. Broadly speaking, these fall into three families: physiological explanations, social and environmental explanations, and selection processes.

Physiological Explanations. A detailed review of potential mechanisms linking birth intervals to perinatal and child health outcomes by Conde-Agudelo et al. (2012) reported that there were at least six plausible physiological mechanisms, and these included: maternal nutrient depletion, folate depletion, cervical insufficiency, vertical transmission of infections, suboptimal lactation related to breastfeeding-pregnancy overlap, and physiological regression. Most of these theories point to the risks of short birth intervals, where the mother has simply not had enough time to recover from the previous pregnancy. For example, the maternal nutrient depletion and folate depletion hypotheses are based upon studies showing that particularly short intervals do not enable the mother to re-accumulate all of the nutrients to a level that is optimal for the development of a new foetus (King, 2003; Smits and Essed, 2001).

As described in the review of previous empirical research, intervals longer than five years have also been linked with worse perinatal outcomes. One potential explanation that has been offered to explain this phenomenon is the role of physiological regression, whereby the physiological adaptations experienced by the mother during pregnancy return over time to a physiological state more akin to that seen amongst women who have not experienced pregnancy before (Zhu et al., 1999). Research suggests that long IPI's can also increase the relative risk of pregnancy complications, which may also contribute to the increased risk of poor outcomes for infants (Gebremedhin et al., 2020).

Social and Environmental Explanations. Social and environmental factors may be important for both the association between birth intervals and poor perinatal outcomes as well as for any potential long-term effects of birth spacing. For example, socioeconomic variation in household resources that affects nutrition or access to health care could affect birth spacing as well as perinatal health outcomes. Furthermore, closely spaced siblings, and the average spacing in the sibling group as a whole, may affect access to parental resources, time, and investment (Blake, 1989). On average we may expect infants and children to receive more attention and focus from parents during the early years of life if they are not competing with another newly born sibling. Short birth intervals could plausibly affect both the older and younger of any given sibling pair, but the detrimental impact is potentially worse for the younger of the pair given empirical evidence regarding the importance of early life investments for long-term development trajectories (Cunha et al., 2006; Heckman, 2006).

The spacing of siblings within the household has also been linked to the degree of intellectual stimulation experience by children (Zajonc, 1976). This perspective, known as the confluence hypothesis, argues that a child's intellectual development is linked to the degree of stimulation experienced in the household, and that the average degree of stimulation experienced is strongly linked to the intellectual maturity of the other members of the household (Zajonc and Markus, 1975). Shorter birth intervals would therefore mean more interactions with relatively younger siblings, who would be less intellectually stimulating than both parents and older siblings.

Spacing between siblings may also affect transmission of infections. Research suggests that the younger sibling in a sibling dyad where the birth interval is approximately two years is particularly likely to be infected by diseases brought into the home environment by the older sibling of the pair (Conde-Agudelo et al., 2012). Although most of the infections transmitted between children in high-income countries today are rhinovirus–variants with negligible long-term health or development consequences (Peltola et al., 2008), in early 20th century Utah it is possible that some infectious diseases may have been more serious. For example, the United States experienced regular epidemics of poliomyelitis from the beginning of the 20th century until a vaccine was developed in the 1950s (Paul et al., 1971). However, today the transmission of infectious diseases, to the extent that they are mild, may actually improve immune system development and performance, a theory that has been dubbed the hygiene hypothesis (Strachan, 1989).

Selection Processes. Although there are numerous plausible mechanisms linking birth spacing to short- and long-term offspring outcomes, the empirical evidence suggests that birth spacing is not randomly distributed across families (Gemmill and Lindberg, 2013). Data from the United States from 2006–2010 shows that births following interpregnancy intervals of 18 months or less were most common amongst relatively disadvantaged, and relatively advantaged mothers: for example, IPIs shorter than 18 months most common amongst both teenage mothers, and mothers aged 30 and older, and amongst both those with less than a high school as well as those with a college degree (Gemmill and Lindberg, 2013). However, births following short intervals were reported as intended by more advantaged mothers, and as being mistimed or unwanted amongst the less advantaged mothers (Gemmill and Lindberg, 2013). Further evidence for the non-random distribution of birth spacing across families has emerged from the various studies that have found that birth intervals have a smaller association with child outcomes after adjusting for factors at the parental level that jointly influence both the timing and spacing of births as well as short- and long-term health and socioeconomic outcomes amongst children (Ball et al., 2014; Hanley et al., 2017; Barclay and Kolk, 2017, 2018; Grätz, 2018).

DATA AND METHODS

Data. In this study we use the Utah Population Database to examine the relationship between birth intervals and preterm birth, low birth weight, infant mortality, obtaining a college degree, educational attainment, occupational attainment, and mortality in adulthood. The Utah Population Database (UPDB) at the Huntsman Cancer Institute at the University of Utah is a remarkable source of in-depth information that supports research on genetics, epidemiology, demography, and public health. The central component of the UPDB is an extensive set of Utah family histories, in which family members are linked to demographic and medical information. Records are linked into family pedigrees spanning many generations based on genealogies from the Genealogical Society of Utah as well from Utah state vital records. The UPDB includes diagnostic records about cancer, cause of death, and medical details associated with births.

In this study we use data on cohorts born from 1947 to 2016 to study how birth intervals are associated with the probability of low birth weight, preterm birth, and infant mortality. Our analyses of college degree attainment, overall educational attainment, and occupational attainment are based upon cohorts born 1950–1980. Our analyses of mortality in adulthood are based upon cohorts born 1900–1949, meaning that we observe men and women up to at least age 67 in our youngest birth cohort.

The measure for the birth interval that we use in this study is the length of the birth-to-birth interval, meaning the period of time in months from one live birth to another. We categorise the length of the birth interval into 10 different categories, which, apart from the shortest category of 9-12 months, are 6 month periods from a minimum of 13 months to 60 months or longer (9-12, 13-18, 19-24, ..., 55-60, 60+). In our analyses we choose a reference category for the preceding and subsequent birth interval of 25-30 months. The distribution of birth intervals from 1900-2016 in Utah is shown in Figure 1. We drop families with multiple births.

Our analysis is based upon the population of sibling groups with at least three children. The reason that we focus upon sibling groups with at least three children is that the sibling fixed effects models that we employ, described in greater detail below, exploit variance within the sibling group in order to generate the estimates. Thus, we need to observe at least two birth intervals within a sibling group in order to be able to estimate the relationship between birth interval length and the outcomes that we examine. To have information on the length of the preceding birth interval we also need to observe at least two sets of sibling-pairs with adjacent birth orders in each sibling group. By two sets of sibling-pairs with adjacent birth orders, we mean that we should have at least two children where are are able to observe the timing of birth for both the index child as well as the older sibling, in order to be able to calculate the length of the preceding birth interval.

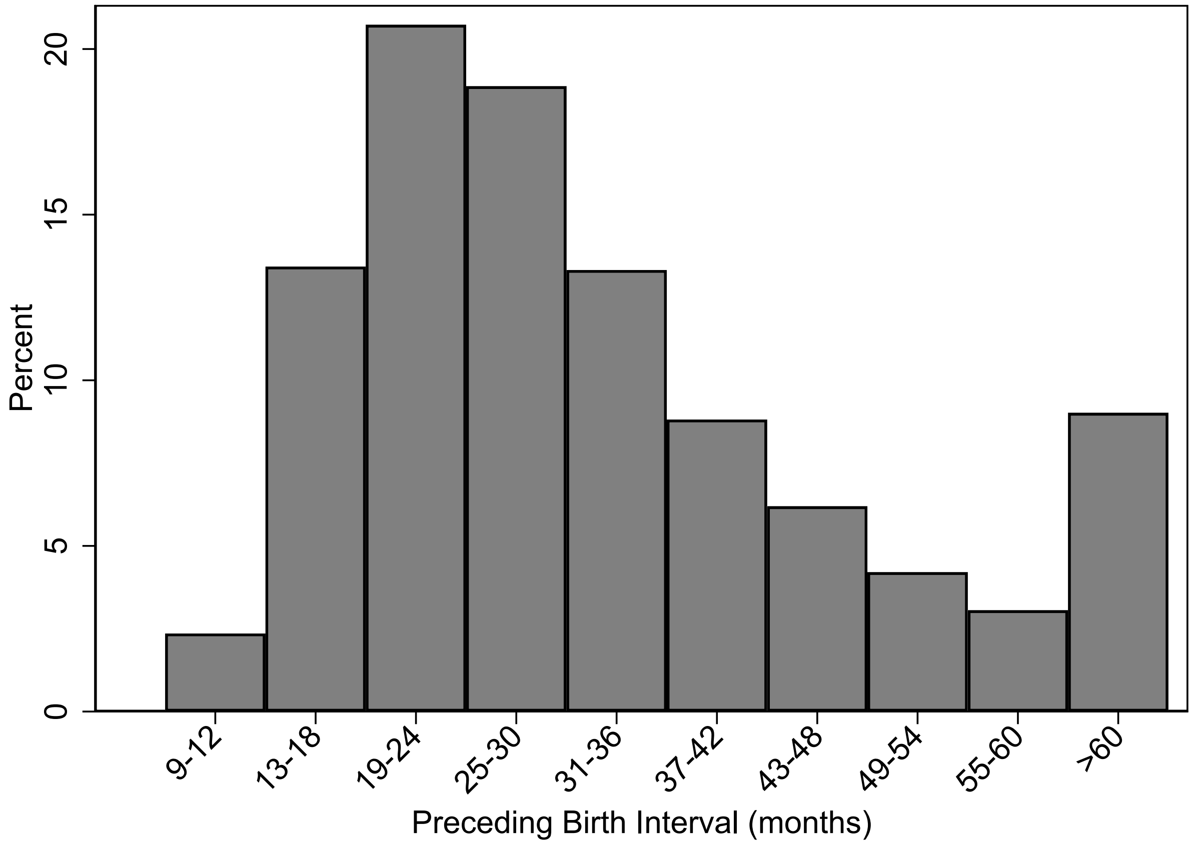

FIGURE 1. Distribution of the length of preceding birth intervals in months by birth cohort in Utah, 1900-2016.

Outcome Variables.

Low Birth Weight. Infants with birth weight less than 2500g are classified as being born with low birth weight.

Preterm Birth. Following standard practice, we categorize preterm births as those births that occur before 37 weeks of gestation.

Infant Mortality. Infant mortality is defined as death in the first 12 months of life.

College Graduation and Occupational Attainment. Our measures of college graduation and occupational attainment are drawn from birth certificate data, where the educational and occupational characteristics of the parents are recorded. That is to say, we can only measure the educational and occupational attainment of index individuals who go on to become parents themselves. To a certain extent this means that we condition on advantage, as childless individuals are often disadvantaged in terms of health and socioeconomic factors. It also means that the age at measurement of educational and socioeconomic varies across individuals by age at childbearing. Utah has one of the highest fertility rates of any States in the United States, so the relative percentage missing for this reason is lower than it might otherwise be.

The measure of occupation status is based on a transformation of the occupational data to the Nam-Powers-Boyd Occupational Status Score (Nam and Powers, 1968; Nam and Boyd, 2004). The Nam-Powers-Boyd score is a measure of occupational prestige that ranges from 1–100. Occupations that rank at the top of the scale include physicians, surgeons, lawyers, and judges (all with scores of 100), and occupations at the bottom of the scale include dishwashers (1), and housekeeping cleaners (6). Some additional examples may assist the interpretation of the results: hairdressers have a score of 27; bus drivers 32; pre-school teachers 50; mail carriers 63; firefighters 76; civil engineers 93; and, sociologists 82.

Adult Mortality. To study mortality we examine cohorts born 1900-1949, with follow-up to 2016. Data on mortality is draw from genealogical records as well as Social Security derived death certificates. This means that we are able to observe deaths occurring in the United States even if they occur outside of Utah.

Covariates. In addition to our main explanatory variable, the length of birth intervals, we include several covariates in our models that are likely to be associated with both birth spacing as well as long-term health. Factors such as birth order, parental age at the time of birth, and birth year may be associated with birth interval length, and are also associated with peri-natal health outcomes. We include controls for birth order as both the confluence hypothesis and the resource dilution hypothesis predict independent effects of birth order and birth spacing, and previous research has indicated that birth order is related to the probability of low birth weight and preterm birth (Kramer, 1987; Shah, 2010). Birth interval length is also likely to be associated with maternal age, and maternal age is associated with perinatal outcomes and infant mortality (Andersen et al., 2000; Finlay et al., 2011). We adjust for maternal age using five-year categories. It is well known that there are secular trends in infant mortality rates and the incidence of low birth weight and preterm birth, so we also adjust our analyses for birth year, using individual-year dummies. We also adjust for offspring sex.

Statistical Analyses.

Perinatal Outcomes. To study the relationship between birth intervals and the outcomes LBW, preterm birth, and infant mortality we use linear regression, and linear regression with sibling fixed effects, in the form of linear probability models. The fixed effects are applied to the sibling group, meaning that we conduct a within-family comparison. The use of sibling fixed effects implicitly adjusts for all factors that remain constant within the sibling group. This means that the within-family comparison adjusts for the size of the sibling group, as well as parental resources, to the degree that the latter remains constant. The fixed effects approach also inherently adjusts for factors that are difficult to observe and measure, such as all elements of shared socioeconomic background and general parenting style, to the extent that such factors are indeed shared by siblings.

For each outcome, LBW, preterm birth, and infant mortality, we estimate two different models: one between-family comparison and one within-family comparison examining the relationship between the preceding birth interval and the outcome variable:

$$y_i = \beta_1 BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i + \beta_6 BirthYear_i + \alpha + \varepsilon_i \tag{1}$$

$$y_{ij} = \beta_1 BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij} + \alpha_j + \varepsilon_{ij} \tag{2}$$

where y_{ij} is the outcome for individual i in sibling group j on preterm birth and LBW. In Model 1 we use a regular linear regression, meaning a between-family comparison, to examine the relationship between BI_i, the length of the preceding birth interval, and control for biological sex, birth order $(2,3,...,10+)$, sibling group size $(2,3,...,10+)$, maternal age $(15-19, 20-24, ..., 40-44, 45+)$, and birth year. BI_i is entered into the model as a series of 10 dummy variables based on 6-month categories for the length of the preceding birth interval. In Model 1 our analysis population is second and later-born children in sibling groups with at least three children, meaning that we exclude first-borns as they have no value for the length of the preceding interval. In Model 2 we introduce the sibling fixed effect α_j, and remove the control for sibling group size as that is adjusted for in the fixed effect approach. We use the sample analysis sample for Model 2 as that used in Model 1. We regard Model 2 as an improvement on Model 1 as the sibling comparison approach that we use in Model 2 minimises residual confounding from unobserved factors that are shared by siblings.

We also examine whether the association between birth intervals and the perinatal outcomes that we study varies by birth cohort:

$$y_i = \beta_1 Cohort_i \times BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i + \beta_6 BirthYear_i + \alpha + \varepsilon_i \tag{3}$$

$$y_{ij} = \beta_1 Cohort_{ij} \times BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij} + \alpha_j + \varepsilon_{ij} \tag{4}$$

where *Cohort* refers to birth cohort grouped as follows: 1947–1959; 1960–1969; 1970–1979; 1980–1989; 1990–1999; 2000-2009; and, 2010–2016. In these models we also include a continuous term for birth year to adjust for any linear effect of birth year within the broader cohort groups.

Educational and Occupational Outcomes. To study the relationship between birth intervals and college degree attainment and occupational status we use linear regression, and linear regression with sibling fixed effects. Occupational status is a continuous variable, but college degree attainment is a binary variable, and for those analyses our models take the form of linear probability models:

$$y_i = \beta_1 BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i + \beta_6 BirthYear_i + \alpha + \varepsilon_i \tag{5}$$

$$y_{ij} = \beta_1 BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij} + \alpha_j + \varepsilon_{ij} \tag{6}$$

where y_{ij} is the outcome for individual i in sibling group j on college degree attainment, educational attainment in years, and occupational status. In Model 5 we use a regular linear regression, meaning a between-family comparison, to examine the relationship between BI_i, the length of the preceding birth interval, and control for biological sex, birth order, sibling group size, maternal age, birth year. BI_i is entered into the model as a series of 10 dummy variables based on 6-month categories for the length of the preceding birth interval. In Model 5 our analysis population is second and later-born children in sibling groups with at least three children, meaning that we exclude first-borns as they have no value for the length of the preceding interval. In Model 6 we introduce the sibling fixed effect α_j, and remove the control for sibling group size as that is adjusted for in the fixed effect approach. We use the sample analysis sample for Model 6 as that used in Model 5. We regard Model 6 as an improvement on Model 5 as the sibling comparison approach that we use in Model 6 minimises residual confounding from unobserved factors that are shared by siblings. To this end we are much better able to isolate the net effect of birth intervals on the multiple long-term outcomes that we study.

Adult Mortality. To study mortality, we use survival analysis in the form of Cox proportional hazard regressions (Cox, 1972). The proportional hazards model is expressed as:

$$h(t|X_1, ..., X_k) = h_0(t) \exp\left(\sum_{j=1}^{k} \beta_j X_j(t)\right) \tag{7}$$

where $h(t|X_1, ..., X_k)$ is the hazard rate for individuals with characteristics $X_1, ..., X_k$ at time t, $h_0(t)$ is the baseline hazard at time t, and β_j, $j = 1, ..., k$ are the estimated coefficients. Since the failure event in our analysis is the death of the individual, the baseline hazard of our model, $h_0(t)$, is age. Individuals are censored at death, or in 2016; whichever comes first. To estimate a sibling comparison model we used stratified Cox models (Allison, 2009), stratified by the shared sibling group ID. The stratified Cox model takes the following form, where the hazard for an individual from stratum s is:

$$h_s(t|X_1,...,X_k) = h_{0s}(t)\ \exp\left(\sum_{j=1}^{k} \beta_j X_j(t)\right) \tag{8}$$

where $h_{0s}(t)$ is the baseline hazard for stratum s, $s = 1,...,S$. Each stratum, s, is a sibling group. In the standard Cox proportional hazard regression the baseline hazard h_0 is common to all individuals in the analysis. In the stratified Cox model, above, we allow the baseline hazard to differ between strata, based upon the assumption that there are unobserved factors particular to each sibling group that may confound the relationship between birth intervals and mortality in adulthood (Allison, 2009, chapter 5). As with the fixed effects approach applied to linear regression, these stratified Cox models adjust for all time-invariant factors that are shared by siblings. We estimate the following models:

$$\log h(t) = \beta_1 BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 MatAge_i + \beta_5 BirthYear_i + \beta_6 Size_i \tag{9}$$

$$\log h(t) = \beta_1 BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij} + \alpha_j \tag{10}$$

where $\log h_i(t)$ is the log hazard of mortality, α_j is the fixed effect for sibling group j, and the index ij refers to the individual i in sibling group j. As with the linear regression analyses, BI_i is entered into the model as a series of 10 dummy variables based on 6-month categories for the length of the preceding birth interval. In Model 9 our analysis population is second and later-born children in sibling groups with at least three children, meaning that we exclude first-borns as they have no value for the length of the preceding interval. In Model 10 we introduce the sibling fixed effect α_j, and remove the control for sibling group size as that is implicitly adjusted for. We use the same analysis sample for Model 10 as that used in Model 9. We regard Model 10 as an improvement on Model 9 as the stratified approach that we use in Model 10 minimises residual confounding from unobserved factors that are shared by siblings.

RESULTS

Descriptives. Table 2 shows descriptive statistics for the outcome and covariates by categories of the length of the preceding birth interval for each of the five outcomes that we study: low birth weight, preterm birth, college graduation, occupational status, and mortality.

TABLE 1. Descriptive statistics: length of the preceding birth interval in relation to low birth weight, preterm birth, and infant mortality.

			Preceding Birth Interval										
			9-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	60+	Everyone
Low Birth Weight	N		19,748	117,779	174,336	156,811	121,205	82,418	58,072	38,913	27,619	73,279	870,180
	LBW	Mean	0.12	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.04
	Female	Mean	0.49	0.49	0.49	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49
	Birth order	Mean	3.22	3.43	3.47	3.44	3.47	3.53	3.61	3.67	3.72	3.80	3.51
	Family size	Mean	5.20	5.34	5.08	4.79	4.59	4.49	4.45	4.41	4.38	4.31	4.78
	Maternal age	Mean	24.55	26.06	27.29	28.02	28.66	29.24	29.84	30.44	31.00	32.91	28.47
	Birth year	Mean	1976.29	1979.65	1985.58	1988.26	1988.64	1988.34	1987.40	1986.88	1986.22	1985.62	1985.94
Preterm Birth	N		19,748	117,779	174,336	156,811	121,205	82,418	58,072	38,913	27,619	73,279	870,180
	Preterm birth	Mean	0.15	0.07	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.06
	Female	Mean	0.49	0.49	0.49	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49
	Birth order	Mean	3.22	3.43	3.47	3.44	3.47	3.53	3.61	3.67	3.72	3.80	3.51
	Family size	Mean	5.20	5.34	5.08	4.79	4.59	4.49	4.45	4.41	4.38	4.31	4.78
	Maternal age	Mean	24.55	26.06	27.29	28.02	28.66	29.24	29.84	30.44	31.00	32.91	28.47
	Birth year	Mean	1976.29	1979.65	1985.58	1988.26	1988.64	1988.34	1987.40	1986.88	1986.22	1985.62	1985.94
Infant Mortality	N		22,472	130,044	186,893	166,494	128,779	87,882	62,440	42,246	30,240	85,874	943,364
	Infant mortality	Mean	0.033	0.014	0.009	0.008	0.008	0.008	0.009	0.009	0.009	0.011	0.010
	Female	Mean	.48	.49	.49	.48	.49	.49	.49	.49	.49	.49	.49
	Birth order	Mean	3.21	3.43	3.48	3.45	3.47	3.54	3.62	3.69	3.74	3.83	3.53
	Family size	Mean	5.18	5.35	5.09	4.80	4.60	4.51	4.46	4.42	4.39	4.31	4.79
	Maternal age	Mean	24.51	26.03	27.25	27.99	28.62	29.22	29.82	30.43	31.00	33.12	28.48
	Birth year	Mean	1975.36	1978.64	1984.42	1987.06	1987.34	1986.93	1985.78	1985.06	1984.16	1981.87	1984.38

TABLE 2. Descriptive statistics: length of the preceding birth interval in relation to college graduation, occupational status, and mortality.

			Preceding Birth Interval										
			9-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	60+	Everyone
College Degree	N		9,078	49,188	54,697	41,821	31,260	21,545	15,892	11,162	8,362	26,258	269,263
	Degree	Mean	0.23	0.29	0.32	0.32	0.32	0.31	0.30	0.29	0.29	0.28	0.30
	Female	Mean	0.50	0.50	0.50	0.49	0.49	0.49	0.50	0.49	0.50	0.50	0.50
	Birth order	Mean	3.27	3.55	3.64	3.68	3.73	3.83	3.92	3.99	4.07	4.14	3.74
	Family size	Mean	5.70	5.91	5.70	5.44	5.20	5.08	5.00	4.92	4.87	4.70	5.40
	Maternal age	Mean	24.17	25.50	26.55	27.26	27.97	28.72	29.51	30.18	30.91	33.34	27.85
	Birth year	Mean	1963.97	1965.17	1966.32	1966.37	1965.97	1965.52	1964.87	1964.73	1964.48	1963.97	1965.49
Occupational Status	N		5,509	29,245	32,020	24,406	18,245	12,849	9,583	6,720	5,115	15,688	159,380
(Nam-Powers-Boyd Score)	NPBOSS	Mean	52.89	55.08	56.17	56.30	56.49	56.55	56.42	56.42	56.27	55.83	55.94
	Female	Mean	0.42	0.43	0.43	0.43	0.43	0.43	0.43	0.42	0.44	0.43	0.43
	Birth order	Mean	3.26	3.55	3.64	3.69	3.74	3.84	3.92	3.99	4.10	4.14	3.74
	Family size	Mean	5.71	5.95	5.73	5.46	5.22	5.12	5.03	4.95	4.88	4.69	5.41
	Maternal age	Mean	24.15	25.43	26.42	27.19	27.89	28.67	29.44	30.13	30.95	33.36	27.80
	Birth year	Mean	1963.21	1964.22	1965.09	1965.18	1964.83	1964.41	1963.99	1963.82	1963.50	1963.12	1964.43
Mortality	Person-months	%	1.76	13.49	22.43	18.86	11.75	7.84	5.79	4.20	3.24	10.64	100.00
	Deaths	N	2,272	17,906	32,790	28,358	16,292	10,000	7,073	4,961	3,603	10,859	134,114
	Mortality	Rate (10-4)	7.78	7.98	8.79	9.04	8.34	7.67	7.35	7.09	6.69	6.14	8.06
	Female	Mean	.49	.49	.50	.49	.49	.49	.48	.49	.50	.49	.49
	Birth order	Mean	3.67	3.78	4.17	4.50	4.40	4.33	4.29	4.27	4.22	4.23	4.23
	Family size	Mean	6.75	6.77	6.99	6.90	6.32	5.90	5.62	5.46	5.24	4.88	6.34
	Maternal age	Mean	25.71	26.55	27.77	29.14	29.88	30.47	31.06	31.48	31.96	34.17	29.47
	Birth year	Mean	1929.81	1928.50	1925.94	1925.49	1927.92	1929.97	1931.35	1932.24	1933.05	1935.07	1928.64

Approximately 4% of all births in the cohorts that we study were low birth weight, and 6% preterm. The clearest pattern by birth intervals is the much higher proportion of those born after 9-12 months who were LBW or preterm – 12% and 15% respectively. Otherwise we see that those born after intervals of 13-18 months, or longer than 60 months, are slightly overrepresented amongst those born LBW or preterm. Likewise, we see that those born 9-12 months after the preceding sibling have a much higher probability of infant mortality – 0.033 – than those born after intervals longer than 18 months, whose probability of dying in the first 12 months of life ranges between 0.008 and 0.011. In our analytical sample, approximately 30% had a college degree. Amongst those born after 9-12 months, however, only 23% had a degree. Amongst those born after intervals of 13-18 months, and longer than 49 months, slightly less than 30% had a college degree. The mean occupational status on the Nam-Powers-Boyd scale was 55.9 in our analytical sample. The only really noticeable deviation away from this mean is found amongst those born after intervals of 9-12 months, who had a score of 52.9. Finally, the descriptives from the mortality analysis sample show that unconditional mortality rates in our sample were actually highest amongst those born after an interval of 25-30 months, and lower amongst those born after very birth interval up to 18 months, and even lower amongst those born after intervals longer than 55 months. The bivariate pattern in the mortality data is therefore distinctive from the patterns observed in the other sample groups.

Low Birth Weight. The results from analyses examining the relationship between the length of preceding birth intervals and the probability of low birth weight can be seen in Figure 2. Figure 2 shows the results from four models: a pooled analysis, with and without sibling fixed effects, and the results from a model where birth intervals have been interacted with birth cohort, again with and without sibling fixed effects. The pooled analyses, in the bottom-right octant, show that the shortest preceding birth intervals are associated with a higher probability of LBW in both the within- and between-family comparisons. In the within-family model, children born after a birth interval of 9-12 months were estimated to have a 0.056 higher probability of LBW relative to children born after a birth intervals of 25-30 months. The baseline probability of LBW in the analytical sample across these cohorts is 0.044, meaning that the relative probability of LBW is more than twice as high for children born after an interval of only 9-12 months. Intervals of 13-18 months are associated with a much smaller elevated probability, a little over 0.01 higher than the reference category, or approximately 24% higher relative to the baseline. Intervals of 19–36 months lead to very similar outcomes. Where the results from the between- and within-family analyses clearly diverge is for children born after intervals longer than 37 months; in the between-family comparison, longer intervals are associated with an increased probability of LBW, while the within-family comparisons indicate a protective effect of longer birth intervals.

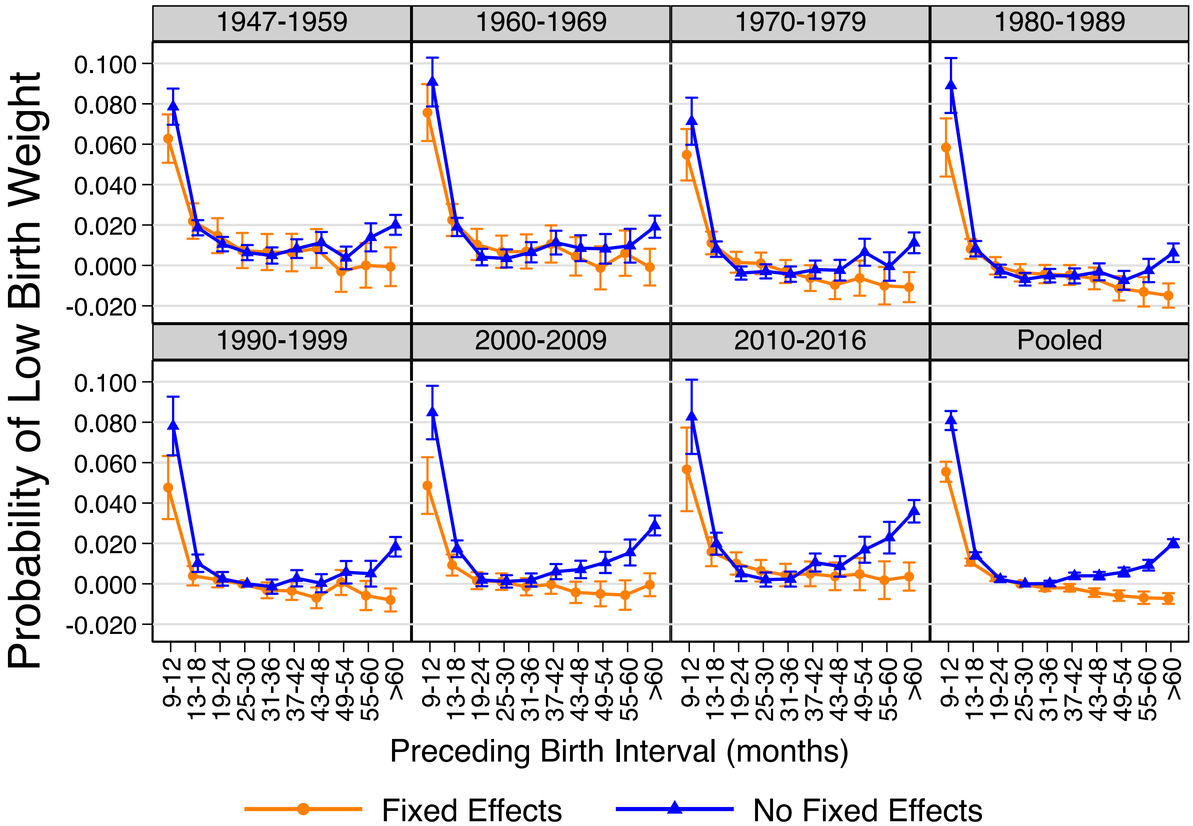

FIGURE 2. The relationship between the length of the preceding birth interval and probability of low birth weight, sibling groups with at least 3 children born in Utah 1947-2016, by birth cohort group. Results from linear probability models applying sibling fixed effects.

The results from the models interacting birth intervals by birth cohort are share a common reference category – children born after 25–30 months in 1990–1999. The results from these analyses show that birth intervals of only 9-12 months are associated with a very substantially higher probability of LBW regardless of birth cohort, and there are few clear divergences from the patterns shown in the pooled analyses. It might be noted that the higher probability of LBW seen in the between-family analyses is perhaps most evident from 2000 onwards. Full tables of results can be seen in Supplementary Tables S1 and S2.

Preterm Birth. Figure 3 shows the results from models examining the link between the probability of preterm birth and birth intervals. Full tables of results can be seen in Supplementary Tables S3 and S4. Figure 3 also shows the results from four models, parallel to those shown in Figure 2. The results in the bottom-right octant from the pooled analysis show that birth

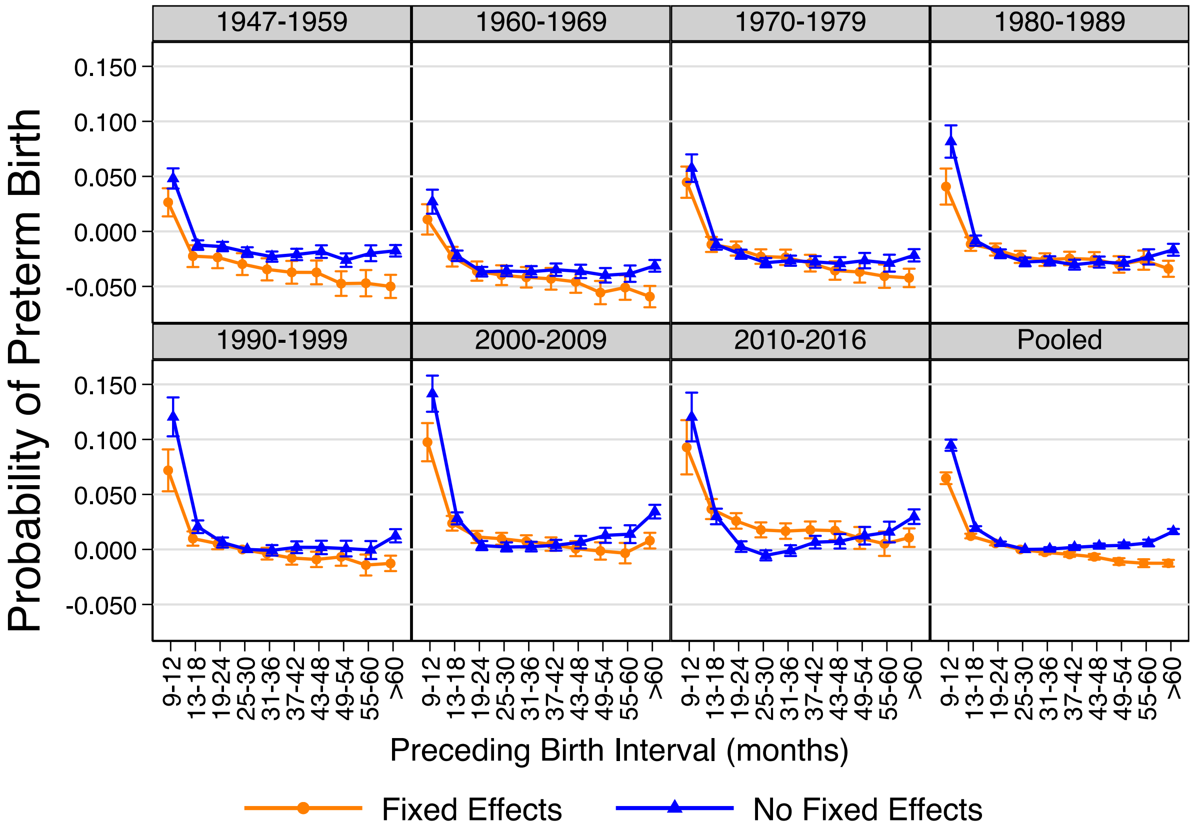

FIGURE 3. The relationship between the length of the preceding birth interval and probability of preterm birth, sibling groups with at least 3 children born in Utah 1947-2016, pooled and by birth cohort group.

intervals of 9-12 months are associated with a substantially higher probability of preterm birth – estimated to be 0.064 in the within-family comparison, and 0.096 in the between-family comparison. The baseline probability of preterm birth across these cohorts was 0.062. Children born after an interval of 13-18 months had an elevated probability of 0.012 in the within-family comparison, and 0.020 in the between-family comparison, of being born preterm. In the between-family comparisons intervals between 19 and 60 months were associated with similar probabilities of preterm birth, while intervals longer than 5 years were associated with an increased probability of preterm birth. However, in the within-family comparison, longer birth intervals were associated with a lower probability of preterm birth. The protective effect of longer birth intervals can be seen across all birth cohorts in the within-family comparisons.

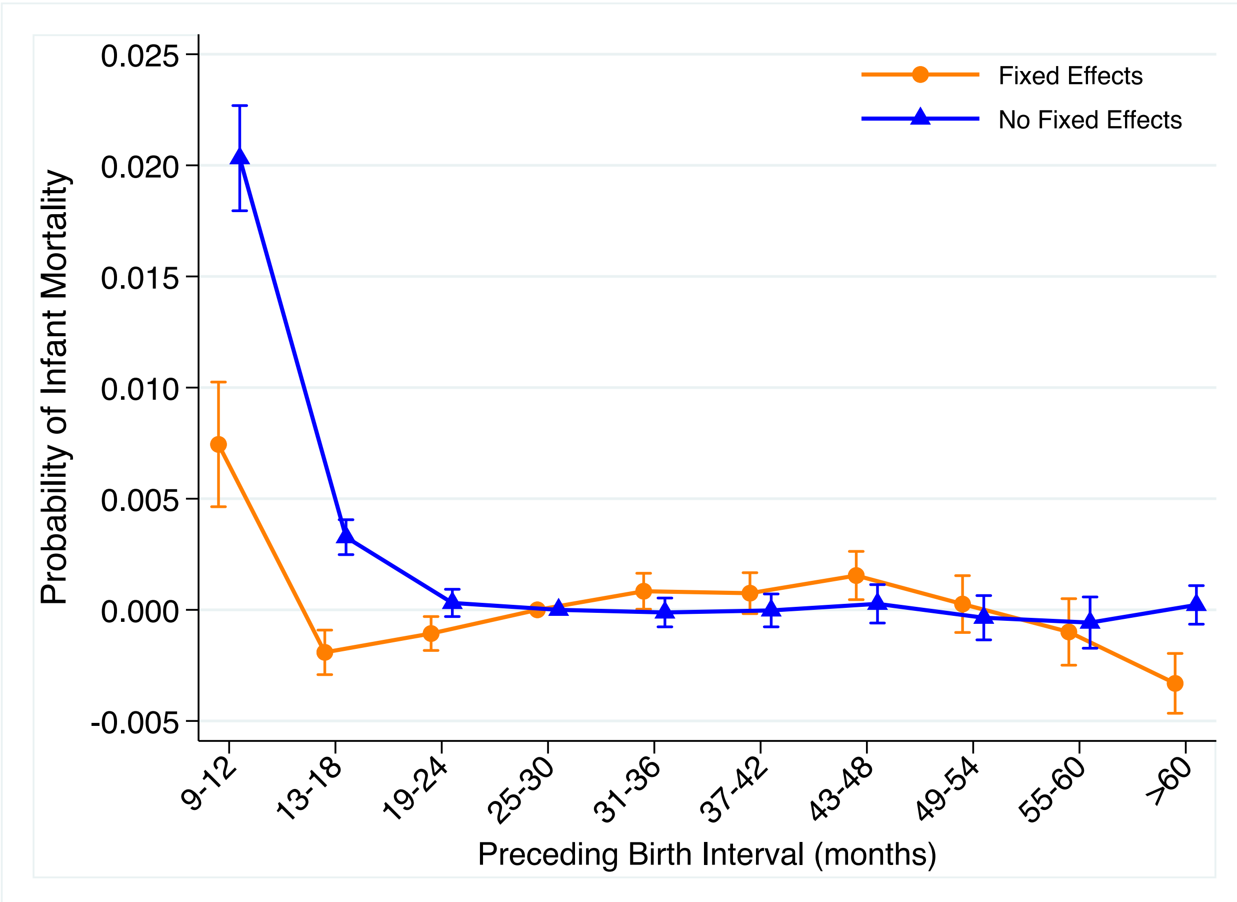

FIGURE 4. The relationship between the length of the preceding birth interval and probability of infant mortality, sibling groups with at least 3 children born in Utah 1947-2016.

Infant Mortality. The results for infant mortality can be seen in Figure 4. Due to the relative infrequency of this outcome, we focus on the pooled results rather than also presenting the interaction by birth cohort. The results from the analysis without a sibling comparison shows that birth intervals shorter than 19 months are associated with a higher probability of mortality in the first 12 months of life, and this is particularly clear for intervals of 9-12 months, which, consistent with the pattern shown in the descriptives, have a probability approximately 2 percentage points higher than the reference category to experience infant mortality. In the between-family comparison there is no discernible meaningful variation in outcomes for children born after intervals longer than 18 months. The results from the sibling comparison models also point towards a higher probability of mortality for infants born after an interval of 9-12 months, but surprisingly also indicate that there is a lower probability of mortality for infants born after

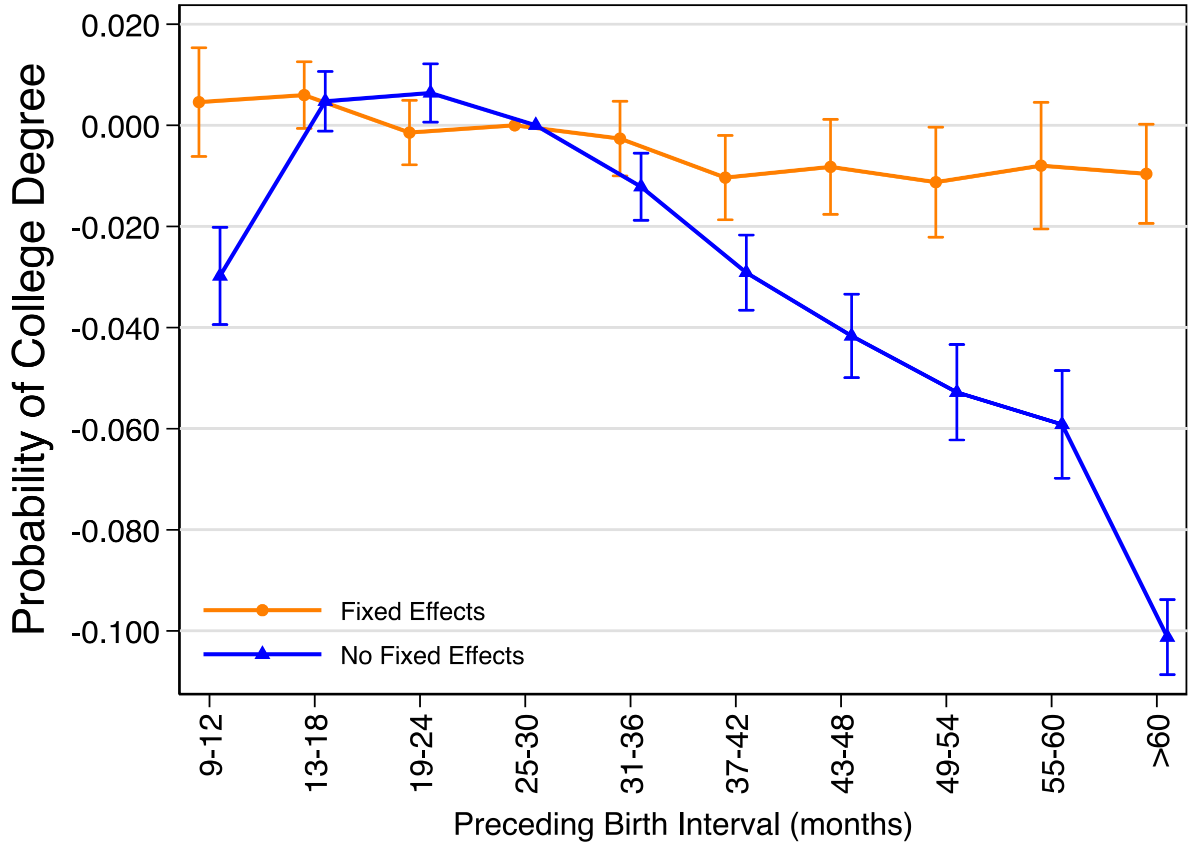

FIGURE 5. The relationship between the length of the preceding birth interval and probability of college graduation at time of latest childbearing, sibling groups with at least 3 children born in Utah 1950-1980.

intervals of 13-24 months, or longer than 60 months. A full table of results can be seen in Supplementary Table S5.

College Graduation. We now turn to several longer-term outcomes. Figure 5 shows the results from models that examine the relationship between the length of the preceding birth interval and the probability of attaining a college degree. The baseline probability of graduating from college for these cohorts, born 1950–1980, was 0.304. The results from the between-family comparisons show an inverted J-curve, where men and women born after birth intervals of 9-12 months, or longer than 31 months, have a lower probability of graduating from college than those born after intervals of 25-30 months. Relative to the baseline probability, the relative difference for those born after 9-12 months is approximately 10% lower, and for those born after an interval of 5 years or longer it is approximately a third lower. However, the results from the sibling fixed effects analysis show no substantial, and only one statistically significant,

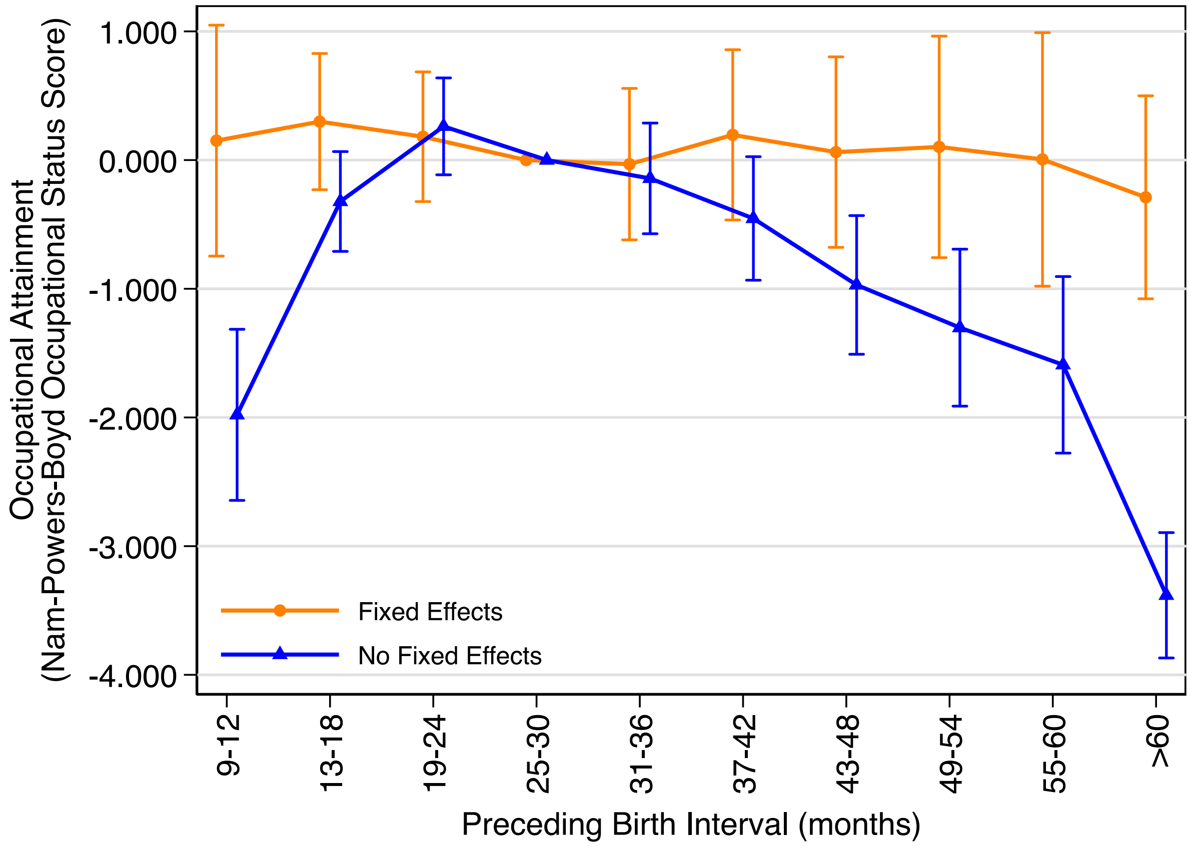

FIGURE 6. The relationship between the length of the preceding birth interval and occupational status measured at time of latest childbearing, sibling groups with at least 3 children born in Utah 1950-1980.

differences from the reference category. Even if we relied only on the point estimates, the within-family comparison would suggest that the largest difference in the probability of college graduation by birth intervals would be only approximately 3% relative to the baseline. The results from the within-family comparison models strongly support the conclusion that birth intervals do not matter for the probability of college graduation in Utah, with the possibility that intervals longer than 36 months are mildly protective. A full table of results can be seen in Supplementary Table S6.

Occupational Status. The results for occupational status are shown in Figure 6. A full table of results can be seen in Supplementary Table S7. As was seen in Figure 5, the results from the between-family analysis show a clear pattern where those born after very short birth intervals, or longer intervals (here 43 months or longer), are disadvantaged in terms of occupational status attainment. The mean score on the Nam-Powers-Boyd scale in our analytical sample is 56, and

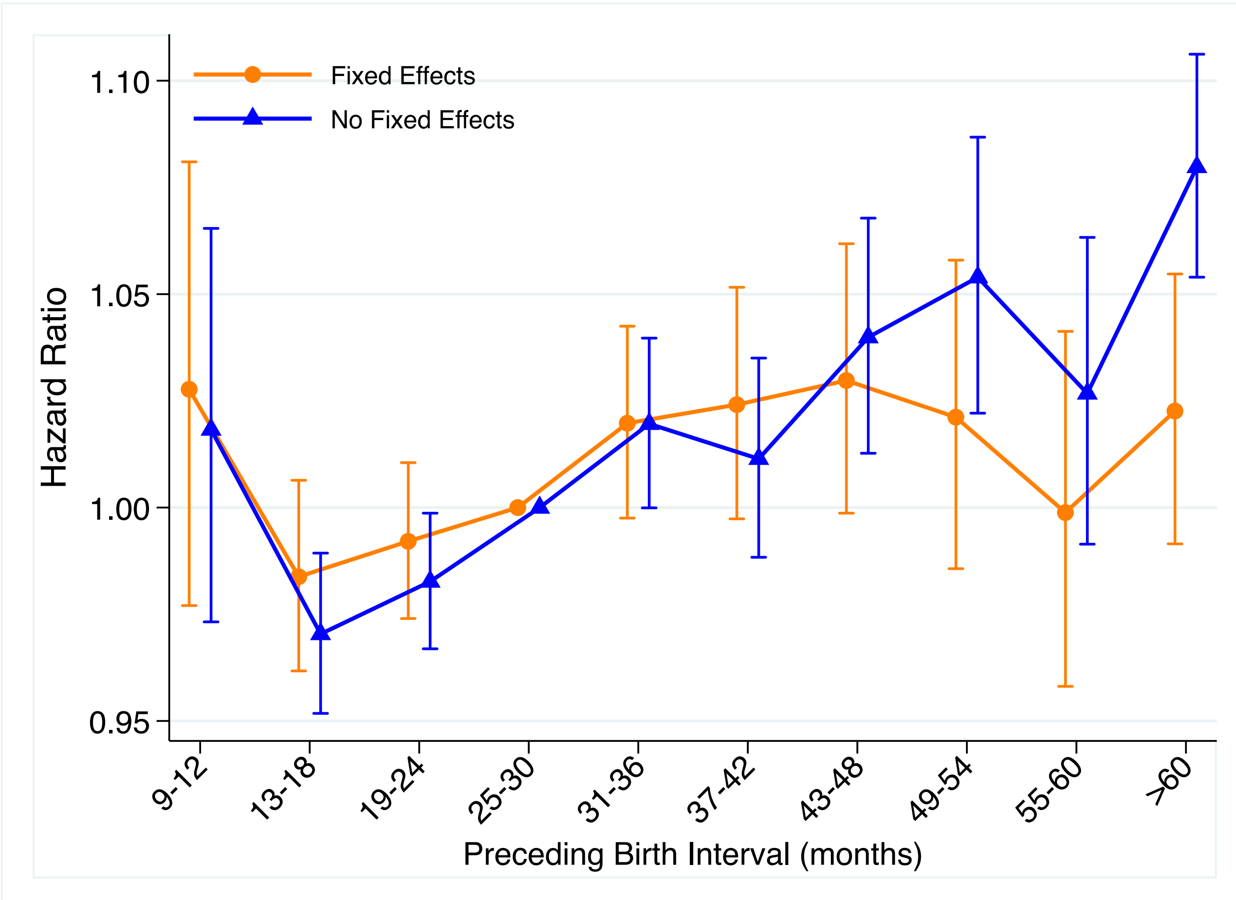

FIGURE 7. The relationship between the length of the preceding birth interval and hazard of mortality in sibling groups with at least 3 children born in Utah 1900–1956, pooled and by birth cohort group.

the standard deviation is 23. Even in the between-family analysis, the relative disadvantage of children born after very short or very long birth intervals appears to be small – less than 10% of one standard deviation for children born after an interval of 9-12 months, and a little over 10% of a standard deviation for children born after an interval of longer than 5 years. However, in the within-family comparison, there are neither any substantially nor statistically significant differences in occupational status attainment by the length of the preceding birth interval.

Adult Mortality. Finally, Figure S1 shows the results for the relationship between birth intervals and adult mortality above age 18. A full table of results can be seen in Supplementary Table S8. All of our sample were followed until at least age 67, and the oldest birth cohort, born in 1900, would be extinct by the end of our follow-up period in 2016. The results in Figure S1 do not point to a clear relationship between birth intervals and adult mortality in either the between- or within-family comparison. There is some suggestion that longer birth intervals are associated with higher mortality in the between-family model, particularly amongst those born after intervals of longer than 5 years; in this case the rate of mortality is 8% higher than that seen amongst those born after intervals of 25-30 months. However, in the within-family comparison the point estimates are both smaller, and non-statistically significant.

Additional Analyses. We have also conducted a number of additional analyses, for instance to examine whether there are significant gender differences in the association between birth intervals and the five outcomes that we have studied. We did not observe any significant gender differences. We also examined whether there were differences by maternal education, but there were no significant differences in our sibling comparison models. To check whether patterns of mortality might be observable at earlier adult ages, we examined mortality between ages 18 and 40, and these results can be seen in Supplementary Figure S1. Mortality between 18-40 does not seem to vary meaningfully by the length of inter-birth intervals, though there is an indication that intervals longer than 5 years may be protective in the sibling comparison analyses.

Discussion

This study adds to a growing literature examining the relationship between birth spacing and offspring outcomes. We both contribute towards a relatively large literature examining how birth spacing is associated with perinatal outcomes in contemporary high-income settings, as well as to a much smaller literature examining how birth spacing may be associated with long-term outcomes. We find evidence that children born after very short birth intervals of 9-12 months have a higher probability of being born LBW or preterm in Utah, even in the 2010s. Children born after intervals of 13-18 months are also at risk, but to a much lesser extent. Unlike a number of recent studies, we find that short intervals are still associated with the probability of LBW and preterm even after comparing siblings born to the same parents (c.f. Ball et al., 2014; Hanley et al., 2017). Although the relative negative impact of being born after a birth interval of 13-18 months is smaller than being born after an interval 9-12 months, the population health impact may be comparable, given that the proportion of children born after an interval of 13-18 months is more than four times as large as the proportion of children born after an interval of 9-12 months. We also find evidence that longer birth intervals are protective against the risk of being born preterm or with LBW, even beyond the interpregnancy intervals recommended by the American College of Obstetricians and Gynecologists (ACOG) and the World Health Organization.

Our analyses of infant mortality also show that very short birth intervals increase the probability of negative outcomes. However, we observe some discrepancies between the estimates for the between-family comparisons and the within-family comparisons, where the between-family comparisons show no meaningful variation amongst birth intervals longer than 18 months, while the fixed effect analyses actually indicate a protective effect of birth intervals of 13-24 months. The point estimates in fixed effects analyses are driven by the families in which there is variance in the exposure, meaning that families that experience only one infant death do not contribute to these estimates. Families that experience multiple infant deaths are strongly selected, and this is particularly true in a low-mortality context. Recent research has also highlighted the possibility that offspring deaths change the fertility behavior of parents, meaning that the length of the birth interval itself is influenced by the death of the preceding sibling; when the outcome for one sibling influences the exposure for another, sibling fixed effects models may be biased (Sjölander et al., 2016; Kravdal, 2020). This is particularly likely for infant mortality, but may also be true for our analyses of LBW and preterm, and is an important limitation of the sibling comparison analyses. We would suggest particular caution in the interpretation of the within-family comparison results for infant mortality.

This study is one of only a handful that have examined the relationship between birth intervals and long-term outcomes or health outcomes. The results from this study are consistent with the most recent literature that has compared siblings born to the same parents to examine how birth intervals are associated with socioeconomic attainment. Previous studies using a sibling fixed effects analysis and data from Sweden, Germany, and the U.S. have reported that neither short- nor long-intervals make a difference to long-term outcomes once unobserved factors that are likely to be correlated with both the timing and spacing of births as well as educational and occupational attainment are held constant (Nguyen, 2014; Barclay and Kolk, 2017; Grätz, 2018). Our results are also consistent with those reported in a previous study using miscarriage as an instrument for birth spacing in the United States, which did not report any negative effect of short birth spacing on the test scores of the younger sibling of a sibling pair (Buckles and Munnich, 2012). Finally, the results from our analyses of long-term mortality, showing that birth spacing is inconsequential are also consistent with previous work conducted using Swedish population data (Barclay and Kolk, 2018).

An interesting inconsistency in our findings is the fact that short birth intervals are associated with an increased probability of preterm birth and LBW, but not with any long-term disadvantage in terms of educational or occupational attainment, despite the fact that both preterm birth and LBW have been shown to be associated with long-term socioeconomic and health disadvantages (Behrman and Rosenzweig, 2004; Black et al., 2007; D'Onofrio et al., 2013; Petrou et al., 2001). Furthermore, we observe this inconsistency despite the fact that we are able to observe the same birth cohorts for both our analyses of perinatal outcomes as well as the long-term educational and socioeconomic outcomes. One potential explanation for this discrepancy is that not all children born preterm have worse long-term outcomes. Recent research suggests that it is actually mainly children born extremely preterm ($<$ 28 weeks) who suffer long-term educational disadvantages (Baranowska-Rataj et al., 2019), which may be explained by foetal brain development trajectories by gestational age (Kinney et al., 1988; Kuban et al., 1999); however, children born very preterm, or moderately preterm, do not seem to suffer long-term educational disadvantages (Baranowska-Rataj et al., 2019). Since the proportion of those born extremely preterm is only a small fraction of the total number of preterm births, this may be part of the explanation for why there can be an association between birth intervals and preterm birth, but not birth intervals and educational and occupational attainment. It may also be the case that parents seek to compensate for potential disadvantage by investing to a greater extent in children born with worse perinatal outcomes, reducing variation in longer-term outcomes.

It is also possible that the discrepancy between the results for LBW and preterm and the long-term outcomes is explained by positive selection. As the results from our analyses of infant mortality show, children born after the very shortest intervals have a significantly higher probability of dying in the first 12 months of life. This indicates that some of the children most negatively affected by short birth intervals do not survive to be included in our analytical sample of long-term outcomes, which would reduce the potential for an association between short intervals and relatively worse long-term outcomes.

Another potential explanation for the discrepancy between the results for perinatal and long-term outcomes is the fact that we only observe educational and socioeconomic attainment outcomes for men and women who become parents themselves. Between 1976 and 2012, childlessness amongst women aged 40-44 in the United States ranged between approximately 10% and 20% (Frejka, 2017). In 2012 childlessness by the end of the childbearing years amongst women in the United States was around 15%, though it was lower in Utah. Childlessness is higher amongst men, at around 20% across the U.S. (Monte and Knop, 2019). However, even if childlessness means that we only lose information on the educational and occupational attainment of 10% of each cohort, this is problematic because childlessness is correlated with socioeconomic and health disadvantages (Jokela et al., 2008; Waren and Pals, 2013; Barclay and Kolk, 2020). As a result, we may miss information on a more disadvantaged section of the population, and subsequently underestimate the negative effects of very short, or very long, birth intervals on educational and socioeconomic outcomes. Although this concern is certainly reasonable, the results from our between-family analyses examining college graduation and occupational status do indicate a J-shaped pattern where those born after short or longer intervals have worse outcomes, meaning that the selection into the sample does not wipe out the association between birth spacing and long-term outcomes; however, our sibling comparison models, which adjust for unobserved factors that remain constant within the family, indicate that birth spacing does not matter after this adjustment, and this is very clearly consistent with previous work on this topic.

Another limitation of our research design is that we study the impact of birth spacing on a variety of different outcomes using data from families with at least three children. This approach, common in the literature using sibling fixed effects to study birth intervals, was necessary in order to implement our sibling comparison design, as a sibling group with two children does not have any variance on the length of the birth interval, and cannot be exploited for an analysis of the impact of birth intervals (Hutcheon and Harper, 2019). This means that we exclude both children without any siblings, as well as children raised in two-child sibling groups, which are amongst the most common family sizes, though Utah does have unusually high rates of fertility. Although this potential limits the generalisability of our findings, it is important to note that one-child sibling groups do not have a birth interval to study, and that a high proportion of all measurable birth intervals occur in sibling groups with three or more children, for the simple reason that there are twice as many birth intervals in a three-child sibling group as a two-child group, three times as many in a four-child sibling group, and so on. Given the hypothesised mechanisms by which short intervals should lead to worse outcomes, we would also expect the consequences of multiple short intervals to be worse in larger sibling groups than in a two-child sibling group, as multiple short intervals in larger sibling groups would further exacerbate factors such as maternal nutrient depletion, or resource dilution amongst siblings at pivotal young ages.

Despite some limitations, we argue that this study is an important contribution to the literature in several respects. This is the first study using population data, albeit at the state-level, from the United States to examine long-term offspring outcomes in relation to birth spacing, and the results from our analyses allow us to conclude that in a country with a much weaker welfare state system than Sweden or even Germany, extremely short birth intervals have no consequences for long-term offspring educational, socioeconomic, or mortality outcomes. Second, this study adds to the weight of evidence that shows that, in contrast to the results for long-term outcomes, short birth intervals do have consequence for the risk of LBW and preterm birth in contemporary high-income populations. However, our results also support the theory that longer birth intervals are protective against poor perinatal outcomes, despite some recommendations that potential mothers should try to avoid birth intervals longer than 5 years. Furthermore, a potential silver lining to our finding that short birth intervals predict worse perinatal outcomes is that, amongst those same cohorts, we do not observe any negative long-term consequences in the outcomes that we study, which may supply some optimism to the fact that very short birth intervals are associated with worse perinatal outcomes even in the 2010s.

REFERENCES

ACOG (2019). Obstetric care consensus no. 8 summary: Interpregnancy care. *Obstetrics & Gynecology 133*(1), 220–225.

Ahrens, K. A., J. A. Hutcheon, C. V. Ananth, O. Basso, P. A. Briss, C. D. Ferré, B. N. Frederiksen, S. Harper, S. Hernández-Díaz, A. H. Hirai, et al. (2019). Report of the office of population affairs' expert work group meeting on short birth spacing and adverse pregnancy outcomes: Methodological quality of existing studies and future directions for research. *Paediatric and Perinatal Epidemiology 33*(1), O5–O14.

Ahrens, K. A., H. Nelson, R. L. Stidd, S. Moskosky, and J. A. Hutcheon (2019). Short interpregnancy intervals and adverse perinatal outcomes in high-resource settings: an updated systematic review. *Paediatric and Perinatal Epidemiology 33*(1), O25–O47.

Allison, P. D. (2009). *Fixed Effects Regression Models, Vol. 160.* SAGE Publications.

Andersen, A.-M. N., J. Wohlfahrt, P. Christens, J. Olsen, and M. Melbye (2000). Maternal age and fetal loss: population based register linkage study. *BMJ 320*(7251), 1708–1712.

Ball, S. J., G. Pereira, P. Jacoby, N. de Klerk, and F. J. Stanley (2014). Re-evaluation of link between interpregnancy interval and adverse birth outcomes: retrospective cohort study matching two intervals per mother. *BMJ 349*, g4333.

Baranowska-Rataj, A., K. Barclay, J. Costa-Font, M. Myrskylä, and B. Özcan (2019). Preterm births and educational disadvantage: Heterogeneous effects across families and schools. *Max Planck Institute for Demographic Research Working Paper WP-2019-016*, 1–37.

Barclay, K., A. Baranowska-Rataj, M. Kolk, and A. Ivarsson (2020). Interpregnancy intervals and perinatal and child health in Sweden: a comparison within families and across social groups. *Population Studies 74*(3), 363–378.

Barclay, K. and M. Kolk (2020). The influence of health in early adulthood on male fertility. *Population and Development Review*.

Barclay, K. J. and M. Kolk (2017). The long-term cognitive and socioeconomic consequences of birth intervals: A within-family sibling comparison using Swedish register data. *Demography 54*(2), 459–484.

Barclay, K. J. and M. Kolk (2018). Birth intervals and health in adulthood: a comparison of siblings using Swedish register data. *Demography 55*(3), 929–955.

Bean, L. L., G. P. Mineau, and D. L. Anderton (1992). High-risk childbearing: fertility and infant mortality on the American frontier. *Social Science History 16*(3), 337–363.

Behrman, J. R. and M. R. Rosenzweig (2004). Returns to birthweight. *Review of Economics and Statistics 86*(2), 586–601.

Black, S. E., P. J. Devereux, and K. G. Salvanes (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. *Quarterly Journal of Economics 122*(1), 409–439.

Blake, J. (1989). *Family Size & Achievement*, Volume 3. Berkeley: University of California Press.

Buckles, K. S. and E. L. Munnich (2012). Birth spacing and sibling outcomes. *Journal of Human Resources 47*(3), 613–642.

Class, Q. A., M. E. Rickert, A. S. Oberg, A. C. Sujan, C. Almqvist, H. Larsson, P. Lichtenstein, and B. D'Onofrio (2017). Within-family analysis of interpregnancy interval and adverse birth outcomes. *Obstetrics and Gynecology 130*(6), 1304–1311.

Conde-Agudelo, A., A. Rosas-Bermudez, F. Castaño, and M. H. Norton (2012). Effects of birth spacing on maternal, perinatal, infant, and child health: a systematic review of causal mechanisms. *Studies in Family Planning 43*(2), 93–114.

Conde-Agudelo, A., A. Rosas-Bermúdez, and A. C. Kafury-Goeta (2006). Birth spacing and risk of adverse perinatal outcomes: a meta-analysis. *JAMA 295*(15), 1809–1823.

Conley, D. and N. G. Bennett (2000). Is biology destiny? Birth weight and life chances. *American Sociological Review 65*(3), 458–467.

Cox, D. R. (1972). Regression models and life-tables. *Journal of the Royal Statistical Society, Series B 34*(2), 187–220.

Cunha, F., J. J. Heckman, L. Lochner, and D. V. Masterov (2006). Interpreting the evidence on life cycle skill formation. In E. Hanushek and F. Welch (Eds.), *Handbook of the Economics of Education*, pp. 697–812. Elsevier.

Dandes, H. M. and D. Dow (1969). Relation of intelligence to family size and density. *Child Development 40*(2), 641–645.

D'Onofrio, B. M., Q. A. Class, M. E. Rickert, H. Larsson, N. Långström, and P. Lichtenstein (2013). Preterm birth and mortality and morbidity: a population-based quasi-experimental study. *JAMA Psychiatry 70*(11), 1231–1240.

Finlay, J. E., E. Özaltin, and D. Canning (2011). The association of maternal age with infant mortality, child anthropometric failure, diarrhoea and anaemia for first births: evidence from 55 low-and middle-income countries. *BMJ Open 1*(2), e000226.

Frejka, T. (2017). Childlessness in the united states. In *Childlessness in Europe: Contexts, causes, and consequences*, pp. 159–179. Springer, Cham.

Gebremedhin, A. T., A. K. Regan, S. Ball, A. P. Betrán, D. Foo, M. Gissler, S. E. Håberg, E. Malacova, M. L. Marinovich, and G. Pereira (2020). Interpregnancy interval and hypertensive disorders of pregnancy: A population-based cohort study. *Paediatric and Perinatal Epidemiology*.

Gemmill, A. and L. D. Lindberg (2013). Short interpregnancy intervals in the united states. *Obstetrics & Gynecology 122*(1), 64.

Grätz, M. (2018). Competition in the family: Inequality between siblings and the intergenerational transmission of educational advantage. *Sociological Science 5*, 246–269.

Hanley, G. E., J. A. Hutcheon, B. A. Kinniburgh, and L. Lee (2017). Interpregnancy interval and adverse pregnancy outcomes: An analysis of successive pregnancies. *Obstetrics & Gynecology 129*(3), 408–415.

Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. *Science 312*(5782), 1900–1902.

Hutcheon, J. A. and S. Harper (2019). Invited commentary: promise and pitfalls of the sibling comparison design in studies of optimal birth spacing. *American Journal of Epidemiology 188*(1), 17–21.

Jokela, M., M. Elovainio, and M. Kivimäki (2008). Lower fertility associated with obesity and underweight: the us national longitudinal survey of youth. *American Journal of Clinical Nutrition 88*(4), 886–893.

King, J. C. (2003). The risk of maternal nutritional depletion and poor outcomes increases in early or closely spaced pregnancies. *The Journal of Nutrition 133*(5), 1732S–1736S.

Kinney, H. C., B. A. Brody, A. S. Kloman, and F. H. Gilles (1988). Sequence of central nervous system myelination in human infancy: Ii. patterns of myelination in autopsied infants. *Journal of Neuropathology & Experimental Neurology 47*(3), 217–234.

Klebanoff, M. A. (2017). Interpregnancy interval and pregnancy outcomes: Causal or not? *Obstetrics & Gynecology 129*(3), 405–407.

Koullali, B., E. I. Kamphuis, M. H. Hof, S. A. Robertson, E. Pajkrt, C. J. De Groot, B. W. Mol, and A. C. Ravelli (2017). The effect of interpregnancy interval on the recurrence rate of spontaneous preterm birth: a retrospective cohort study. *American Journal of Perinatology 34*(02), 174–182.

Kramer, M. S. (1987). Determinants of low birth weight: methodological assessment and meta-analysis. *Bulletin of the World Health Organization 65*(5), 663–737.

Kravdal, Ø. (2020). Are sibling models a suitable tool in analyses of how reproductive factors affect child mortality? *Demographic Research 42*, 777–798.

Kuban, K., U. Sanocka, A. Leviton, E. N. Allred, M. Pagano, O. Dammann, J. Share, D. Rosenfeld, M. Abiri, D. DiSalvo, et al. (1999). White matter disorders of prematurity: association with intraventricular hemorrhage and ventriculomegaly. *Journal of Pediatrics 134*(5), 539–546.

Lonhart, J. A., J. A. Mayo, A. M. Padula, P. H. Wise, D. K. Stevenson, and G. M. Shaw (2019). Short interpregnancy interval as a risk factor for preterm birth in non-Hispanic black and white women in California. *Journal of Perinatology 39*, 1175–1181.

Lynch, K. A. and J. B. Greenhouse (1994). Risk factors for infant mortality in nineteenth-century Sweden. *Population Studies 48*(1), 117–133.

Mayo, J. A., B. Z. Shachar, D. K. Stevenson, and G. M. Shaw (2017). Interpregnancy interval and adverse pregnancy outcomes: An analysis of successive pregnancies andinterpregnancy interval and pregnancy outcomes causal or not? *Obstetrics & Gynecology 130*(2), 463.

Molitoris, J. (2017). The effect of birth spacing on child mortality in Sweden, 1878–1926. *Population and Development Review 43*(1), 61–82.

Molitoris, J. (2018). Heterogeneous effects of birth spacing on neonatal mortality risks in Bangladesh. *Studies in Family Planning 49*(1), 3–21.

Molitoris, J., K. Barclay, and M. Kolk (2019). When and where birth spacing matters for child survival: An international comparison using the DHS. *Demography 56*(4), 1349–1370.

Monte, L. M. and B. Knop (2019). Men's fertility and fatherhood: 2014. *Current Population Reports* (P70-162).

Nam, C. B. and M. Boyd (2004). Occupational status in 2000; over a century of census-based measurement. *Population Research and Policy Review 23*(4), 327–358.

Nam, C. B. and M. G. Powers (1968). Changes in the relative status level of workers in the united states, 1950–60. *Social Forces 47*(2), 158–170.

Nguyen, N. T. H. (2014). *Family structure and outcomes in adolescence, young adulthood, and adulthood*. Ph. D. thesis, Department of Economics, Rutgers University, New Brunswick, NJ.

Paul, J. R. et al. (1971). *A history of poliomyelitis*. New Haven & London: Yale Univ, Press.

Peltola, V., M. Waris, R. Österback, P. Susi, O. Ruuskanen, and T. Hyypiä (2008). Rhinovirus transmission within families with children: incidence of symptomatic and asymptomatic infections. *Journal of Infectious Diseases 197*(3), 382–389.

Petrou, S., T. Sach, and L. Davidson (2001). The long-term costs of preterm birth and low birth weight: results of a systematic review. *Child 27*(2), 97–115.

Pettersson-Lidbom, P. and P. Skogman Thoursie (2009). Does child spacing affect children's outcomes? evidence from a swedish reform. *Institute for Labour Market Policy Evaluation (IFAU) Working Paper Series 7*, 1–67.

Pfouts, J. H. (1980). Birth order, age-spacing, iq differences, and family relations. *Journal of Marriage and the Family 42*(3), 517–531.

Powell, B. and L. C. Steelman (1990). Beyond sibship size: Sibling density, sex composition, and educational outcomes. *Social Forces 69*(1), 181–206.

Powell, B. and L. C. Steelman (1993). The educational benefits of being spaced out: Sibship density and educational progress. *American Sociological Review 58*(3), 367–381.

Shachar, B., J. Mayo, D. Lyell, R. Baer, L. Jeliffe-Pawlowski, D. Stevenson, and G. Shaw (2016). Interpregnancy interval after live birth or pregnancy termination and estimated risk of preterm birth: a retrospective cohort study. *BJOG: An International Journal of Obstetrics & Gynaecology 123*(12), 2009–2017.

Shah, P. S. (2010). Parity and low birth weight and preterm birth: a systematic review and meta-analyses. *Acta Obstetricia et Gynecologica Scandinavica 89*(7), 862–875.

Sjölander, A., T. Frisell, R. Kuja-Halkola, S. Öberg, and J. Zetterqvist (2016). Carryover effects in sibling comparison designs. *Epidemiology 27*(6), 852–858.

Smits, L. J. and G. G. Essed (2001). Short interpregnancy intervals and unfavourable pregnancy outcome: role of folate depletion. *The Lancet 358*(9298), 2074–2077.

Steelman, L. C., B. Powell, R. Werum, and S. Carter (2002). Reconsidering the effects of sibling configuration: Recent advances and challenges. *Annual Review of Sociology 28*, 243–269.

Strachan, D. P. (1989). Hay fever, hygiene, and household size. *British Medical Journal 299*, 1259–1260.

Waren, W. and H. Pals (2013). Comparing characteristics of voluntarily childless men and women. *Journal of Population Research 30*(2), 151–170.

WHO (2005). *Report of a WHO Technical Consultation on Birth Spacing*. Geneva, Switzerland: World Health Organization.

Yang, J. M., K. Cheney, R. Taylor, and K. Black (2019). Interpregnancy intervals and women's knowledge of the ideal timing between birth and conception. *BMJ Sexual & Reproductive Health 45*(4), 249–254.

Zajonc, R. B. (1976). Family configuration and intelligence. *Science 192*, 227–236.

Zajonc, R. B. and G. B. Markus (1975). Birth order and intellectual development. *Psychological Review 82*, 74–88.

Zhu, B.-P., R. T. Rolfs, B. E. Nangle, and J. M. Horan (1999). Effect of the interval between pregnancies on perinatal outcomes. *New England Journal of Medicine 340*(8), 589–594.

Supplementary Materials

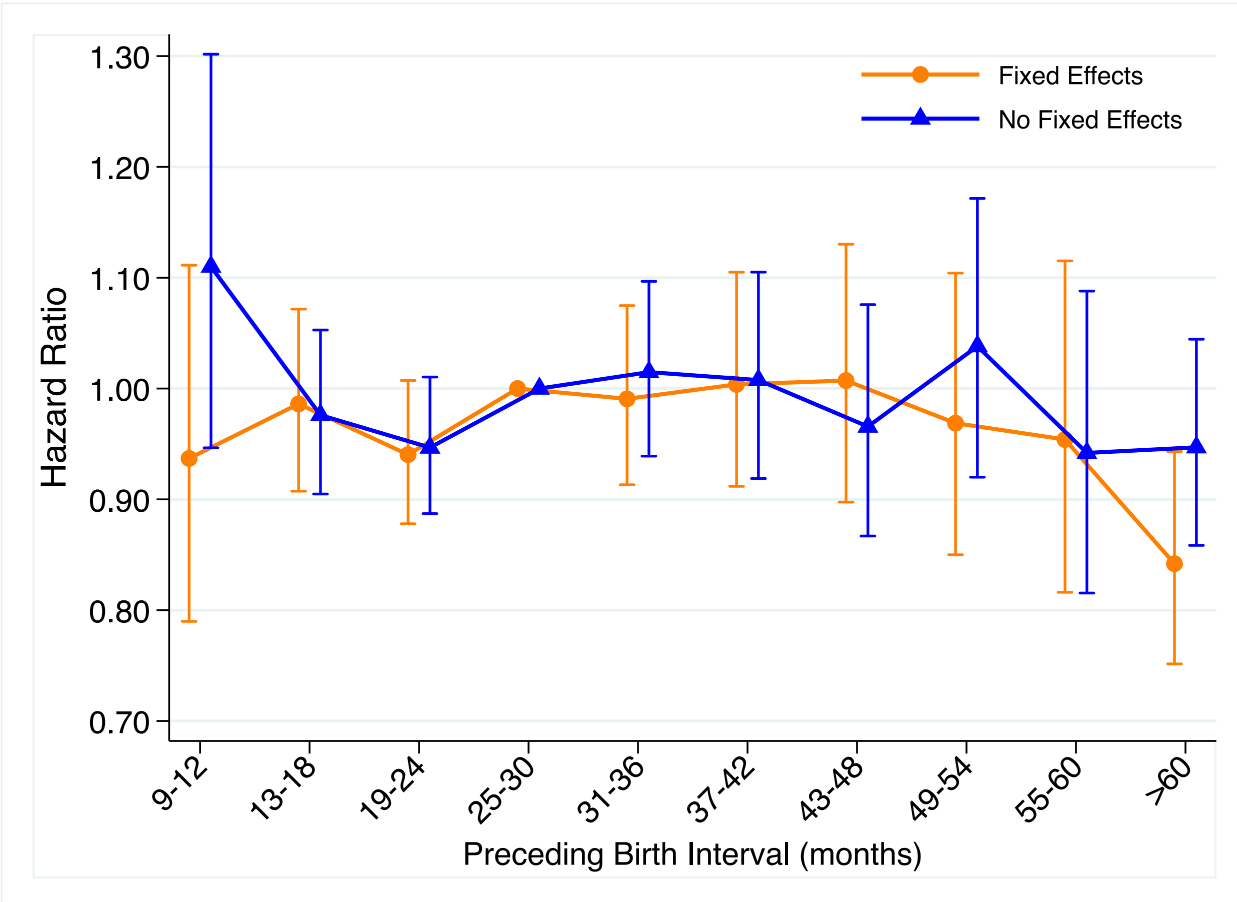

FIGURE S1. The relationship between the length of the preceding birth interval and hazard of mortality between ages 18-40 in sibling groups with at least 3 children born in Utah 1900–1956, pooled and by birth cohort group.

Table S1: Results from linear probability models, with and without the application of sibling fixed effects, regressing low birth weight on the length of the preceding birth interval, for men and women born in Utah, 1947–2016.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth intervals	9-12	0.0823	0.0024	0.078, 0.087	0.0556	0.0025	0.051, 0.061
	13-18	0.0147	0.0008	0.013, 0.016	0.0108	0.0009	0.009, 0.013
	19-24	0.0025	0.0007	0.001, 0.004	0.0028	0.0007	0.001, 0.004
	25-30 (ref)	0.0000			0.0000		
	31-36	0.0000	0.0007	-0.001, 0.001	-0.0023	0.0008	-0.004, -0.001
	37-42	0.0038	0.0008	0.002, 0.005	-0.0020	0.0009	-0.004, 0.000
	43-48	0.0039	0.0009	0.002, 0.006	-0.0046	0.0011	-0.007, -0.002
	49-54	0.0057	0.0011	0.003, 0.008	-0.0059	0.0013	-0.009, -0.003
	55-60	0.0091	0.0013	0.006, 0.012	-0.0070	0.0016	-0.010, -0.004
	60+	0.0201	0.0010	0.018, 0.022	-0.0073	0.0014	-0.010, -0.005
Sex	Male (ref)	0.0000			0.0000		
	Female	0.0091	0.0004	0.008, 0.010	0.0083	0.0005	0.007, 0.009
Birth order	2 (ref)	0.0000			0.0000		
	3	-0.0011	0.0006	-0.002, 0.000	-0.0107	0.0009	-0.012, -0.009
	4	0.0025	0.0008	0.001, 0.004	-0.0224	0.0015	-0.025, -0.019
	5	0.0040	0.0011	0.002, 0.006	-0.0327	0.0022	-0.037, -0.028
	6	0.0061	0.0014	0.003, 0.009	-0.0419	0.0028	-0.047, -0.036
	7	0.0053	0.0018	0.002, 0.009	-0.0517	0.0034	-0.058, -0.045
	8	0.0074	0.0024	0.003, 0.012	-0.0590	0.0041	-0.067, -0.051
	9	0.0045	0.0032	-0.002, 0.011	-0.0701	0.0048	-0.080, -0.061
	10	0.0090	0.0035	0.002, 0.016	-0.0783	0.0056	-0.089, -0.067
Birth year	1947	0.0113	0.0042	0.003, 0.019	-0.1720	0.0128	-0.197, -0.147
	1948	0.0121	0.0036	0.005, 0.019	-0.1716	0.0124	-0.196, -0.147
	1949	0.0141	0.0032	0.008, 0.020	-0.1630	0.0120	-0.187, -0.139
	1950	0.0146	0.0030	0.009, 0.020	-0.1573	0.0117	-0.180, -0.134
	1951	0.0179	0.0029	0.012, 0.024	-0.1520	0.0114	-0.174, -0.130
	1952	0.0093	0.0027	0.004, 0.015	-0.1559	0.0111	-0.178, -0.134
	1953	0.0101	0.0027	0.005, 0.015	-0.1479	0.0108	-0.169, -0.127
	1954	0.0114	0.0026	0.006, 0.017	-0.1432	0.0106	-0.164, -0.122
	1955	0.0097	0.0026	0.005, 0.015	-0.1391	0.0103	-0.159, -0.119
	1956	0.0041	0.0026	-0.001, 0.009	-0.1410	0.0100	-0.161, -0.121
	1957	0.0054	0.0025	0.000, 0.010	-0.1366	0.0097	-0.156, -0.118
	1958	0.0091	0.0026	0.004, 0.014	-0.1258	0.0095	-0.144, -0.107
	1959	0.0085	0.0026	0.003, 0.014	-0.1223	0.0092	-0.140, -0.104

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Table S1 – *Continued from previous page*

	Between-family comparison			Within-family comparison		
	β	SE	95% CI	β	SE	95% CI
1960	0.0073	0.0026	0.002, 0.012	-0.1196	0.0090	-0.137, -0.102
1961	0.0063	0.0026	0.001, 0.011	-0.1148	0.0087	-0.132, -0.098
1962	0.0062	0.0026	0.001, 0.011	-0.1110	0.0085	-0.128, -0.094
1963	0.0073	0.0027	0.002, 0.013	-0.1022	0.0082	-0.118, -0.086
1964	0.0087	0.0028	0.003, 0.014	-0.1024	0.0080	-0.118, -0.087
1965	0.0134	0.0030	0.007, 0.019	-0.0922	0.0079	-0.108, -0.077
1966	0.0171	0.0033	0.011, 0.024	-0.0886	0.0077	-0.104, -0.073
1967	0.0115	0.0032	0.005, 0.018	-0.0867	0.0074	-0.101, -0.072
1968	0.3237	0.1979	-0.064, 0.712	0.2402	0.1945	-0.141, 0.622
1969	0.2508	0.1715	-0.085, 0.587	0.1857	0.1527	-0.114, 0.485
1970	0.0110	0.0030	0.005, 0.017	-0.0750	0.0067	-0.088, -0.062
1971	0.0061	0.0029	0.000, 0.012	-0.0783	0.0063	-0.091, -0.066
1972	0.0046	0.0029	-0.001, 0.010	-0.0748	0.0061	-0.087, -0.063
1973	0.0044	0.0028	-0.001, 0.010	-0.0683	0.0058	-0.080, -0.057
1974	-0.0035	0.0025	-0.008, 0.001	-0.0711	0.0054	-0.082, -0.061
1975	-0.0046	0.0024	-0.009, 0.000	-0.0655	0.0052	-0.076, -0.055
1976	-0.0045	0.0024	-0.009, 0.000	-0.0640	0.0049	-0.073, -0.054
1977	-0.0051	0.0023	-0.010, -0.001	-0.0581	0.0046	-0.067, -0.049
1978	-0.0002	0.0023	-0.005, 0.004	-0.0521	0.0043	-0.061, -0.044
1979	-0.0031	0.0022	-0.008, 0.001	-0.0514	0.0040	-0.059, -0.043
1980	-0.0060	0.0022	-0.010, -0.002	-0.0486	0.0038	-0.056, -0.041
1981	-0.0014	0.0022	-0.006, 0.003	-0.0391	0.0036	-0.046, -0.032
1982	0.0013	0.0023	-0.003, 0.006	-0.0355	0.0034	-0.042, -0.029
1983	-0.0022	0.0022	-0.007, 0.002	-0.0321	0.0032	-0.038, -0.026
1984	-0.0012	0.0023	-0.006, 0.003	-0.0261	0.0030	-0.032, -0.020
1985	-0.0021	0.0023	-0.007, 0.002	-0.0239	0.0029	-0.030, -0.018
1986	-0.0043	0.0023	-0.009, 0.000	-0.0234	0.0028	-0.029, -0.018
1987	0.0006	0.0024	-0.004, 0.005	-0.0144	0.0027	-0.020, -0.009
1988	-0.0035	0.0023	-0.008, 0.001	-0.0124	0.0025	-0.017, -0.007
1989	-0.0005	0.0024	-0.005, 0.004	-0.0068	0.0027	-0.012, -0.002
1990 (ref)	0.0000			0.0000		
1991	0.0023	0.0025	-0.003, 0.007	0.0056	0.0027	0.000, 0.011
1992	-0.0027	0.0024	-0.007, 0.002	0.0056	0.0026	0.001, 0.011
1993	0.0017	0.0025	-0.003, 0.007	0.0158	0.0028	0.010, 0.021
1994	0.0018	0.0025	-0.003, 0.007	0.0204	0.0029	0.015, 0.026
1995	0.0035	0.0025	-0.001, 0.008	0.0247	0.0030	0.019, 0.031
1996	0.0049	0.0025	0.000, 0.010	0.0331	0.0032	0.027, 0.039
1997	0.0070	0.0025	0.002, 0.012	0.0375	0.0034	0.031, 0.044

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Table S1 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1998	0.0090	0.0024	0.004, 0.014	0.0424	0.0036	0.035, 0.049
	1999	0.0077	0.0024	0.003, 0.012	0.0469	0.0038	0.039, 0.054
	2000	0.0050	0.0023	0.000, 0.010	0.0517	0.0039	0.044, 0.059
	2001	0.0037	0.0023	-0.001, 0.008	0.0552	0.0041	0.047, 0.063
	2002	0.0057	0.0023	0.001, 0.010	0.0609	0.0044	0.052, 0.070
	2003	0.0049	0.0023	0.000, 0.009	0.0685	0.0046	0.059, 0.077
	2004	0.0083	0.0023	0.004, 0.013	0.0722	0.0048	0.063, 0.082
	2005	0.0105	0.0023	0.006, 0.015	0.0804	0.0051	0.070, 0.090
	2006	0.0076	0.0023	0.003, 0.012	0.0835	0.0053	0.073, 0.094
	2007	0.0084	0.0023	0.004, 0.013	0.0907	0.0056	0.080, 0.102
	2008	0.0070	0.0022	0.003, 0.011	0.0949	0.0058	0.084, 0.106
	2009	0.0108	0.0023	0.006, 0.015	0.1052	0.0061	0.093, 0.117
	2010	0.0106	0.0023	0.006, 0.015	0.1107	0.0063	0.098, 0.123
	2011	0.0064	0.0023	0.002, 0.011	0.1134	0.0066	0.101, 0.126
	2012	0.0081	0.0023	0.004, 0.013	0.1198	0.0069	0.106, 0.133
	2013	0.0085	0.0023	0.004, 0.013	0.1278	0.0071	0.114, 0.142
	2014	0.0093	0.0024	0.005, 0.014	0.1330	0.0075	0.118, 0.148
	2015	0.0168	0.0026	0.012, 0.022	0.1406	0.0078	0.125, 0.156
	2016	0.0167	0.0027	0.011, 0.022	0.1477	0.0081	0.132, 0.164
Maternal age	15-19	0.0330	0.0024	0.028, 0.038	0.0057	0.0033	-0.001, 0.012
	20-24	0.0103	0.0008	0.009, 0.012	-0.0011	0.0016	-0.004, 0.002
	25-29	0.0026	0.0006	0.001, 0.004	-0.0001	0.0009	-0.002, 0.002
	30-34 (ref)	0.0000			0.0000		
	35-39	0.0037	0.0008	0.002, 0.005	0.0014	0.0012	-0.001, 0.004
	40-44	0.0142	0.0019	0.010, 0.018	0.0043	0.0026	-0.001, 0.009
	45+	0.0284	0.0087	0.011, 0.046	0.0112	0.0090	-0.006, 0.029
Family size	2 (ref)	0.0000					
	3	-0.3533	0.0163	-0.385, -0.321			
	4	-0.3577	0.0163	-0.390, -0.326			
	5	-0.3592	0.0163	-0.391, -0.327			
	6	-0.3622	0.0163	-0.394, -0.330			
	7	-0.3616	0.0163	-0.394, -0.330			
	8	-0.3662	0.0163	-0.398, -0.334			
	9	-0.3655	0.0164	-0.398, -0.333			
	10	-0.3683	0.0164	-0.400, -0.336			
N			870,180			870,180	

Table S2: Results from linear probability models, with and without the application of sibling fixed effects, regressing low birth weight on an interaction between birth cohort and the length of the preceding birth interval, for men and women born in Utah, 1950-1980.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth year x	1947-1959, 9-12	0.0864	0.0056	0.086, 0.006	0.0649	0.0061	0.065, 0.006
Birth intervals	1947-1959, 13-18	0.0258	0.0037	0.026, 0.004	0.0239	0.0045	0.024, 0.004
	1947-1959, 19-24	0.0173	0.0037	0.017, 0.004	0.0165	0.0044	0.016, 0.004
	1947-1959, 25-30	0.0128	0.0037	0.013, 0.004	0.0091	0.0045	0.009, 0.004
	1947-1959, 31-36	0.0112	0.0038	0.011, 0.004	0.0083	0.0046	0.008, 0.005
	1947-1959, 37-42	0.0145	0.0040	0.014, 0.004	0.0081	0.0048	0.008, 0.005
	1947-1959, 43-48	0.0175	0.0042	0.017, 0.004	0.0101	0.0049	0.010, 0.005
	1947-1959, 49-54	0.0098	0.0043	0.010, 0.004	-0.0012	0.0052	-0.001, 0.005
	1947-1959, 55-60	0.0200	0.0048	0.020, 0.005	0.0017	0.0057	0.002, 0.006
	1947-1959, 60+	0.0262	0.0041	0.026, 0.004	0.0012	0.0049	0.001, 0.005
	1960-1969, 9-12	0.0974	0.0067	0.097, 0.007	0.0772	0.0072	0.077, 0.007
	1960-1969, 13-18	0.0248	0.0034	0.025, 0.003	0.0239	0.0041	0.024, 0.004
	1960-1969, 19-24	0.0095	0.0033	0.009, 0.003	0.0117	0.0040	0.012, 0.004
	1960-1969, 25-30	0.0085	0.0034	0.009, 0.003	0.0081	0.0041	0.008, 0.004
	1960-1969, 31-36	0.0115	0.0036	0.011, 0.004	0.0082	0.0043	0.008, 0.004
	1960-1969, 37-42	0.0162	0.0039	0.016, 0.004	0.0119	0.0047	0.012, 0.005
	1960-1969, 43-48	0.0134	0.0041	0.013, 0.004	0.0059	0.0049	0.006, 0.005
	1960-1969, 49-54	0.0130	0.0045	0.013, 0.005	0.0001	0.0054	0.000, 0.005
	1960-1969, 55-60	0.0146	0.0050	0.015, 0.005	0.0074	0.0057	0.007, 0.006
	1960-1969, 60+	0.0242	0.0038	0.024, 0.004	0.0005	0.0046	0.000, 0.005
	1970-1979, 9-12	0.0756	0.0061	0.076, 0.006	0.0559	0.0065	0.056, 0.006
	1970-1979, 13-18	0.0115	0.0025	0.012, 0.002	0.0121	0.0029	0.012, 0.003
	1970-1979, 19-24	-0.0007	0.0022	-0.001, 0.002	0.0024	0.0026	0.002, 0.003
	1970-1979, 25-30	0.0000	0.0023	0.000, 0.002	0.0018	0.0027	0.002, 0.003
	1970-1979, 31-36	-0.0013	0.0025	-0.001, 0.002	-0.0023	0.0029	-0.002, 0.003
	1970-1979, 37-42	0.0009	0.0028	0.001, 0.003	-0.0054	0.0033	-0.005, 0.003
	1970-1979, 43-48	0.0007	0.0030	0.001, 0.003	-0.0088	0.0036	-0.009, 0.004
	1970-1979, 49-54	0.0095	0.0037	0.010, 0.004	-0.0054	0.0044	-0.005, 0.004
	1970-1979, 55-60	0.0025	0.0039	0.002, 0.004	-0.0093	0.0047	-0.009, 0.005
	1970-1979, 60+	0.0144	0.0031	0.014, 0.003	-0.0100	0.0038	-0.010, 0.004
	1980-1989, 9-12	0.0923	0.0070	0.092, 0.007	0.0591	0.0073	0.059, 0.007
	1980-1989, 13-18	0.0105	0.0021	0.010, 0.002	0.0086	0.0025	0.009, 0.003
	1980-1989, 19-24	-0.0009	0.0018	-0.001, 0.002	0.0002	0.0022	0.000, 0.002
	1980-1989, 25-30	-0.0052	0.0018	-0.005, 0.002	-0.0033	0.0022	-0.003, 0.002
	1980-1989, 31-36	-0.0035	0.0019	-0.003, 0.002	-0.0039	0.0023	-0.004, 0.002
	1980-1989, 37-42	-0.0036	0.0021	-0.004, 0.002	-0.0043	0.0025	-0.004, 0.003
	1980-1989, 43-48	-0.0017	0.0023	-0.002, 0.002	-0.0061	0.0027	-0.006, 0.003
	1980-1989, 49-54	-0.0058	0.0025	-0.006, 0.003	-0.0109	0.0031	-0.011, 0.003
	1980-1989, 55-60	-0.0010	0.0031	-0.001, 0.003	-0.0128	0.0037	-0.013, 0.004
	1980-1989, 60+	0.0079	0.0025	0.008, 0.002	-0.0146	0.0031	-0.015, 0.003
	1990-1999, 9-12	0.0796	0.0074	0.080, 0.007	0.0478	0.0080	0.048, 0.008
	1990-1999, 13-18	0.0108	0.0022	0.011, 0.002	0.0041	0.0024	0.004, 0.002
	1990-1999, 19-24	0.0027	0.0017	0.003, 0.002	0.0020	0.0019	0.002, 0.002

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Table S2 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1990-1999, 25-30 (ref)	0.0000			0.0000		
	1990-1999, 31-36	-0.0014	0.0018	-0.001, 0.002	-0.0033	0.0020	-0.003, 0.002
	1990-1999, 37-42	0.0027	0.0021	0.003, 0.002	-0.0034	0.0023	-0.003, 0.002
	1990-1999, 43-48	0.0003	0.0023	0.000, 0.002	-0.0071	0.0026	-0.007, 0.003
	1990-1999, 49-54	0.0058	0.0028	0.006, 0.003	0.0007	0.0032	0.001, 0.003
	1990-1999, 55-60	0.0051	0.0033	0.005, 0.003	-0.0059	0.0037	-0.006, 0.004
	1990-1999, 60+	0.0186	0.0025	0.019, 0.002	-0.0079	0.0029	-0.008, 0.003
	2000-2009, 9-12	0.0846	0.0068	0.085, 0.007	0.0483	0.0072	0.048, 0.007
	2000-2009, 13-18	0.0162	0.0023	0.016, 0.002	0.0089	0.0027	0.009, 0.003
	2000-2009, 19-24	0.0005	0.0018	0.000, 0.002	0.0011	0.0021	0.001, 0.002
	2000-2009, 25-30	-0.0003	0.0018	0.000, 0.002	0.0006	0.0021	0.001, 0.002
	2000-2009, 31-36	0.0004	0.0018	0.000, 0.002	-0.0021	0.0022	-0.002, 0.002
	2000-2009, 37-42	0.0045	0.0021	0.005, 0.002	-0.0007	0.0024	-0.001, 0.002
	2000-2009, 43-48	0.0056	0.0023	0.006, 0.002	-0.0048	0.0027	-0.005, 0.003
	2000-2009, 49-54	0.0091	0.0028	0.009, 0.003	-0.0053	0.0031	-0.005, 0.003
	2000-2009, 55-60	0.0141	0.0034	0.014, 0.003	-0.0060	0.0037	-0.006, 0.004
	2000-2009, 60+	0.0276	0.0026	0.028, 0.003	-0.0009	0.0029	-0.001, 0.003
	2010-2016, 9-12	0.0809	0.0095	0.081, 0.009	0.0557	0.0106	0.056, 0.011
	2010-2016, 13-18	0.0174	0.0031	0.017, 0.003	0.0151	0.0036	0.015, 0.004
	2010-2016, 19-24	0.0024	0.0023	0.002, 0.002	0.0092	0.0028	0.009, 0.003
	2010-2016, 25-30	-0.0006	0.0023	-0.001, 0.002	0.0057	0.0027	0.006, 0.003
	2010-2016, 31-36	-0.0003	0.0024	0.000, 0.002	0.0034	0.0028	0.003, 0.003
	2010-2016, 37-42	0.0079	0.0027	0.008, 0.003	0.0043	0.0031	0.004, 0.003
	2010-2016, 43-48	0.0060	0.0029	0.006, 0.003	0.0028	0.0035	0.003, 0.003
	2010-2016, 49-54	0.0142	0.0036	0.014, 0.004	0.0041	0.0041	0.004, 0.004
	2010-2016, 55-60	0.0203	0.0042	0.020, 0.004	0.0009	0.0048	0.001, 0.005
	2010-2016, 60+	0.0335	0.0032	0.034, 0.003	0.0029	0.0036	0.003, 0.004
Sex	Male	0.0000			0.0000		
	Female	0.0091	0.0004	0.009, 0.000	0.0083	0.0005	0.008, 0.000
Birth order	2	0.0000			0.0000		
	3	-0.0013	0.0006	-0.001, 0.001	-0.0101	0.0009	-0.010, 0.001
	4	0.0022	0.0008	0.002, 0.001	-0.0215	0.0015	-0.022, 0.002
	5	0.0038	0.0011	0.004, 0.001	-0.0319	0.0022	-0.032, 0.002
	6	0.0059	0.0014	0.006, 0.001	-0.0413	0.0028	-0.041, 0.003
	7	0.0051	0.0018	0.005, 0.002	-0.0514	0.0035	-0.051, 0.003
	8	0.0071	0.0024	0.007, 0.002	-0.0588	0.0041	-0.059, 0.004
	9	0.0044	0.0032	0.004, 0.003	-0.0699	0.0049	-0.070, 0.005
	10	0.0089	0.0035	0.009, 0.003	-0.0780	0.0056	-0.078, 0.006
Maternal age	15-19	0.0323	0.0024	0.032, 0.002	0.0062	0.0033	0.006, 0.003
	20-24	0.0099	0.0008	0.010, 0.001	-0.0009	0.0016	-0.001, 0.002
	25-29	0.0026	0.0006	0.003, 0.001	-0.0003	0.0009	0.000, 0.001
	30-34	0.0000			0.0000		
	35-39	0.0036	0.0008	0.004, 0.001	0.0016	0.0012	0.002, 0.001
	40-44	0.0142	0.0019	0.014, 0.002	0.0045	0.0026	0.004, 0.003
	45+	0.0292	0.0087	0.029, 0.009	0.0119	0.0090	0.012, 0.009
Birth year		0.0001	0.0001	0.000, 0.000	0.0046	0.0003	0.005, 0.000

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Table S2 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
Family size	2	0.0000					
	3	-0.3539	0.0163	-0.354, 0.016			
	4	-0.3582	0.0163	-0.358, 0.016			
	5	-0.3597	0.0163	-0.360, 0.016			
	6	-0.3628	0.0163	-0.363, 0.016			
	7	-0.3622	0.0163	-0.362, 0.016			
	8	-0.3670	0.0164	-0.367, 0.016			
	9	-0.3663	0.0164	-0.366, 0.016			
	10	-0.3691	0.0164	-0.369, 0.016			
N			870,180			870,180	

Table S3: Results from linear probability models, with and without the application of sibling fixed effects, regressing preterm birth on the length of the preceding birth interval, for men and women born in Utah, 1947–2016.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth intervals	9-12	0.0960	0.0026	0.091, 0.101	0.0644	0.0027	0.059, 0.070
	13-18	0.0200	0.0010	0.018, 0.022	0.0122	0.0011	0.010, 0.014
	19-24	0.0059	0.0008	0.004, 0.007	0.0056	0.0009	0.004, 0.007
	25-30 (ref)	0.0000			0.0000		
	31-36	0.0001	0.0009	-0.002, 0.002	-0.0030	0.0010	-0.005, -0.001
	37-42	0.0017	0.0010	0.000, 0.004	-0.0049	0.0011	-0.007, -0.003
	43-48	0.0029	0.0011	0.001, 0.005	-0.0073	0.0013	-0.010, -0.005
	49-54	0.0035	0.0013	0.001, 0.006	-0.0116	0.0015	-0.015, -0.009
	55-60	0.0057	0.0016	0.003, 0.009	-0.0131	0.0018	-0.017, -0.010
	60+	0.0161	0.0012	0.014, 0.018	-0.0135	0.0015	-0.017, -0.010
Sex	Male (ref)	0.0000			0.0000		
	Female	-0.0083	0.0005	-0.009, -0.007	-0.0077	0.0006	-0.009, -0.007
Birth order	2 (ref)	0.0000			0.0000		
	3	0.0035	0.0007	0.002, 0.005	-0.0077	0.0010	-0.010, -0.006
	4	0.0117	0.0009	0.010, 0.014	-0.0159	0.0017	-0.019, -0.012
	5	0.0160	0.0012	0.014, 0.018	-0.0239	0.0024	-0.029, -0.019
	6	0.0203	0.0016	0.017, 0.023	-0.0313	0.0031	-0.037, -0.025
	7	0.0208	0.0021	0.017, 0.025	-0.0402	0.0038	-0.048, -0.033
	8	0.0287	0.0029	0.023, 0.034	-0.0412	0.0046	-0.050, -0.032
	9	0.0281	0.0039	0.020, 0.036	-0.0530	0.0056	-0.064, -0.042
	10	0.0303	0.0041	0.022, 0.038	-0.0644	0.0065	-0.077, -0.052
Birth year	1947	-0.0208	0.0043	-0.029, -0.012	-0.1931	0.0145	-0.221, -0.165
	1948	-0.0164	0.0038	-0.024, -0.009	-0.1952	0.0140	-0.223, -0.168
	1949	0.0178	0.0040	0.010, 0.026	-0.1548	0.0137	-0.182, -0.128
	1950	0.0069	0.0036	0.000, 0.014	-0.1601	0.0133	-0.186, -0.134
	1951	-0.0094	0.0033	-0.016, -0.003	-0.1721	0.0129	-0.197, -0.147
	1952	-0.0143	0.0031	-0.020, -0.008	-0.1754	0.0126	-0.200, -0.151
	1953	-0.0165	0.0031	-0.023, -0.011	-0.1720	0.0123	-0.196, -0.148
	1954	-0.0131	0.0031	-0.019, -0.007	-0.1637	0.0120	-0.187, -0.140
	1955	-0.0220	0.0030	-0.028, -0.016	-0.1660	0.0116	-0.189, -0.143
	1956	-0.0273	0.0029	-0.033, -0.022	-0.1683	0.0114	-0.191, -0.146
	1957	-0.0295	0.0029	-0.035, -0.024	-0.1663	0.0110	-0.188, -0.145
	1958	-0.0332	0.0029	-0.039, -0.028	-0.1639	0.0107	-0.185, -0.143
	1959	-0.0295	0.0029	-0.035, -0.024	-0.1561	0.0105	-0.177, -0.136

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Table S3 – *Continued from previous page*

	Between-family comparison			Within-family comparison		
	β	SE	95% CI	β	SE	95% CI
1960	-0.0317	0.0029	-0.037, -0.026	-0.1530	0.0102	-0.173, -0.133
1961	-0.0337	0.0029	-0.039, -0.028	-0.1474	0.0098	-0.167, -0.128
1962	-0.0357	0.0029	-0.041, -0.030	-0.1502	0.0096	-0.169, -0.131
1963	-0.0366	0.0029	-0.042, -0.031	-0.1432	0.0093	-0.161, -0.125
1964	-0.0369	0.0029	-0.043, -0.031	-0.1409	0.0090	-0.159, -0.123
1965	-0.0314	0.0031	-0.038, -0.025	-0.1320	0.0089	-0.149, -0.115
1966	-0.0334	0.0032	-0.040, -0.027	-0.1336	0.0086	-0.151, -0.117
1967	-0.0339	0.0032	-0.040, -0.028	-0.1327	0.0083	-0.149, -0.116
1968	0.4857	0.2015	0.091, 0.881	0.3774	0.2221	-0.058, 0.813
1969	0.3561	0.1861	-0.009, 0.721	0.3404	0.1923	-0.037, 0.717
1970	0.0019	0.0037	-0.005, 0.009	-0.0823	0.0078	-0.098, -0.067
1971	-0.0170	0.0033	-0.024, -0.010	-0.0999	0.0073	-0.114, -0.086
1972	-0.0218	0.0033	-0.028, -0.015	-0.1011	0.0070	-0.115, -0.087
1973	-0.0111	0.0034	-0.018, -0.004	-0.0814	0.0067	-0.095, -0.068
1974	-0.0143	0.0032	-0.021, -0.008	-0.0785	0.0064	-0.091, -0.066
1975	-0.0155	0.0031	-0.022, -0.009	-0.0765	0.0061	-0.088, -0.065
1976	-0.0302	0.0028	-0.036, -0.025	-0.0877	0.0057	-0.099, -0.077
1977	-0.0300	0.0028	-0.035, -0.025	-0.0816	0.0053	-0.092, -0.071
1978	-0.0298	0.0027	-0.035, -0.024	-0.0777	0.0051	-0.088, -0.068
1979	-0.0322	0.0027	-0.037, -0.027	-0.0760	0.0047	-0.085, -0.067
1980	-0.0249	0.0028	-0.030, -0.020	-0.0644	0.0045	-0.073, -0.056
1981	-0.0252	0.0027	-0.031, -0.020	-0.0597	0.0043	-0.068, -0.051
1982	-0.0253	0.0027	-0.031, -0.020	-0.0572	0.0040	-0.065, -0.049
1983	-0.0270	0.0027	-0.032, -0.022	-0.0548	0.0039	-0.062, -0.047
1984	-0.0227	0.0028	-0.028, -0.017	-0.0447	0.0037	-0.052, -0.037
1985	-0.0208	0.0029	-0.026, -0.015	-0.0409	0.0036	-0.048, -0.034
1986	-0.0209	0.0029	-0.027, -0.015	-0.0348	0.0035	-0.042, -0.028
1987	-0.0186	0.0029	-0.024, -0.013	-0.0309	0.0033	-0.037, -0.024
1988	-0.0194	0.0029	-0.025, -0.014	-0.0270	0.0032	-0.033, -0.021
1989	0.0021	0.0032	-0.004, 0.008	-0.0012	0.0035	-0.008, 0.006
1990 (ref)	0.0000			0.0000		
1991	-0.0001	0.0032	-0.006, 0.006	0.0040	0.0036	-0.003, 0.011
1992	0.0023	0.0032	-0.004, 0.009	0.0147	0.0035	0.008, 0.022
1993	0.0074	0.0033	0.001, 0.014	0.0241	0.0037	0.017, 0.031
1994	0.0068	0.0033	0.000, 0.013	0.0299	0.0038	0.022, 0.037
1995	0.0070	0.0032	0.001, 0.013	0.0306	0.0039	0.023, 0.038
1996	0.0095	0.0032	0.003, 0.016	0.0426	0.0041	0.034, 0.051
1997	0.0149	0.0033	0.009, 0.021	0.0528	0.0043	0.044, 0.061

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Table S3 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1998	0.0164	0.0032	0.010, 0.023	0.0589	0.0046	0.050, 0.068
	1999	0.0074	0.0031	0.001, 0.013	0.0536	0.0047	0.044, 0.063
	2000	0.0047	0.0030	-0.001, 0.011	0.0649	0.0049	0.055, 0.074
	2001	0.0077	0.0030	0.002, 0.014	0.0703	0.0051	0.060, 0.080
	2002	0.0117	0.0030	0.006, 0.018	0.0789	0.0054	0.068, 0.089
	2003	0.0100	0.0030	0.004, 0.016	0.0869	0.0056	0.076, 0.098
	2004	0.0149	0.0030	0.009, 0.021	0.0962	0.0059	0.085, 0.108
	2005	0.0143	0.0030	0.008, 0.020	0.0986	0.0061	0.087, 0.111
	2006	0.0140	0.0030	0.008, 0.020	0.1088	0.0064	0.096, 0.121
	2007	0.0127	0.0030	0.007, 0.019	0.1113	0.0067	0.098, 0.124
	2008	0.0146	0.0030	0.009, 0.020	0.1235	0.0070	0.110, 0.137
	2009	0.0131	0.0030	0.007, 0.019	0.1304	0.0072	0.116, 0.145
	2010	0.0114	0.0030	0.006, 0.017	0.1346	0.0075	0.120, 0.149
	2011	0.0097	0.0030	0.004, 0.016	0.1422	0.0078	0.127, 0.158
	2012	0.0078	0.0030	0.002, 0.014	0.1455	0.0082	0.130, 0.162
	2013	0.0048	0.0030	-0.001, 0.011	0.1526	0.0084	0.136, 0.169
	2014	0.0089	0.0031	0.003, 0.015	0.1615	0.0088	0.144, 0.179
	2015	0.0115	0.0033	0.005, 0.018	0.1641	0.0092	0.146, 0.182
	2016	0.0154	0.0034	0.009, 0.022	0.1765	0.0095	0.158, 0.195
Maternal age	15-19	0.0322	0.0025	0.027, 0.037	0.0086	0.0037	0.001, 0.016
	20-24	0.0126	0.0009	0.011, 0.014	0.0002	0.0019	-0.003, 0.004
	25-29	0.0036	0.0007	0.002, 0.005	0.0012	0.0011	-0.001, 0.003
	30-34 (ref)	0.0000			0.0000		
	35-39	0.0065	0.0010	0.004, 0.008	0.0023	0.0014	0.000, 0.005
	40-44	0.0130	0.0022	0.009, 0.017	0.0011	0.0030	-0.005, 0.007
	45+	0.0281	0.0095	0.009, 0.047	0.0087	0.0100	-0.011, 0.028
Family size	2 (ref)	0.0000					
	3	-0.3383	0.0161	-0.370, -0.307			
	4	-0.3441	0.0161	-0.376, -0.313			
	5	-0.3466	0.0161	-0.378, -0.315			
	6	-0.3523	0.0161	-0.384, -0.321			
	7	-0.3514	0.0161	-0.383, -0.320			
	8	-0.3602	0.0161	-0.392, -0.329			
	9	-0.3568	0.0162	-0.389, -0.325			
	10	-0.3644	0.0162	-0.396, -0.333			
N			870,180			870,180	

Table S4: Results from linear probability models, with and without the application of sibling fixed effects, regressing preterm birth on an interaction between birth cohort and the length of the preceding birth interval, for men and women born in Utah, 1950-1980.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth year x	1947-1959, 9-12	0.0382	0.0060	0.038, 0.006	0.0301	0.0065	0.030, 0.007
Birth intervals	1947-1959, 13-18	-0.0230	0.0043	-0.023, 0.004	-0.0189	0.0051	-0.019, 0.005
	1947-1959, 19-24	-0.0248	0.0043	-0.025, 0.004	-0.0203	0.0050	-0.020, 0.005
	1947-1959, 25-30	-0.0302	0.0044	-0.030, 0.004	-0.0265	0.0051	-0.027, 0.005
	1947-1959, 31-36	-0.0345	0.0044	-0.035, 0.004	-0.0314	0.0051	-0.031, 0.005
	1947-1959, 37-42	-0.0326	0.0046	-0.033, 0.005	-0.0341	0.0053	-0.034, 0.005
	1947-1959, 43-48	-0.0301	0.0047	-0.030, 0.005	-0.0343	0.0055	-0.034, 0.006
	1947-1959, 49-54	-0.0378	0.0049	-0.038, 0.005	-0.0444	0.0057	-0.044, 0.006
	1947-1959, 55-60	-0.0315	0.0052	-0.032, 0.005	-0.0442	0.0061	-0.044, 0.006
	1947-1959, 60+	-0.0291	0.0046	-0.029, 0.005	-0.0471	0.0054	-0.047, 0.005
	1960-1969, 9-12	0.0196	0.0063	0.020, 0.006	0.0137	0.0070	0.014, 0.007
	1960-1969, 13-18	-0.0302	0.0038	-0.030, 0.004	-0.0203	0.0046	-0.020, 0.005
	1960-1969, 19-24	-0.0452	0.0037	-0.045, 0.004	-0.0336	0.0045	-0.034, 0.004
	1960-1969, 25-30	-0.0448	0.0038	-0.045, 0.004	-0.0374	0.0046	-0.037, 0.005
	1960-1969, 31-36	-0.0455	0.0039	-0.045, 0.004	-0.0394	0.0048	-0.039, 0.005
	1960-1969, 37-42	-0.0437	0.0041	-0.044, 0.004	-0.0408	0.0050	-0.041, 0.005
	1960-1969, 43-48	-0.0453	0.0043	-0.045, 0.004	-0.0436	0.0051	-0.044, 0.005
	1960-1969, 49-54	-0.0489	0.0045	-0.049, 0.004	-0.0535	0.0054	-0.053, 0.005
	1960-1969, 55-60	-0.0474	0.0048	-0.047, 0.005	-0.0490	0.0057	-0.049, 0.006
	1960-1969, 60+	-0.0401	0.0040	-0.040, 0.004	-0.0576	0.0050	-0.058, 0.005
	1970-1979, 9-12	0.0529	0.0066	0.053, 0.007	0.0464	0.0073	0.046, 0.007
	1970-1979, 13-18	-0.0171	0.0029	-0.017, 0.003	-0.0104	0.0035	-0.010, 0.004
	1970-1979, 19-24	-0.0260	0.0027	-0.026, 0.003	-0.0143	0.0033	-0.014, 0.003
	1970-1979, 25-30	-0.0339	0.0028	-0.034, 0.003	-0.0216	0.0034	-0.022, 0.003
	1970-1979, 31-36	-0.0321	0.0029	-0.032, 0.003	-0.0224	0.0036	-0.022, 0.004
	1970-1979, 37-42	-0.0333	0.0032	-0.033, 0.003	-0.0276	0.0039	-0.028, 0.004
	1970-1979, 43-48	-0.0348	0.0035	-0.035, 0.003	-0.0345	0.0043	-0.034, 0.004
	1970-1979, 49-54	-0.0322	0.0040	-0.032, 0.004	-0.0358	0.0049	-0.036, 0.005
	1970-1979, 55-60	-0.0346	0.0043	-0.035, 0.004	-0.0398	0.0054	-0.040, 0.005
	1970-1979, 60+	-0.0274	0.0034	-0.027, 0.003	-0.0416	0.0043	-0.042, 0.004
	1980-1989, 9-12	0.0800	0.0076	0.080, 0.008	0.0419	0.0084	0.042, 0.008
	1980-1989, 13-18	-0.0109	0.0026	-0.011, 0.003	-0.0106	0.0032	-0.011, 0.003
	1980-1989, 19-24	-0.0232	0.0023	-0.023, 0.002	-0.0158	0.0028	-0.016, 0.003
	1980-1989, 25-30	-0.0308	0.0023	-0.031, 0.002	-0.0225	0.0028	-0.022, 0.003
	1980-1989, 31-36	-0.0298	0.0024	-0.030, 0.002	-0.0251	0.0029	-0.025, 0.003
	1980-1989, 37-42	-0.0331	0.0025	-0.033, 0.002	-0.0240	0.0031	-0.024, 0.003
	1980-1989, 43-48	-0.0309	0.0027	-0.031, 0.003	-0.0249	0.0033	-0.025, 0.003
	1980-1989, 49-54	-0.0318	0.0031	-0.032, 0.003	-0.0295	0.0038	-0.030, 0.004
	1980-1989, 55-60	-0.0260	0.0037	-0.026, 0.004	-0.0259	0.0044	-0.026, 0.004
	1980-1989, 60+	-0.0194	0.0029	-0.019, 0.003	-0.0341	0.0037	-0.034, 0.004
	1990-1999, 9-12	0.1218	0.0090	0.122, 0.009	0.0722	0.0097	0.072, 0.010
	1990-1999, 13-18	0.0212	0.0029	0.021, 0.003	0.0101	0.0033	0.010, 0.003
	1990-1999, 19-24	0.0065	0.0023	0.006, 0.002	0.0053	0.0026	0.005, 0.003

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Table S4 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1990-1999, 25-30 (ref)	0.0000			0.0000		
	1990-1999, 31-36	-0.0008	0.0024	-0.001, 0.002	-0.0039	0.0027	-0.004, 0.003
	1990-1999, 37-42	0.0019	0.0027	0.002, 0.003	-0.0078	0.0031	-0.008, 0.003
	1990-1999, 43-48	0.0017	0.0031	0.002, 0.003	-0.0093	0.0036	-0.009, 0.004
	1990-1999, 49-54	0.0007	0.0036	0.001, 0.004	-0.0069	0.0041	-0.007, 0.004
	1990-1999, 55-60	-0.0006	0.0042	-0.001, 0.004	-0.0144	0.0049	-0.014, 0.005
	1990-1999, 60+	0.0125	0.0031	0.012, 0.003	-0.0132	0.0036	-0.013, 0.004
	2000-2009, 9-12	0.1456	0.0084	0.146, 0.008	0.0971	0.0088	0.097, 0.009
	2000-2009, 13-18	0.0314	0.0029	0.031, 0.003	0.0232	0.0034	0.023, 0.003
	2000-2009, 19-24	0.0064	0.0023	0.006, 0.002	0.0106	0.0028	0.011, 0.003
	2000-2009, 25-30	0.0051	0.0023	0.005, 0.002	0.0090	0.0027	0.009, 0.003
	2000-2009, 31-36	0.0054	0.0024	0.005, 0.002	0.0064	0.0029	0.006, 0.003
	2000-2009, 37-42	0.0066	0.0027	0.007, 0.003	0.0042	0.0031	0.004, 0.003
	2000-2009, 43-48	0.0094	0.0030	0.009, 0.003	-0.0002	0.0035	0.000, 0.003
	2000-2009, 49-54	0.0156	0.0036	0.016, 0.004	-0.0022	0.0040	-0.002, 0.004
	2000-2009, 55-60	0.0168	0.0042	0.017, 0.004	-0.0043	0.0047	-0.004, 0.005
	2000-2009, 60+	0.0374	0.0033	0.037, 0.003	0.0068	0.0036	0.007, 0.004
	2010-2016, 9-12	0.1264	0.0114	0.126, 0.011	0.0917	0.0126	0.092, 0.013
	2010-2016, 13-18	0.0353	0.0040	0.035, 0.004	0.0357	0.0047	0.036, 0.005
	2010-2016, 19-24	0.0077	0.0029	0.008, 0.003	0.0247	0.0036	0.025, 0.004
	2010-2016, 25-30	-0.0004	0.0028	0.000, 0.003	0.0167	0.0035	0.017, 0.003
	2010-2016, 31-36	0.0040	0.0030	0.004, 0.003	0.0154	0.0036	0.015, 0.004
	2010-2016, 37-42	0.0117	0.0033	0.012, 0.003	0.0167	0.0039	0.017, 0.004
	2010-2016, 43-48	0.0126	0.0037	0.013, 0.004	0.0158	0.0043	0.016, 0.004
	2010-2016, 49-54	0.0177	0.0044	0.018, 0.004	0.0092	0.0051	0.009, 0.005
	2010-2016, 55-60	0.0211	0.0051	0.021, 0.005	0.0037	0.0057	0.004, 0.006
	2010-2016, 60+	0.0353	0.0038	0.035, 0.004	0.0089	0.0043	0.009, 0.004
Sex	Male	0.0000			0.0000		
	Female	-0.0083	0.0005	-0.008, 0.001	-0.0077	0.0006	-0.008, 0.001
Birth order	2	0.0000			0.0000		
	3	0.0025	0.0007	0.003, 0.001	-0.0069	0.0010	-0.007, 0.001
	4	0.0101	0.0009	0.010, 0.001	-0.0151	0.0017	-0.015, 0.002
	5	0.0139	0.0012	0.014, 0.001	-0.0237	0.0025	-0.024, 0.002
	6	0.0179	0.0016	0.018, 0.002	-0.0319	0.0031	-0.032, 0.003
	7	0.0181	0.0021	0.018, 0.002	-0.0418	0.0039	-0.042, 0.004
	8	0.0258	0.0029	0.026, 0.003	-0.0433	0.0047	-0.043, 0.005
	9	0.0252	0.0039	0.025, 0.004	-0.0552	0.0057	-0.055, 0.006
	10	0.0273	0.0041	0.027, 0.004	-0.0661	0.0065	-0.066, 0.007
Maternal age	15-19	0.0312	0.0025	0.031, 0.003	0.0105	0.0037	0.011, 0.004
	20-24	0.0111	0.0009	0.011, 0.001	0.0001	0.0019	0.000, 0.002
	25-29	0.0032	0.0007	0.003, 0.001	0.0005	0.0011	0.000, 0.001
	30-34	0.0000			0.0000		
	35-39	0.0064	0.0010	0.006, 0.001	0.0029	0.0014	0.003, 0.001
	40-44	0.0130	0.0022	0.013, 0.002	0.0013	0.0030	0.001, 0.003
	45+	0.0290	0.0095	0.029, 0.010	0.0094	0.0100	0.009, 0.010
Birth year		-0.0003	0.0001	0.000, 0.000	0.0045	0.0003	0.004, 0.000

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Table S4 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
Family size	2	0.0000					
	3	-0.3397	0.0161	-0.340, 0.016			
	4	-0.3451	0.0161	-0.345, 0.016			
	5	-0.3474	0.0161	-0.347, 0.016			
	6	-0.3529	0.0161	-0.353, 0.016			
	7	-0.3519	0.0161	-0.352, 0.016			
	8	-0.3606	0.0162	-0.361, 0.016			
	9	-0.3569	0.0162	-0.357, 0.016			
	10	-0.3642	0.0162	-0.364, 0.016			
N			870,180			870,180	

Table S5: Results from linear probability models, with and without the application of sibling fixed effects, regressing infant mortality on the length of the preceding birth interval, for men and women born in Utah, 1947–2016.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth intervals	9-12	0.0203	0.0012	0.018, 0.023	0.0074	0.0014	0.005, 0.010
	13-18	0.0033	0.0004	0.002, 0.004	-0.0019	0.0005	-0.003, -0.001
	19-24	0.0003	0.0003	0.000, 0.001	-0.0011	0.0004	-0.002, 0.000
	25-30 (ref)	0.0000			0.0000		
	31-36	-0.0001	0.0003	-0.001, 0.001	0.0008	0.0004	0.000, 0.002
	37-42	0.0000	0.0004	-0.001, 0.001	0.0008	0.0005	0.000, 0.002
	43-48	0.0003	0.0004	-0.001, 0.001	0.0015	0.0006	0.000, 0.003
	49-54	-0.0004	0.0005	-0.001, 0.001	0.0003	0.0007	-0.001, 0.002
	55-60	-0.0006	0.0006	-0.002, 0.001	-0.0010	0.0008	-0.002, 0.001
	60+	0.0002	0.0004	-0.001, 0.001	-0.0033	0.0007	-0.005, -0.002
Sex	Male (ref)	0.0000			0.0000		
	Female	-0.0027	0.0002	-0.003, -0.002	-0.0029	0.0003	-0.003, -0.002
Birth order	2 (ref)	0.0000			0.0000		
	3	0.0002	0.0003	0.000, 0.001	-0.0076	0.0005	-0.009, -0.007
	4	0.0011	0.0004	0.000, 0.002	-0.0144	0.0008	-0.016, -0.013
	5	0.0015	0.0005	0.000, 0.003	-0.0212	0.0012	-0.024, -0.019
	6	0.0017	0.0007	0.000, 0.003	-0.0272	0.0015	-0.030, -0.024
	7	0.0030	0.0011	0.001, 0.005	-0.0324	0.0019	-0.036, -0.029
	8	0.0053	0.0015	0.002, 0.008	-0.0344	0.0023	-0.039, -0.030
	9	0.0086	0.0022	0.004, 0.013	-0.0357	0.0029	-0.041, -0.030
	10	0.0082	0.0022	0.004, 0.012	-0.0424	0.0032	-0.049, -0.036
Birth year	1947	0.0189	0.0019	0.015, 0.023	-0.0857	0.0065	-0.098, -0.073
	1948	0.0202	0.0019	0.017, 0.024	-0.0818	0.0064	-0.094, -0.069
	1949	0.0207	0.0018	0.017, 0.024	-0.0778	0.0062	-0.090, -0.066
	1950	0.0182	0.0017	0.015, 0.022	-0.0779	0.0060	-0.090, -0.066
	1951	0.0173	0.0016	0.014, 0.020	-0.0760	0.0058	-0.087, -0.065
	1952	0.0168	0.0015	0.014, 0.020	-0.0736	0.0057	-0.085, -0.062
	1953	0.0164	0.0015	0.013, 0.019	-0.0699	0.0055	-0.081, -0.059
	1954	0.0154	0.0015	0.012, 0.018	-0.0681	0.0054	-0.079, -0.058
	1955	0.0138	0.0014	0.011, 0.017	-0.0673	0.0052	-0.078, -0.057
	1956	0.0125	0.0014	0.010, 0.015	-0.0653	0.0051	-0.075, -0.055
	1957	0.0155	0.0015	0.013, 0.018	-0.0603	0.0050	-0.070, -0.051
	1958	0.0163	0.0015	0.013, 0.019	-0.0575	0.0049	-0.067, -0.048
	1959	0.0140	0.0014	0.011, 0.017	-0.0561	0.0047	-0.065, -0.047

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Table S5 – *Continued from previous page*

	Between-family comparison			Within-family comparison		
	β	SE	95% CI	β	SE	95% CI
1960	0.0121	0.0014	0.009, 0.015	-0.0556	0.0046	-0.065, -0.047
1961	0.0130	0.0014	0.010, 0.016	-0.0504	0.0045	-0.059, -0.042
1962	0.0123	0.0014	0.010, 0.015	-0.0507	0.0043	-0.059, -0.042
1963	0.0123	0.0015	0.009, 0.015	-0.0490	0.0042	-0.057, -0.041
1964	0.0115	0.0015	0.009, 0.014	-0.0466	0.0041	-0.055, -0.039
1965	0.0113	0.0016	0.008, 0.014	-0.0451	0.0041	-0.053, -0.037
1966	0.0101	0.0016	0.007, 0.013	-0.0446	0.0039	-0.052, -0.037
1967	0.0075	0.0015	0.005, 0.011	-0.0461	0.0038	-0.053, -0.039
1968	0.0095	0.0016	0.006, 0.013	-0.0400	0.0036	-0.047, -0.033
1969	0.0081	0.0015	0.005, 0.011	-0.0396	0.0035	-0.046, -0.033
1970	0.0069	0.0014	0.004, 0.010	-0.0391	0.0033	-0.046, -0.033
1971	0.0053	0.0013	0.003, 0.008	-0.0364	0.0031	-0.043, -0.030
1972	0.0050	0.0013	0.002, 0.008	-0.0371	0.0030	-0.043, -0.031
1973	0.0030	0.0012	0.001, 0.005	-0.0360	0.0028	-0.042, -0.030
1974	0.0041	0.0012	0.002, 0.006	-0.0324	0.0027	-0.038, -0.027
1975	0.0038	0.0011	0.002, 0.006	-0.0298	0.0026	-0.035, -0.025
1976	0.0020	0.0010	0.000, 0.004	-0.0293	0.0024	-0.034, -0.025
1977	0.0029	0.0010	0.001, 0.005	-0.0245	0.0023	-0.029, -0.020
1978	0.0027	0.0010	0.001, 0.005	-0.0233	0.0021	-0.027, -0.019
1979	0.0023	0.0010	0.000, 0.004	-0.0210	0.0020	-0.025, -0.017
1980	0.0016	0.0010	0.000, 0.003	-0.0209	0.0018	-0.025, -0.017
1981	0.0016	0.0010	0.000, 0.004	-0.0174	0.0017	-0.021, -0.014
1982	0.0023	0.0010	0.000, 0.004	-0.0152	0.0016	-0.018, -0.012
1983	0.0001	0.0009	-0.002, 0.002	-0.0150	0.0015	-0.018, -0.012
1984	0.0015	0.0010	0.000, 0.003	-0.0118	0.0014	-0.015, -0.009
1985	0.0018	0.0010	0.000, 0.004	-0.0085	0.0014	-0.011, -0.006
1986	0.0016	0.0010	0.000, 0.004	-0.0083	0.0013	-0.011, -0.006
1987	0.0000	0.0009	-0.002, 0.002	-0.0064	0.0012	-0.009, -0.004
1988	-0.0010	0.0009	-0.003, 0.001	-0.0053	0.0012	-0.008, -0.003
1989	0.0017	0.0010	0.000, 0.004	-0.0010	0.0013	-0.003, 0.001
1990 (ref)	0.0000			0.0000		
1991	-0.0014	0.0009	-0.003, 0.000	0.0010	0.0012	-0.001, 0.003
1992	-0.0011	0.0009	-0.003, 0.001	0.0037	0.0012	0.001, 0.006
1993	-0.0003	0.0010	-0.002, 0.002	0.0065	0.0012	0.004, 0.009
1994	-0.0009	0.0009	-0.003, 0.001	0.0080	0.0012	0.006, 0.010
1995	-0.0019	0.0009	-0.004, 0.000	0.0100	0.0013	0.007, 0.012
1996	-0.0023	0.0009	-0.004, -0.001	0.0113	0.0014	0.009, 0.014
1997	-0.0019	0.0009	-0.004, 0.000	0.0150	0.0015	0.012, 0.018

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Table S5 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1998	-0.0016	0.0009	-0.003, 0.000	0.0167	0.0016	0.014, 0.020
	1999	-0.0026	0.0009	-0.004, -0.001	0.0189	0.0016	0.016, 0.022
	2000	-0.0016	0.0009	-0.003, 0.000	0.0217	0.0018	0.018, 0.025
	2001	-0.0021	0.0008	-0.004, -0.001	0.0237	0.0019	0.020, 0.027
	2002	-0.0023	0.0008	-0.004, -0.001	0.0253	0.0020	0.021, 0.029
	2003	-0.0023	0.0008	-0.004, -0.001	0.0273	0.0021	0.023, 0.031
	2004	-0.0016	0.0008	-0.003, 0.000	0.0310	0.0023	0.027, 0.035
	2005	-0.0026	0.0008	-0.004, -0.001	0.0327	0.0024	0.028, 0.037
	2006	-0.0010	0.0009	-0.003, 0.001	0.0367	0.0025	0.032, 0.042
	2007	-0.0014	0.0008	-0.003, 0.000	0.0376	0.0027	0.032, 0.043
	2008	-0.0029	0.0008	-0.004, -0.001	0.0388	0.0028	0.033, 0.044
	2009	-0.0019	0.0008	-0.003, 0.000	0.0433	0.0029	0.038, 0.049
	2010	-0.0021	0.0008	-0.004, -0.001	0.0451	0.0031	0.039, 0.051
	2011	-0.0021	0.0008	-0.004, -0.001	0.0474	0.0032	0.041, 0.054
	2012	-0.0012	0.0008	-0.003, 0.000	0.0514	0.0033	0.045, 0.058
	2013	-0.0013	0.0009	-0.003, 0.000	0.0531	0.0035	0.046, 0.060
	2014	-0.0018	0.0009	-0.004, 0.000	0.0546	0.0036	0.047, 0.062
	2015	-0.0016	0.0009	-0.003, 0.000	0.0579	0.0038	0.050, 0.065
	2016	-0.0016	0.0009	-0.003, 0.000	0.0599	0.0039	0.052, 0.068
Maternal age	15-19	0.0061	0.0012	0.004, 0.008	0.0054	0.0018	0.002, 0.009
	20-24	0.0008	0.0004	0.000, 0.002	0.0002	0.0008	-0.001, 0.002
	25-29	0.0000	0.0003	-0.001, 0.001	0.0000	0.0005	-0.001, 0.001
	30-34 (ref)	0.0000			0.0000		
	35-39	0.0005	0.0004	0.000, 0.001	-0.0016	0.0006	-0.003, 0.000
	40-44	0.0078	0.0011	0.006, 0.010	0.0007	0.0014	-0.002, 0.004
	45+	0.0125	0.0047	0.003, 0.022	-0.0014	0.0050	-0.011, 0.008
Family size	2 (ref)	0.0000					
	3	-0.1201	0.0091	-0.138, -0.102			
	4	-0.1206	0.0091	-0.138, -0.103			
	5	-0.1201	0.0091	-0.138, -0.102			
	6	-0.1201	0.0091	-0.138, -0.102			
	7	-0.1183	0.0091	-0.136, -0.100			
	8	-0.1193	0.0092	-0.137, -0.101			
	9	-0.1201	0.0092	-0.138, -0.102			
	10	-0.1218	0.0092	-0.140, -0.104			
N			943,364			943,364	

Table S6: Results from linear probability models, with and without the application of sibling fixed effects, regressing college degree on the length of the preceding birth interval, for men and women born in Utah, 1950-1980.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth intervals	9-12	-0.03	0.00	-0.04, -0.02	0.00	0.01	-0.01, 0.02
	13-18 (ref)	0.00	0.00	0.00, 0.01	0.01	0.00	0.00, 0.01
	19-24	0.01	0.00	0.00, 0.01	0.00	0.00	-0.01, 0.00
	25-30	0.00			0.00		
	31-36	-0.01	0.00	-0.02, -0.01	0.00	0.00	-0.01, 0.00
	37-42	-0.03	0.00	-0.04, -0.02	-0.01	0.00	-0.02, 0.00
	43-48	-0.04	0.00	-0.05, -0.03	-0.01	0.00	-0.02, 0.00
	49-54	-0.05	0.00	-0.06, -0.04	-0.01	0.01	-0.02, 0.00
	55-60	-0.06	0.01	-0.07, -0.05	-0.01	0.01	-0.02, 0.00
	60+	-0.10	0.00	-0.11, -0.09	-0.01	0.01	-0.02, 0.00
Sex	Male (ref)	0.00			0.00		
	Female	-0.11	0.00	-0.11, -0.11	-0.11	0.00	-0.11, -0.11
Birth order	2 (ref)	0.00			0.00		
	3	-0.09	0.00	-0.09, -0.08	-0.03	0.00	-0.04, -0.03
	4	-0.16	0.00	-0.17, -0.16	-0.06	0.01	-0.07, -0.05
	5	-0.22	0.00	-0.22, -0.21	-0.07	0.01	-0.08, -0.06
	6	-0.27	0.00	-0.28, -0.26	-0.09	0.01	-0.11, -0.07
	7	-0.30	0.01	-0.31, -0.29	-0.09	0.01	-0.12, -0.07
	8	-0.35	0.01	-0.36, -0.33	-0.11	0.01	-0.13, -0.09
	9	-0.37	0.01	-0.39, -0.35	-0.12	0.02	-0.15, -0.09
	10	-0.42	0.01	-0.44, -0.40	-0.13	0.02	-0.16, -0.09
Birth year	1950	-0.06	0.01	-0.08, -0.05	-0.14	0.02	-0.18, -0.10
	1951	-0.08	0.01	-0.09, -0.07	-0.15	0.02	-0.19, -0.11
	1952	-0.08	0.01	-0.09, -0.06	-0.15	0.02	-0.19, -0.12
	1953	-0.09	0.01	-0.10, -0.07	-0.16	0.02	-0.20, -0.13
	1954	-0.10	0.01	-0.11, -0.08	-0.17	0.02	-0.21, -0.14
	1955	-0.10	0.01	-0.12, -0.09	-0.17	0.02	-0.20, -0.14
	1956	-0.10	0.01	-0.11, -0.08	-0.16	0.02	-0.19, -0.13
	1957	-0.10	0.01	-0.11, -0.08	-0.15	0.01	-0.18, -0.12
	1958	-0.09	0.01	-0.11, -0.08	-0.16	0.01	-0.18, -0.13
	1959	-0.09	0.01	-0.10, -0.07	-0.13	0.01	-0.16, -0.11
	1960	-0.08	0.01	-0.09, -0.07	-0.13	0.01	-0.15, -0.10
	1961	-0.07	0.01	-0.09, -0.06	-0.11	0.01	-0.13, -0.09
	1962	-0.06	0.01	-0.08, -0.05	-0.10	0.01	-0.12, -0.08

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Table S6 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1963	-0.05	0.01	-0.07, -0.04	-0.08	0.01	-0.10, -0.06
	1964	-0.03	0.01	-0.05, -0.02	-0.07	0.01	-0.09, -0.05
	1965	-0.03	0.01	-0.05, -0.02	-0.05	0.01	-0.07, -0.03
	1966	-0.04	0.01	-0.05, -0.02	-0.05	0.01	-0.07, -0.03
	1967	-0.02	0.01	-0.03, 0.00	-0.02	0.01	-0.04, 0.00
	1968	-0.01	0.01	-0.03, 0.00	-0.02	0.01	-0.04, 0.00
	1969	0.00	0.01	-0.02, 0.01	-0.01	0.01	-0.03, 0.01
	1970 (ref)	0.00			0.00		
	1971	-0.01	0.01	-0.02, 0.01	0.00	0.01	-0.02, 0.02
	1972	0.00	0.01	-0.01, 0.02	0.00	0.01	-0.02, 0.02
	1973	0.01	0.01	-0.01, 0.02	0.01	0.01	-0.01, 0.02
	1974	0.00	0.01	-0.01, 0.02	0.01	0.01	0.00, 0.03
	1975	0.01	0.01	0.00, 0.03	0.01	0.01	0.00, 0.03
	1976	0.02	0.01	0.00, 0.03	0.02	0.01	0.00, 0.04
	1977	0.01	0.01	0.00, 0.02	0.01	0.01	-0.01, 0.03
	1978	0.02	0.01	0.01, 0.04	0.03	0.01	0.00, 0.05
	1979	0.03	0.01	0.02, 0.04	0.02	0.01	0.00, 0.05
	1980	0.03	0.01	0.02, 0.04	0.04	0.01	0.01, 0.06
Maternal age	15-19	-0.39	0.01	-0.40, -0.38	-0.02	0.01	-0.04, 0.00
	20-24	-0.24	0.00	-0.25, -0.24	-0.01	0.01	-0.02, 0.00
	25-29	-0.10	0.00	-0.10, -0.09	0.00	0.00	-0.01, 0.00
	30-34 (ref)	0.00			0.00		
	35-39	0.06	0.00	0.06, 0.07	-0.01	0.01	-0.02, 0.00
	40-44	0.12	0.01	0.11, 0.14	0.01	0.01	-0.01, 0.03
	45+	0.10	0.02	0.06, 0.15	-0.05	0.03	-0.11, 0.00
Family size	2 (ref)	0.00					
	3	0.00	0.03	-0.05, 0.05			
	4	0.03	0.03	-0.02, 0.08			
	5	0.06	0.03	0.00, 0.11			
	6	0.08	0.03	0.03, 0.14			
	7	0.09	0.03	0.03, 0.14			
	8	0.10	0.03	0.05, 0.16			
	9	0.10	0.03	0.05, 0.16			
	10	0.09	0.03	0.03, 0.14			
N		269,263			269,263		

Table S7: Results from linear regression models, with and without the application of sibling fixed effects, regressing the Nam-Powers-Boyd Occupational Status score on the length of the preceding birth interval, for men and women born in Utah, 1950-1980.

		Between-family comparison			Within-family comparison		
Variable	Category	β	SE	95% CI	β	SE	95% CI
Birth intervals	9-12	-1.98	0.34	-2.64, -1.31	0.15	0.46	-0.75, 1.05
	13-18 (ref)	-0.32	0.20	-0.71, 0.07	0.30	0.27	-0.23, 0.83
	19-24	0.26	0.19	-0.11, 0.64	0.18	0.26	-0.32, 0.69
	25-30	0.00			0.00		
	31-36	-0.14	0.22	-0.57, 0.29	-0.03	0.30	-0.62, 0.56
	37-42	-0.45	0.24	-0.93, 0.03	0.20	0.34	-0.47, 0.86
	43-48	-0.97	0.27	-1.51, -0.43	0.06	0.38	-0.68, 0.80
	49-54	-1.30	0.31	-1.91, -0.69	0.10	0.44	-0.76, 0.96
	55-60	-1.59	0.35	-2.28, -0.91	0.01	0.50	-0.98, 0.99
	60+	-3.38	0.25	-3.87, -2.89	-0.29	0.40	-1.08, 0.50
Sex	Male (ref)	0.00			0.00		
	Female	-10.30	0.11	-10.53, -10.08	-11.18	0.16	-11.50, -10.86
Birth order	2 (ref)	0.00			0.00		
	3	-3.58	0.16	-3.91, -3.26	-1.70	0.26	-2.20, -1.20
	4	-6.29	0.20	-6.68, -5.89	-2.94	0.41	-3.74, -2.14
	5	-8.23	0.25	-8.72, -7.74	-3.29	0.56	-4.38, -2.19
	6	-10.63	0.32	-11.25, -10.01	-4.49	0.71	-5.88, -3.10
	7	-11.72	0.41	-12.53, -10.92	-4.41	0.86	-6.09, -2.73
	8	-13.84	0.54	-14.89, -12.78	-5.54	1.01	-7.52, -3.55
	9	-15.42	0.73	-16.86, -13.99	-6.06	1.22	-8.44, -3.68
	10	-17.22	0.76	-18.71, -15.73	-6.62	1.40	-9.36, -3.89
Birth year	1950	3.38	0.50	2.40, 4.36	-2.91	1.73	-6.31, 0.48
	1951	2.38	0.48	1.44, 3.32	-3.57	1.64	-6.79, -0.36
	1952	2.91	0.47	1.99, 3.82	-3.32	1.56	-6.38, -0.27
	1953	2.10	0.46	1.20, 3.00	-3.97	1.48	-6.86, -1.07
	1954	1.63	0.45	0.74, 2.52	-3.98	1.40	-6.72, -1.24
	1955	1.10	0.45	0.23, 1.98	-3.81	1.32	-6.40, -1.21
	1956	1.39	0.45	0.52, 2.26	-3.14	1.25	-5.59, -0.68
	1957	0.44	0.44	-0.43, 1.31	-3.64	1.18	-5.95, -1.32
	1958	0.15	0.44	-0.71, 1.02	-4.00	1.11	-6.18, -1.82
	1959	0.07	0.45	-0.80, 0.95	-3.19	1.04	-5.24, -1.15
	1960	-0.61	0.44	-1.48, 0.26	-4.08	0.98	-6.01, -2.16
	1961	-0.33	0.45	-1.22, 0.55	-2.94	0.92	-4.74, -1.14
	1962	-0.02	0.46	-0.92, 0.88	-2.31	0.87	-4.01, -0.62

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Table S7 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		β	SE	95% CI	β	SE	95% CI
	1963	-0.07	0.47	-1.00, 0.85	-2.04	0.82	-3.64, -0.43
	1964	0.62	0.48	-0.33, 1.56	-1.61	0.78	-3.14, -0.08
	1965	-0.67	0.50	-1.65, 0.31	-2.30	0.75	-3.77, -0.83
	1966	-0.52	0.53	-1.56, 0.51	-0.98	0.75	-2.44, 0.49
	1967	0.16	0.53	-0.87, 1.19	-0.56	0.71	-1.95, 0.83
	1968	-0.66	0.52	-1.69, 0.37	-1.25	0.69	-2.60, 0.10
	1969	0.12	0.52	-0.89, 1.13	-0.18	0.68	-1.51, 1.16
	1970 (ref)	0.00			0.00		
	1971	0.24	0.50	-0.74, 1.22	0.21	0.66	-1.09, 1.51
	1972	0.44	0.50	-0.55, 1.43	0.33	0.68	-0.99, 1.66
	1973	0.78	0.50	-0.21, 1.77	1.50	0.70	0.13, 2.87
	1974	0.45	0.49	-0.52, 1.41	0.40	0.74	-1.06, 1.86
	1975	0.72	0.48	-0.23, 1.67	1.96	0.77	0.45, 3.47
	1976	0.14	0.47	-0.78, 1.07	0.40	0.82	-1.22, 2.01
	1977	0.02	0.47	-0.90, 0.94	0.45	0.88	-1.26, 2.17
	1978	-0.76	0.48	-1.70, 0.17	0.45	0.96	-1.44, 2.33
	1979	-1.78	0.48	-2.72, -0.84	-0.38	1.03	-2.41, 1.64
	1980	-2.66	0.49	-3.62, -1.71	-0.89	1.14	-3.12, 1.34
Maternal age	15-19	-15.66	0.39	-16.42, -14.89	-0.73	0.86	-2.41, 0.95
	20-24	-8.96	0.21	-9.37, -8.56	-0.33	0.53	-1.37, 0.72
	25-29	-3.62	0.17	-3.96, -3.29	0.01	0.33	-0.63, 0.65
	30-34 (ref)	0.00			0.00		
	35-39	2.48	0.23	2.04, 2.93	-0.61	0.39	-1.38, 0.16
	40-44	3.99	0.39	3.23, 4.76	-2.41	0.77	-3.92, -0.89
	45+	3.54	1.45	0.71, 6.38	-6.50	2.32	-11.05, -1.95
Family size	2 (ref)	0.00					
	3	0.27	1.61	-2.89, 3.42			
	4	1.30	1.61	-1.85, 4.46			
	5	2.24	1.61	-0.92, 5.39			
	6	2.90	1.61	-0.26, 6.06			
	7	2.83	1.62	-0.35, 6.00			
	8	3.27	1.63	0.08, 6.46			
	9	3.05	1.65	-0.18, 6.27			
	10	3.62	1.65	0.39, 6.84			
N			159,380			159,380	

Table S8: Results from event history analyses, with and without stratification by shared mother, showing the relationship between mortality at ages 0-65+ and the length of the preceding birth interval, for men and women born in Utah, 1900-1949.

		Between-family comparison			Within-family comparison		
Variable	Category	HR	SE	95% CI	HR	SE	95% CI
Birth intervals	9-12	1.02	0.02	0.97-1.07	1.03	0.03	0.98-1.08
	13-18	0.97	0.01	0.95-0.99	0.98	0.01	0.96-1.01
	19-24	0.98	0.01	0.97-1.00	0.99	0.01	0.97-1.01
	25-30 (ref)	1.00			1.00		
	31-36	1.02	0.01	1.00-1.04	1.02	0.01	1.00-1.04
	37-42	1.01	0.01	0.99-1.04	1.02	0.01	1.00-1.05
	43-48	1.04	0.01	1.01-1.07	1.03	0.02	1.00-1.06
	49-54	1.05	0.02	1.02-1.09	1.02	0.02	0.99-1.06
	55-60	1.03	0.02	0.99-1.06	1.00	0.02	0.96-1.04
	60+	1.08	0.01	1.05-1.11	1.02	0.02	0.99-1.05
Sex	Male (ref)	1.00			1.00		
	Female	0.65	0.00	0.65-0.66	0.60	0.00	0.59-0.60
Birth order	2 (ref)	1.00			1.00		
	3	1.02	0.01	1.01-1.04	1.01	0.01	0.99-1.03
	4	1.03	0.01	1.01-1.05	1.01	0.02	0.98-1.04
	5	1.03	0.01	1.00-1.05	1.01	0.02	0.97-1.05
	6	1.05	0.01	1.03-1.08	1.03	0.03	0.98-1.08
	7	1.04	0.02	1.00-1.07	1.03	0.03	0.97-1.09
	8	1.05	0.02	1.01-1.09	1.05	0.04	0.99-1.13
	9	1.03	0.02	0.98-1.07	1.03	0.04	0.95-1.11
	10	1.07	0.02	1.03-1.12	1.04	0.05	0.95-1.13
Birth year	1900 (ref)	1.00			1.00		
	1901	0.98	0.06	0.88-1.09	0.97	0.05	0.87-1.08
	1902	0.99	0.05	0.89-1.11	0.95	0.05	0.86-1.05
	1903	0.96	0.05	0.86-1.06	0.92	0.05	0.83-1.02
	1904	0.93	0.05	0.84-1.03	0.88	0.05	0.79-0.97
	1905	0.96	0.05	0.88-1.06	0.88	0.05	0.80-0.98
	1906	0.96	0.05	0.87-1.06	0.87	0.04	0.78-0.96
	1907	1.00	0.05	0.91-1.09	0.89	0.05	0.80-0.98
	1908	0.93	0.04	0.85-1.02	0.84	0.04	0.75-0.93
	1909	0.93	0.04	0.85-1.02	0.83	0.04	0.75-0.92
	1910	1.00	0.05	0.92-1.10	0.84	0.05	0.76-0.94
	1911	0.99	0.04	0.90-1.08	0.83	0.05	0.75-0.93
	1912	0.98	0.04	0.89-1.07	0.83	0.05	0.74-0.93

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Table S8 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		HR	SE	95% CI	HR	SE	95% CI
	1913	0.98	0.04	0.90-1.07	0.84	0.05	0.75-0.94
	1914	0.97	0.04	0.89-1.06	0.80	0.05	0.71-0.90
	1915	0.96	0.04	0.88-1.05	0.81	0.05	0.72-0.91
	1916	0.94	0.04	0.86-1.03	0.81	0.05	0.71-0.92
	1917	0.89	0.04	0.82-0.98	0.77	0.05	0.68-0.88
	1918	0.89	0.04	0.82-0.97	0.77	0.05	0.67-0.88
	1919	0.88	0.04	0.81-0.96	0.76	0.05	0.66-0.87
	1920	0.88	0.04	0.80-0.96	0.78	0.06	0.68-0.91
	1921	0.90	0.04	0.83-0.98	0.77	0.06	0.67-0.90
	1922	0.90	0.04	0.82-0.98	0.75	0.06	0.65-0.88
	1923	0.89	0.04	0.82-0.98	0.74	0.06	0.63-0.86
	1924	0.85	0.04	0.78-0.93	0.69	0.06	0.59-0.81
	1925	0.83	0.04	0.75-0.90	0.69	0.06	0.58-0.82
	1926	0.80	0.04	0.73-0.87	0.67	0.06	0.56-0.79
	1927	0.77	0.04	0.70-0.84	0.64	0.06	0.53-0.76
	1928	0.77	0.04	0.71-0.85	0.65	0.06	0.54-0.77
	1929	0.76	0.03	0.69-0.83	0.63	0.06	0.53-0.76
	1930	0.74	0.03	0.68-0.81	0.63	0.06	0.52-0.77
	1931	0.71	0.03	0.65-0.78	0.59	0.06	0.49-0.72
	1932	0.69	0.03	0.63-0.75	0.57	0.06	0.46-0.69
	1933	0.67	0.03	0.61-0.74	0.57	0.06	0.46-0.71
	1934	0.66	0.03	0.60-0.72	0.53	0.06	0.43-0.66
	1935	0.63	0.03	0.57-0.69	0.50	0.06	0.40-0.62
	1936	0.62	0.03	0.56-0.68	0.49	0.06	0.39-0.61
	1937	0.62	0.03	0.56-0.68	0.51	0.06	0.40-0.64
	1938	0.62	0.03	0.56-0.68	0.50	0.06	0.40-0.64
	1939	0.62	0.03	0.56-0.69	0.52	0.06	0.41-0.66
	1940	0.58	0.03	0.53-0.64	0.47	0.06	0.37-0.60
	1941	0.58	0.03	0.53-0.64	0.49	0.06	0.39-0.64
	1942	0.59	0.03	0.53-0.65	0.48	0.06	0.37-0.62
	1943	0.56	0.03	0.50-0.62	0.47	0.06	0.36-0.61
	1944	0.54	0.03	0.49-0.60	0.45	0.06	0.35-0.59
	1945	0.55	0.03	0.50-0.62	0.48	0.07	0.37-0.63
	1946	0.54	0.03	0.49-0.60	0.47	0.07	0.36-0.63
	1947	0.54	0.03	0.49-0.60	0.49	0.07	0.37-0.65
	1948	0.51	0.03	0.45-0.56	0.43	0.06	0.32-0.58
	1949	0.52	0.03	0.47-0.59	0.44	0.07	0.33-0.59
Maternal age	15-19	1.11	0.03	1.06-1.16	0.95	0.04	0.88-1.02

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Table S8 – *Continued from previous page*

		Between-family comparison			Within-family comparison		
		HR	SE	95% CI	HR	SE	95% CI
	20-24	1.07	0.01	1.05-1.09	1.00	0.02	0.96-1.04
	25-29	1.02	0.01	1.01-1.04	1.00	0.01	0.98-1.03
	30-34 (ref)	1.00			1.00		
	35-39	0.98	0.01	0.96-1.00	1.00	0.01	0.98-1.03
	40-44	0.97	0.01	0.94-1.00	1.02	0.03	0.97-1.07
	45+	0.94	0.04	0.87-1.01	1.05	0.05	0.96-1.16
Family size	2 (ref)	1.00					
	3	0.98	0.02	0.93-1.02			
	4	1.00	0.02	0.96-1.05			
	5	1.06	0.02	1.01-1.11			
	6	1.08	0.03	1.04-1.14			
	7	1.12	0.03	1.07-1.18			
	8	1.13	0.03	1.08-1.19			
	9	1.15	0.03	1.09-1.21			
	10	1.16	0.03	1.10-1.22			
N		240,666			240,666		