Demography (2012) 49:1231–1257
DOI 10.1007/s13524-012-0132-x

Maternal Age and Offspring Adult Health: Evidence From the Health and Retirement Study

Mikko Myrskylä · Andrew Fenelon

Published online: 28 August 2012

Abstract Advanced maternal age is associated with negative offspring health outcomes. This interpretation often relies on physiological processes related to aging, such as decreasing oocyte quality. We use a large, population-based sample of American adults to analyze how selection and lifespan overlap between generations influence the maternal age–offspring adult health association. We find that offspring born to mothers younger than age 25 or older than 35 have worse outcomes with respect to mortality, self-rated health, height, obesity, and the number of diagnosed conditions than those born to mothers aged 25–34. Controls for maternal education and age at which the child lost the mother eliminate the effect for advanced maternal age up to age 45. The association between young maternal age and negative offspring outcomes is robust to these controls. Our findings suggest that the advanced maternal age–offspring adult health association reflects selection and factors related to lifespan overlap. These may include shared frailty or parental investment but are not directly related to the physiological health of the mother during conception, fetal development, or birth. The results for young maternal age add to the evidence suggesting that children born to young mothers might be better off if the parents waited a few years.

Keywords Maternal age · Maternal education · Reproductive aging · Orphanhood Health

Electronic supplementary material The online version of this article (doi:10.1007/s13524-012-0132-x) contains supplementary material, which is available to authorized users.

M. Myrskylä (✉)
Research Group Lifecourse Dynamics and Demographic Change,
Max Planck Institute for Demographic Research, Konrad-Zuse-Str. 1, 18057 Rostock, Germany
e-mail: myrskyla@demogr.mpg.de

A. Fenelon
Population Studies & Training Center, Brown University, Providence, RI, USA

Introduction

A hundred years ago, Alexander Graham Bell suggested that children born to young mothers have the longest lifespan and children born to older mothers have the shortest (Bell 1918). Since Bell, Lansing (1947, 1948) and others have demonstrated that the negative advanced parental age–offspring health association exists also among a wide range of nonhuman organisms, including rotifers, fruit flies, and yeast (for a review, see Priest et al. 2002). For humans, evidence of the negative association between advanced maternal age (mother aged 35 or older at the time of birth) and offspring health has been accumulating in recent years (Jacobsson et al. 2004; Liu et al. 2011; Nassar and Usta 2009; Tarín et al. 1998). Although some have found little or no evidence for the link between advanced maternal age and offspring adult health and mortality (e.g., Hubbard et al. 2009; Robine et al. 2003; Westendorp and Kirkwood 2001), the majority of studies have suggested that advanced maternal age is associated with a range of negative child and adult health outcomes, including Alzheimer's disease (Rocca et al. 1991), hypertension (Brion et al. 2008), diabetes (Gale 2010), cancer (Hemminki and Kyyrönen 1999; Johnson et al. 2009), and mortality (Kemkes-Grottenthaler 2004).

Discussion of the mechanisms behind the advanced maternal age–offspring health association is dominated by physiobiological interpretations that stress the importance of the health of the mother and her reproductive system during conception, gestation, and birth (Armstrong 2001; Durkin et al. 2008; Fang et al. 2008; Gale 2010; Johnson et al. 2009; Kemkes-Grottenthaler 2004; Menezes et al. 2010; Rocca et al. 1991). Socioeconomic selection and differences in the age at which the child loses the mother have received considerably less attention. These, however, may be integral to the maternal age–offspring health association.

First, childhood socioeconomic status is associated with adult health (Hayward and Gorman 2004; Strand and Kunst 2007). If maternal age correlates with childhood socioeconomic status, social selection may explain some of the maternal age–adult health link. Second, the age at which a child loses the mother—that is, the lifespan overlap between the mother and the child—is systematically related to maternal age: other things being equal, a child born to a 40-year-old mother can expect to lose the mother at an age that is 20 years younger than the age that a child born to a 20-year-old mother will lose the mother. Parental loss at a young age may influence a range of later-life outcomes, from education to health and longevity (Case et al. 2004; van Poppel 2000).

We use a large, population-based sample of American adults to analyze the roles of selection by socioeconomic status and lifespan overlap between the mother and the child in the maternal age–offspring adult health association. Consistent with prior literature, we find that children born to young and old mothers have worse adult health, are shorter, and have higher mortality than those born to mothers aged 25–34 years. Controls for maternal education and lifespan overlap wipe out the effect for advanced maternal age up to age 45. The association between young maternal age and negative offspring outcomes, however, is robust to these controls. Our findings suggest that up to maternal age 45, the maternal age–offspring adult health association is attributable to selection and factors proxied by age at which the child loses the mother. These factors may include within-family frailty or decreases in parental

investment. The physiological health status of the mother, however, seems to matter only insofar as it predicts the age at which the child loses the mother but does not appear to directly impact the health experience of the child at adult ages. Our results on young maternal age add to the evidence suggesting that children born to young mothers might be better off if the prospective parents waited a few years.

Importance

Prior research has suggested that the effects of advanced maternal age on offspring health are potentially large. Bell (1918) analyzed the descendants of William Hyde, an early settler in Connecticut in the seventeenth century, and found that those born to mothers aged 40 and older had 10.6 years shorter life expectancy than those born to mothers younger than 25 years. Jalavisto (1959) analyzed seventeenth- to nineteenth-century Finnish and Swedish families and found maternal age above 40 to be associated with five years shorter life expectancy than maternal age below 25. Kemkes-Grottenthaler (2004) found a similar difference in an analysis of seventeenth- to twentieth-century German data. Gavrilov et al. (1997) studied Russian nobility from the eighteenth to nineteenth centuries and found that daughters born to mothers older than 40 had 3.6 years shorter remaining life expectancy at age 30 than daughters born to mothers younger than 40. Analyses of European aristocracy, however, found only weak association between advanced maternal age and offspring longevity (Gavrilov and Gavrilova 2000).[1] Smith et al. (2009) analyzed Utah cohorts born in 1850–1900 and found that compared with maternal age 20–29, maternal age above 35 is associated with 8 % increased adult mortality for sons.

The advanced maternal age–offspring health association applies not only to all-cause mortality but also to specific medical conditions. Hemminki and Kyyrönen (1999) found that maternal age above 35 was associated with 50 % excess risk for leukemia. Yip et al. (2006) reported childhood retinoblastoma to have incidence rate ratio 2.39 for maternal age above 40 versus maternal age below 25, and Johnson et al. (2009) found that childhood cancer risk increases by 8 % for every five-year increase in maternal age beyond age 20. Advanced maternal age has also been linked with autism (Durkin et al. 2008), bipolar affective disorder (Menezes et al. 2010), Alzheimer's disease (Rocca et al. 1991), hypertension (Brion et al. 2008), and diabetes (Gale 2010).

These associations have prompted some to ask, "How old is too old?" (Heffner 2004). It has been suggested that people should be better informed about the risks associated with advanced maternal age (Benzies 2008). Indeed, if the maternal age–offspring health association is causal, fertility postponement into ever higher ages (Billari et al. 2007; Frejka and Sobotka 2009) may become a public health concern.

[1] Gavrilov and Gavrilova (2000) and others (for a review, see Liu et al. 2011) have found evidence that advanced paternal age may also be linked with offspring health. We focus on maternal age. However, as paternal age correlates with maternal age (Ní Bhrolcháin 2001), paternal age may confound the maternal age–offspring health association. Online Resource 1 documents that our results are robust to controls for paternal age.

Mechanisms

Our main interest is in advanced maternal age and its effects. Although young maternal age is also associated with negative offspring health (D'Onofrio et al. 2009; Fraser et al. 1995; Geronimus and Korenman 1992; Levine et al. 2007; Scholl et al. 1992), the mechanism that produces the maternal age–offspring health association for young mothers may be different from the mechanism behind the association for older mothers. Thus, we discuss young maternal age only briefly and concentrate on advanced maternal age.

The mechanisms thought to be responsible for the young maternal age–offspring health link are related to the physiological immaturity and sociodemographic disadvantage that often accompany young parenthood (Fraser et al. 1995). Some of the young maternal age–offspring health association may be due to selection (Geronimus and Korenman 1992), but there is no consensus on this (D'Onofrio et al. 2009). On the other hand, the negative association between advanced maternal age and adult health is thought to be driven by the physiological reproductive aging of the mother. As the female body ages, physiobiological functioning—which is critical for a healthy conception, fetal development, low-risk birth, and post-birth development—deteriorates. This deterioration may result in compromised birth outcomes or suboptimal post-birth development. Two potential alternative mechanisms are selection by maternal characteristics and differences in intergenerational transfers by maternal age. We discuss each of these below.

Maternal Age and Reproductive Aging

Delayed motherhood is characterized by increased probability of obstetric complications and perinatal problems (Tarín et al. 1998). These problems are largely related to declining fecundity, which has long been recognized in demographic and epidemiological literature (Heffner 2004; Leridon 2004; Menken et al. 1986). For women, fecundity decline and the probability of adverse pregnancy outcomes begin to increase in one's late 20s and early 30s (American Society for Reproductive Medicine 2003; van Noord-Zaadstra et al. 1991). The biological mechanisms responsible for the fecundity decline are related to accumulation of DNA damage in germ cells (Kaytor et al. 1997), decreasing oocyte quality (Armstrong 2001; Eichenlaub-Ritter 1998), and weakening of the placenta (Bottini et al. 2001). These processes relate to a wide array of negative birth outcomes, including chromosomal abnormalities and birth defects.

Maternal aging may promote the development of conditions for the child in adulthood by impacting the early life conditions of the offspring. DNA damage in germ cells, chromosomal changes, and pregnancy complications that increase with age have been suggested as causes of the association between advanced maternal age and schizophrenia and Alzheimer's disease (Croen et al. 2007; Durkin et al. 2008; Menezes et al. 2010) and between advanced maternal age and cancer (Johnson et al. 2009). Alternatively, aging-induced changes in hormonal levels or other physiological parameters that modify the intrauterine environment may influence offspring health, such as risk of cancer (Ekbom et al. 1997; Johnson et al. 2009).

Advanced maternal age may also be positively linked with offspring health. Birth weight may increase with maternal age (Fessler et al. 2005), and low birth weight predicts adult diseases, such as coronary artery disease and diabetes (Barker 2002). The detrimental effect of higher germ cell damage of older parents may be offset by the increased longevity of those able to bear children later in life. Finally, older parents may have access to greater resources and higher socioeconomic status, which are linked to improved offspring health.

Alternative Mechanisms

For many of the health outcomes discussed above, evidence for the aging-related mechanism that might cause the maternal age–offspring outcomes link is largely speculative. In addition to the aging-related mechanisms, one should acknowledge the potential role of alternative, non-aging-related mechanisms. These include selection (women who have children at certain ages may be different from those who have children at other ages), changing resources (those who have children later may have accumulated more resources than those who have children earlier), differences in parental investment, and shared frailty. Although these explanations are occasionally mentioned, their contribution to the maternal age–offspring health association has received little direct analysis. We point to two particularly important factors: parental socioeconomic status and age at which the child loses the parents. Both factors are potential confounders because they are likely to be correlated with both parental age and offspring health.

Childhood socioeconomic status is strongly associated with adult health and mortality (Galobardes et al. 2004; Hayward and Gorman 2004; Strand and Kunst 2007). The mechanisms through which childhood social environment influences adult health may be direct, operating through childhood health; or indirect, operating through adult characteristics such as attained socioeconomic status and health behaviors (Preston et al. 1998). Independent of the mechanism, if maternal age correlates with childhood socioeconomic status, social selection may explain some of the maternal age–adult health link. Currently, older parents are often more affluent and have higher educational attainment than younger parents (Bray et al. 2006). These socioeconomic differences influence health in childhood and adulthood so that those born to young, often socially deprived, mothers have worse health outcomes than those born to older mothers (Bradley et al. 2002). There is, however, no evidence that advanced parental age was positively associated with socioeconomic status in historical periods, or in the first half of the twentieth century, when participants of this and many other studies on parental age effects were born.

The age at which the child loses the parent is in turn systematically related to parental age: holding other factors constant, a child born to a 20-year-old mother will, on average, lose the mother at an age 20 years older than would a child who is born to a 40-year-old mother. The age at which the child loses the parent may proxy shared family frailty. Long-lived parents have long-lived children, and long-lived parents having children at older ages may influence the association. Additionally, children who lose their parents at a younger age may be scarred by the psychological shock associated with parental loss, or they may receive less parental investment than their counterparts with greater lifespan overlap with their parents. As a result, individuals

who lose their parents at a younger age may have lower socioeconomic attainment and worse health at adult ages (Andersson et al. 1996; Case et al. 2004; van Poppel 2000). Thus, having an older parent may be more a socioeconomic liability than a physiological one.

Methods

Participants

This is a prospective cohort study. We use the Health and Retirement Study (HRS), a nationally representative panel survey of Americans aged 50 and older and their spouses. The HRS has five entry cohorts with follow-up: the initial HRS cohort, born in 1931–1941 and entering the study in 1992; the Assets and Health Dynamics Among the Oldest Old cohort, born before 1924 and entering in 1993; the Children of the Depression cohort, born in 1924–1930 and entering in 1998; the War Babies cohort, born in 1942–1947 and entering in 1998; and the Early Baby Boomer cohort, born 1948–1953 and entering in 2004. We use these HRS cohorts and include in our analytical sample persons who were aged 40 or older when entering the study. Follow-up is until 2008. The initial sample size is 30,294 persons. After exclusion of subjects with missing data on maternal age (10,881 persons) or other variables (1,078 persons), our sample size is 18,335 subjects with average age of 56.3 years at first interview and with 3,142 deaths over an average follow-up of 11.2 years.

Variables

Dependent Variables

We analyze all-cause mortality and four nonfatal health outcomes: obesity, height, self-rated health, and a frailty index defined as the cumulative sum of eight diagnosed conditions. All measurements except mortality are based on the first interview.

For mortality, survival time is measured from the first interview. Month and year of death are obtained from the National Death Index. Height is measured in centimeters. Obesity is measured using an indicator equal to 1 if body mass index (BMI, defined as kg/m^2) is 30 or more, and 0 otherwise. Both height and weight are based on self-reports. Self-rated health is reported as excellent, very good, good, fair, or poor. We code these to a five-point continuous variable with 1 = excellent and 5 = poor.

We conceptualize frailty as a result of multiple interacting factors and define the frailty index as a cumulative sum of eight diagnosed conditions. These are based on self-reports to questions of the type, "Has a doctor ever told you that you have [the condition]?" The conditions for which HRS has information are high blood pressure or hypertension; diabetes or high blood sugar; cancer or a malignant tumor (not skin cancer); chronic lung disease except asthma; heart attack, coronary heart disease, or other heart problems; stroke or transient ischemic attack (TIA); emotional, nervous, or psychiatric problems; and arthritis or rheumatism. From these data, we construct a frailty index, which is the cumulative sum of diagnosed conditions, ranging from 0 to 8.

Independent Variables

The key independent variable is maternal age, defined as the age of the mother (years) at the time of the child's birth. The HRS asks questions about whether the mother is alive; if yes, how old the mother is; and if not, when and at what age the mother died. These answers, combined with the survey year and birth year of the respondent, allow calculation of maternal age. We categorize maternal age as 14–19, 20–24, 25–34 (reference group), 35–39, 40–44, and 45–49.

Other independent variables of particular interest are maternal education and lifespan overlap between the child and the mother. Maternal education is measured with a binary indicator equal to 1 if the mother has eight or more years of schooling, and 0 otherwise. We use this measure because some of the HRS waves have only categorical information on maternal education, and binary education was the only consistently comparable measure that could be constructed.

Lifespan overlap between the child and the mother is measured by using an indicator equal to 1 if the mother was alive when the person was aged 40, and 0 otherwise. This indicator is crude, but we prefer this measure over a continuous measure of the number of years children overlap with their mothers because of its simplicity and to avoid problems of censoring for those children with living mothers. We show that the results are robust to alternative, more nuanced specifications of lifespan overlap in the Online Resource 1.

We control for lifespan overlap for two reasons. First, lifespan overlap is systematically and negatively related to maternal age, as discussed above. Second, lifespan overlap may be related to offspring health through numerous mechanisms. Lifespan overlap may capture differences in intergenerational social and economic transfers that result from differences in the age at which the child lost the parent. Lifespan overlap may also capture age-related differences in the effect of the psychological shock that is related to parental loss. In addition, lifespan overlap may implicitly reflect differences in general maternal health insofar as they are reflected in the years that the parent lives after the birth of the child. Finally, lifespan overlap may capture differences in familial longevity, which may have genetic, epigenetic, or behavioral roots.

Optimally one would measure each of these mechanisms directly, but lack of data prevents us from doing so. Nevertheless, controlling for lifespan overlap helps to elucidate whether the impact of parental age on offspring health is due to the physiological health of parental reproductive systems at and around the time of birth or due to alternative factors that operate later in life. In addition, we are able to shed light on the importance of the intergenerational transfers mechanism by including as control variables the person's own socioeconomic attainment, measured by education (less than high school, high school, some college, and bachelor's degree or higher) and household income (logged). If lifespan overlap influences the maternal age–offspring health association through intergenerational transfers, controls for respondent socioeconomic status should attenuate the size and significance of the regression coefficient for lifespan overlap. If lifespan overlap reflects other factors, such as within-family frailty, the importance of lifespan overlap should be robust to these controls.

Other independent variables are birth year, age and age squared at baseline (years), sex, and race/ethnicity (white, black, other).

Statistical Models

We estimate five different models for each health outcome. The following set of equations illustrates the hierarchy of the models by using self-rated health as the model outcome variable:

$$Y = \alpha + \beta_1 \mathbf{MAB} + \beta_2 \mathbf{DEM} + \varepsilon \quad (1)$$

$$Y = \alpha + \beta_1 \mathbf{MAB} + \beta_2 \mathbf{DEM} + \beta_3 \mathit{MatEdu} + \varepsilon \quad (2)$$

$$Y = \alpha + \beta_1 \mathbf{MAB} + \beta_2 \mathbf{DEM} + \beta_4 \mathit{Overlap} + \varepsilon \quad (3)$$

$$Y = \alpha + \beta_1 \mathbf{MAB} + \beta_2 \mathbf{DEM} + \beta_3 \mathit{MatEdu} + \beta_4 \mathit{Overlap} + \varepsilon \quad (4)$$

$$Y = \alpha + \beta_1 \mathbf{MAB} + \beta_2 \mathbf{DEM} + \beta_3 \mathit{MatEdu} + \beta_4 \mathit{Overlap} + \beta_5 \mathbf{SES} + \varepsilon, \quad (5)$$

where Y is the health outcome; **MAB** is the vector of maternal age; **DEM** is the vector of demographic characteristics (birth year, age and age squared, sex, and race/ethnicity); *MatEdu* is the indicator for maternal education; *Overlap* is the indicator for lifespan overlap (mother alive/dead when ego is aged 40); and **SES** is the vector of person's own education and logged household income.

Model 1 estimates the association between maternal age and health and adjusts for basic demographic variables. Model 2 adds maternal education as a control variable to Model 1. Comparing Models 1 and 2 demonstrates the confounding influence of maternal education in the maternal age–offspring health association. Model 3 adds lifespan overlap with the mother to Model 1. Comparing the results between Models 1 and 3 reveals the confounding influence of lifespan overlap in the maternal age–offspring health association.

Model 4 simultaneously adds maternal education and lifespan overlap with the mother to Model 1. Comparing the results between Model 1 and Model 4 shows the joint confounding influence of education and lifespan overlap in the maternal age–offspring health association. Model 5 adds controls for adult socioeconomic status. Comparing the lifespan overlap coefficient in Models 4 and 5 helps understand the pathways through which lifespan overlap influences the maternal age–offspring health association. Because own socioeconomic status is on the pathway from maternal age to offspring health, interpretation of the maternal age coefficient must be cautious in Model 5.

We estimate Models 1–5 for the five health outcomes using four model specifications. For self-rated health and height, we use the ordinary linear regression model. For the count variable frailty, we use the negative binomial regression because the

data exhibited overdispersion. For obesity, we use a logistic model. For all-cause mortality, we use a Cox proportional hazards model. All models account for the households clustering of subjects by using a robust variance-covariance estimator. In the Cox model, we use time-on-study for time scale and adjust for age and age squared; this approach performed well in a study comparing six different choices of time scale in cohort studies (Pencina et al. 2007). We handle ties with the Breslow method. We checked the proportional hazards assumption for maternal age by testing the significance of the interaction terms with the log of follow-up time. The tests did not indicate deviations from proportionality.

For each outcome we also illustrate the maternal age–offspring health associations with a semiparametric regression model (Lokshin 2006) that imposes no shape on the dependent variable–maternal age association (the nonparametric part) while controlling for other independent variables as in a normal regression (the parametric part). We estimate these models with controls corresponding to Model 1 (descriptive association) and Model 4 (controls for maternal education and lifespan overlap).

Results

Descriptive Analyses

Table 1 shows the sample characteristics. Advanced maternal age is relatively rare: only 12 % have maternal age 35 or older. Young maternal age is more common: 16.6 % have maternal age below 20. The respondents were born, on average, in 1939–1940, and there is little variation in birth year by maternal age. Those with the oldest mothers are slightly older than those with younger mothers: at first interview, mean age was 57.1 years for those with maternal age 40–44 and 56.1 years for those with maternal age 25–34. The proportion of women is approximately 60 % in all maternal age groups except among those with maternal age 45–49, where only 49 % are women. This difference is not statistically significant ($p > .05$) and may reflect small sample variation.

Mean follow-up is 8.2 years for those who died and 11.8 for the censored. The proportion who died during the follow-up is highest for young and old maternal age and lowest in the maternal age group 25–34. Frailty index, self-rated health, proportion obese, and height exhibit a similar U-shaped pattern: the health outcomes are worst for those born to young or old mothers and best for those born to mothers aged 25–34.

The independent variables show that there is a U-shape (inverted) association also in maternal education, which is lowest among those with young or old mothers and highest among those with maternal age 20–34. Lifespan overlap, in turn, decreases almost monotonically with maternal age. Over 50 % of those with maternal age above 40 lost their mothers by the time they themselves were 40 years old. Among those with maternal age below 35, this percentage is only 20 %. Own socioeconomic characteristics show a similar pattern to what we observed for health outcomes. Those born to mothers aged 25–34 have a higher household income and are more likely to have a college education than those born to older or younger mothers.

Table 1 Baseline demographic and health characteristics (means and standard deviations) by maternal age: Health and Retirement Study, participants aged 40 or older at baseline

	Maternal Age						
	Overall	14–19	20–24	25–34	35–39	40–44	45–49
Demographic Characteristics							
Number of respondents (%)	18,335	3,046	5,481	7,598	1,521	544	145
	(100)	(16.6)	(29.9)	(41.4)	(8.3)	(3.0)	(0.8)
Birth year (SD)	1939.6	1939.3	1939.7	1939.8	1939.4	1938.6	1937.7
	(8.4)	(8.6)	(8.6)	(8.3)	(8.1)	(8.0)	(7.9)
Age at first interview (SD)	56.3	56.4	56.4	56.1	56.2	57.1	57.3
	(6.7)	(7.0)	(6.8)	(6.5)	(6.5)	(6.7)	(6.9)
Women (%)	59.4	58.3	59.9	59.5	59.9	59.0	49.0
Race/Ethnicity (%)							
White	81.0	71.8	82.1	84.1	81.5	80.0	64.1
African American	15.3	24.3	14.2	12.5	14.6	14.0	28.3
Other	3.7	3.9	3.7	3.4	3.9	6.1	7.6
Dependent Variables							
Died during the follow-up (%)	17.1	19.3	17.2	15.6	18.3	18.9	29.7
Mean follow-up, years (SD)							
For those who died	8.2	8.0	8.4	8.1	8.4	8.1	9.0
	(4.4)	(4.4)	(4.5)	(4.3)	(4.5)	(4.1)	(4.2)
For censored	11.8	11.9	11.6	11.7	12.0	12.0	12.5
	(5.0)	(4.9)	(5.0)	(5.0)	(4.9)	(4.8)	(4.7)
Frailty index[a] (SD)	1.1	1.2	1.1	1.0	1.2	1.2	1.4
	(1.2)	(1.2)	(1.2)	(1.1)	(1.2)	(1.3)	(1.3)
Self-rated health[b] (SD)	2.6	2.7	2.6	2.5	2.7	2.7	3.1
	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)	(1.3)	(1.2)
Height, centimeters (SD)	168.9	168.5	168.8	169.3	168.7	168.5	169.2
	(10.1)	(10.2)	(10.0)	(10.0)	(10.0)	(10.3)	(10.0)
Obese (BMI≥30) (%)	25.5	30.1	25.4	23.5	26.4	25.9	26.9
Independent Variables							
Mother's educ. 8+ years (%)	69.7	68.0	72.9	71.9	58.6	54.6	37.9
Mother alive when ego aged 40 (%)	79.1	87.3	87.8	78.2	60.0	47.8	25.5
Own household income, $ (SD)	56,702	46,581	57,505	61,987	52,581	48,692	35,242
	(96,036)	(77,686)	(78,136)	(120,286)	(56,805)	(55,201)	(29,552)
Own education (%)							
Less than high school	22.5	28.0	21.2	20.3	23.6	27.6	44.1
High school	53.4	55.1	55.0	52.0	52.7	50.9	44.8
Some college	15.9	11.9	16.1	17.9	15.1	14.5	6.2
BA or higher	8.2	5.1	7.8	9.9	8.7	7.0	4.8

[a]Frailty index calculated as the sum of the following eight diagnosed medical conditions: cancer, lung disease, mental health problems, diabetes, heart disease, stroke, blood pressure, and arthritis.

[b]Coded as a linear variable with range from 1 = excellent to 5 = poor.

In summary, mother's education, lifespan overlap, and socioeconomic outcomes are associated with maternal age, highlighting the importance of adjusting for these characteristics in the maternal age–offspring health analysis.

Regression Analyses

Frailty

Table 2 shows the association between the frailty index and maternal age. Model 1 estimates the association while controlling for basic demographic characteristics; Model 2 adds maternal education to Model 1; Model 3 adds maternal lifespan overlap to Model 1; Model 4 adds simultaneously maternal education and maternal lifespan overlap to Model 1; and Model 5 adds own socioeconomic attainment to Model 4. Figure 1 illustrates the results for Model 1 and Model 4.

Model 1 shows that there is a strong U-shaped association between maternal age and the frailty index, such that those born to young or old mothers have the highest incidence of health conditions. The negative binomial regression coefficients for five-year age groups from 14–19 to 45–49 are, respectively, 0.131, 0.036, 0 (reference age 25–29), 0.093, 0.108, and 0.223 ($p < .05$ for each except the reference coefficient). These correspond to 14 %, 4 %, 10 %, 11 %, and 25 % elevated incidence ($100 \times [\exp(\beta) - 1]$) for maternal ages 14–19, 20–24, 35–39, 40–44, and 45–49, respectively, with maternal age 25–29 as the reference. Coefficients for the control variables are in the expected direction. Figure 1 illustrates how frailty index starts to increase at the maternal age of about 30 for Model 1.

Model 2 adds controls for maternal education. The effects associated with young maternal age (<25) are virtually unchanged, while those associated with advanced maternal age are slightly attenuated but stay statistically and substantively significant. Unsurprisingly, those whose mother had eight or more years of schooling have fewer conditions than those with less-educated mothers.

Model 3 adds controls for lifespan overlap to Model 1. The effects associated with young maternal age are marginally strengthened, but those associated with advanced maternal age are markedly attenuated. The coefficient for lifespan overlap, –0.158 ($p < .001$), indicates that those whose mother was alive when they were aged 40 had 15 % lower incidence of health conditions than those whose mother had died.

Model 4 controls simultaneously for maternal education and lifespan overlap. The negative effects associated with young maternal age are robust to these controls. The effects associated with advanced maternal age, however, are attenuated to a point at which they lose statistical significance. Those born to mothers aged 35–39 and 40–44 have, respectively, 5 % ($p = .22$) and 4 % ($p = .62$) higher incidence of health conditions than those born to mothers aged 25–34. These are statistically and substantively negligible differences. The coefficient associated with maternal age 45–49 stays at 0.12 (12 % higher incidence) but loses significance. Figure 1 illustrates how the frailty index increases very little before maternal age 45 after maternal education and lifespan overlap are controlled (Model 4), whereas the young maternal age effect is robust to these adjustments.

Table 2 Maternal age and frailty index—Negative binomial model, with frailty index calculated as the sum of eight diagnosed medical conditions (cancer, lung disease, mental health problems, diabetes, heart disease, stroke, blood pressure, and arthritis): Health and Retirement Study

	Model 1	Model 2	Model 3	Model 4	Model 5
Maternal Age (ref. = 25–34)					
14–19	0.131***	0.130***	0.149***	0.147***	0.109***
20–24	0.036*	0.038*	0.050**	0.051**	0.038*
35–39	0.093***	0.076**	0.064*	0.050	0.051
40–44	0.108*	0.088*	0.058	0.043	0.034
45–49	0.223**	0.187*	0.145†	0.117	0.076
Birth Year	0.011***	0.012***	0.012***	0.013***	0.017***
Age at First Interview	0.142***	0.141***	0.142***	0.141***	0.139***
Age^2 at First Interview / 100	−0.083***	−0.083***	−0.082***	−0.082***	−0.078***
Female	0.095***	0.092***	0.092***	0.089***	0.067***
Race/Ethnicity (ref. = white)					
African American	0.268***	0.242***	0.253***	0.230***	0.179***
Other	0.092*	0.045	0.085*	0.042	0.012
Maternal Characteristics					
Mother's education 8+ years		−0.129***		−0.121***	−0.010
Mother alive when ego aged 40			−0.158***	−0.149***	−0.132***
Own Education (ref. = high school)					
Less than high school					0.144***
Some college					−0.142***
BA or higher					−0.241***
Own Household Income (log)					−0.057***
Constant	−27.454***	−28.955***	−28.859***	−30.170***	−38.379***
Observations	18,335	18,335	18,335	18,335	18,335
AIC	50,603.21	50,542.62	50,532.16	50,479.77	50,060.40
BIC	50,704.83	50,652.06	50,641.59	50,597.01	50,208.91
Chi-square	1,096.01	1,158.60	1,169.06	1,223.46	1,650.82
Pseudo-R^2	.02	.02	.02	.02	.03

Notes: Model 1: Negative binomial model controlling for birth year, age, age squared, sex, and race/ethnicity. Model 2: Adds maternal education to Model 1. Model 3: Adds lifespan overlap between the mother and the child to Model 1. Model 4: Adds maternal education and lifespan overlap with the mother to Model 1. Model 5: Adds controls for own education and household income to Model 4. All models control for household clustering in the standard error estimation.

†$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

Model 5 adds own socioeconomic attainment to Model 4. These controls attenuate slightly the coefficients for young maternal age but do not affect the advanced maternal age coefficients. Maternal education, however, loses all predictive power, suggesting that maternal education influences health and confounds the maternal age–offspring health association through offspring socioeconomic attainment. The lifespan overlap coefficient is more robust to controls for own socioeconomic attainment, decreasing by only 11 %, from −0.149 to −0.132. This suggests that the mechanism through which lifespan overlap is associated with offspring health only partially reflects intergenerational transmission of economic and social resources.

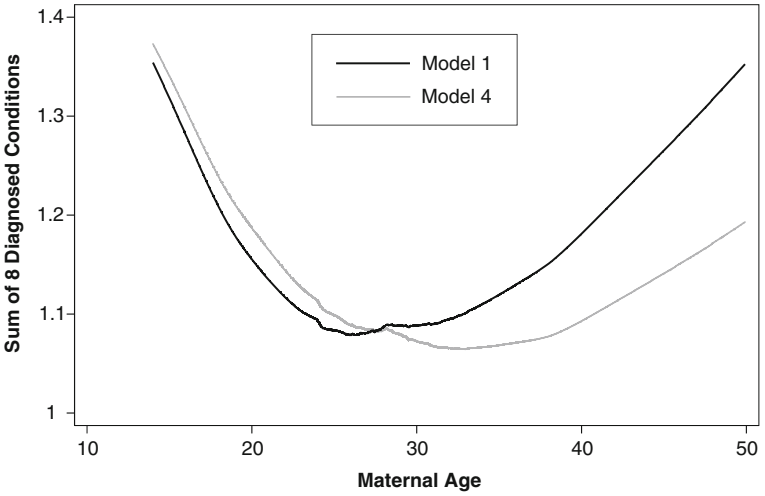

Fig. 1 Maternal age and frailty index. Estimates are based on a semiparametric lowess model. Black line corresponds to Model 1 and controls for only demographic characteristics birth year, age, age squared, sex, and race/ethnicity. Gray line corresponds to Model 4 and adds as controls maternal education and lifespan overlap with the child and the mother

Self-rated Health

Table 3 shows the results for self-rated health; Fig. 2 illustrates the results with semiparametric regression. The patterns are highly similar to those for frailty. Model 1 shows that those born to mothers younger than 25 or older than 35 have worse self-rated health than those born to mothers aged 25–34. Controlling for maternal education (Model 2) or lifespan overlap (Model 3) slightly strengthens the effects for young maternal age and attenuates the effects for advanced maternal age but does not alter the overall U-shaped pattern. Controlling simultaneously for maternal education and lifespan overlap (Model 4) attenuates the effects for advanced maternal age up to age 45 to a level that is uninteresting both statistically and substantively. The coefficient for maternal age 45–49 stays relatively large and statistically significant ($p < .05$).

Controls for own socioeconomic status (Model 5) attenuate the maternal age coefficients that remained significant in Model 4 (ages below 25 and above 45) by 40 %–50 %, suggesting that young and very old maternal ages are associated with self-rated heath through socioeconomic status. Maternal education is attenuated by 61 %, but lifespan overlap by only 25 %. As with the frailty index, lifespan overlap influences the maternal age–offspring health association only partially through socio-economic attainment.

Height

Table 4 shows the results for height; Fig. 3 illustrates the results using semiparametric regression. Model 1 shows that those with maternal age below 25 or above 35 are shorter than those with maternal age 25–34. Controlling for maternal education (Model 2) or lifespan overlap (Model 3) does not change the associations for young maternal age. Controlling for maternal education removes the effects associated with

Table 3 Maternal age and self-rated health— Linear model, with self-rated health is coded as a linear response variable (1 = excellent and 5 = poor): Health and Retirement Study

	Model 1	Model 2	Model 3	Model 4	Model 5
Maternal Age (ref. = 25–34)					
14–19	0.161***	0.155***	0.181***	0.172***	0.086***
20–24	0.048*	0.056**	0.063**	0.068***	0.040*
35–39	0.136***	0.078*	0.101**	0.051	0.057
40–44	0.149**	0.078	0.090†	0.031	0.012
45–49	0.441***	0.310**	0.342***	0.231*	0.132
Birth Year	0.009***	0.012***	0.010***	0.012***	0.023***
Age at First Interview	0.073***	0.072***	0.072***	0.072***	0.067***
Age^2 at First Interview / 100	−0.037**	−0.037**	−0.036**	−0.037**	−0.029*
Female	0.024	0.015	0.020	0.013	−0.032†
Race/Ethnicity (ref. = white)					
African American	0.519***	0.429***	0.501***	0.416***	0.291***
Other	0.473***	0.306***	0.466***	0.303***	0.240***
Maternal Characteristics					
Mother's education 8+ years		−0.468***		−0.459***	−0.180***
Mother alive when ego aged 40			−0.196***	−0.161***	−0.120***
Own Education (ref. = high school)					
Less than high school					0.440***
Some college					−0.270***
BA or higher					−0.366***
Own Household Income (log)					−0.142***
Constant	−17.793***	−22.808***	−19.301***	−23.944***	−43.548***
Observations	18,335	18,335	18,335	18,335	18,335
AIC	57,494.11	56,898.97	57,415.97	56,845.38	55,078.29
BIC	57,587.91	57,000.58	57,517.58	56,954.81	55,218.99
F Statistic	80.64	126.91	80.93	121.77	212.09
R^2	0.05	0.08	0.05	0.08	0.16
R^2, Adjusted	0.05	0.08	0.05	0.08	0.16

Notes: Model 1: Linear model controlling for birth year, age, age squared, sex, and race/ethnicity. Model 2: Adds maternal education to Model 1. Model 3: Adds lifespan overlap between the mother and the child to Model 1. Model 4: Adds maternal education and lifespan overlap with the mother to Model 1. Model 5: Adds controls for own education and household income to Model 4. All models control for household clustering in the standard error estimation.

$^{\dagger}p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

advanced maternal age, but controlling for lifespan overlap does not. Simultaneous controls for maternal education and lifespan overlap (Model 4) have little impact on young maternal age coefficients, but those for advanced maternal age decrease to a statistically insignificant level.

Controls for own socioeconomic status (Model 5) have little impact on maternal age coefficients but attenuate the maternal education coefficient by 36 %. This is less than what was observed for frailty and self-rated health because height is determined at an early age, making it unlikely that maternal education influenced height through socioeconomic attainment. The coefficient for lifespan overlap is attenuated by 22 %,

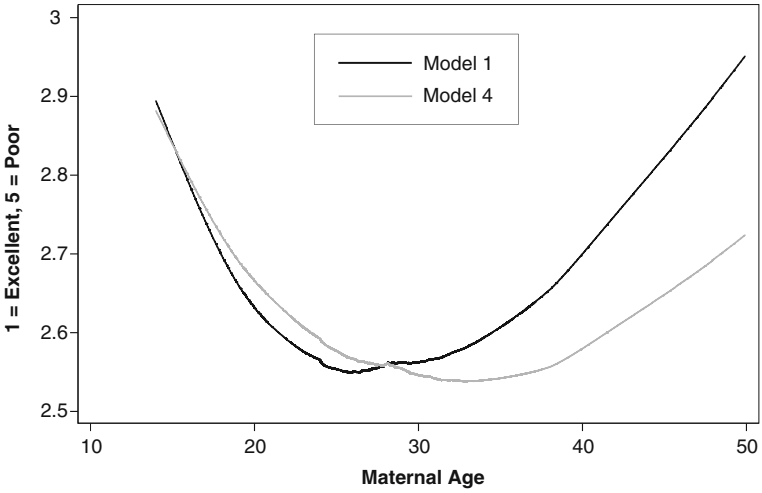

Fig. 2 Maternal age and self–rated health. Estimates are based on a semiparametric lowess model. Black line corresponds to Model 1 and controls for only demographic characteristics birth year, age, age squared, sex, and race/ethnicity. Gray line corresponds to Model 4 and adds as controls maternal education and lifespan overlap with the child and the mother

which is comparable to the attenuation seen for frailty and self-rated health. The weak attenuation is expected because the time ordering of events makes it unlikely that lifespan overlap influenced height through socioeconomic attainment.

Obesity

Table 5 shows the results for obesity; Fig. 4 illustrates the results using semiparametric regression. Model 1 suggests a U-shaped association between maternal age and the odds of being obese, although the coefficients for ages above 40 are not significant (Model 1). Controlling for maternal education (Model 2) or lifespan overlap (Model 3) or simultaneously controlling for these factors (Model 4) strengthens the young maternal age coefficients. The associations for advanced maternal age vanish when maternal education and lifespan overlap are controlled (Model 4). Controls for socioeconomic status (Model 5) remove the predictive power of maternal education but, as in the previous models, attenuate the coefficient for lifespan overlap only slightly.

Mortality

Table 6 shows the results for mortality; Fig. 5 illustrates the results using semiparametric regression. Model 1 suggests a U-shaped pattern between maternal age and offspring mortality: those with maternal age below 20 or above 45 have significantly higher mortality than those with maternal age 25–34. The coefficients for ages 20–24 and 35–44 are consistent with the U-shaped pattern but are not always significant. Controlling for maternal education (Model 2) or lifespan overlap (Model 3) or simultaneously controlling for these factors (Model 4) strengthens the associations for young maternal age. The associations for advanced maternal age lose

Table 4 Maternal age and height—Linear model, with height measured in centimeters: Health and Retirement Study

	Model 1	Model 2	Model 3	Model 4	Model 5
Maternal Age (ref. = 25–34)					
14–19	−0.889***	−0.864***	−0.941***	−0.901***	−0.702***
20–24	−0.338**	−0.373**	−0.378**	−0.399**	−0.336**
35–39	−0.459*	−0.197	−0.368†	−0.137	−0.166
40–44	−0.604†	−0.286	−0.452	−0.185	−0.156
45–49	−1.405**	−0.814	−1.148†	−0.643	−0.408
Birth Year	0.027*	0.014	0.025*	0.013	−0.013
Age at First Interview	0.102	0.104	0.102	0.105	0.101
Age^2 at First Interview / 100	−0.124	−0.122	−0.126	−0.124	−0.132†
Female	−14.608***	−14.568***	−14.598***	−14.562***	−14.493***
Race/Ethnicity (ref. = white)					
African American	0.531***	0.940***	0.578***	0.968***	1.251***
Other	−4.612***	−3.856***	−4.593***	−3.851***	−3.703***
Maternal Characteristics					
Mother's education 8+ years		2.110***		2.089***	1.340***
Mother alive when ego aged 40			0.508***	0.349**	0.272*
Own Education (ref. = high school)					
Less than high school					−1.612***
Some college					0.582***
BA or higher					0.837***
Own Household Income (log)					0.200***
Constant	123.781***	146.375***	127.690***	148.836***	197.899***
Observations	18,335	18,335	18,335	18,335	18,335
AIC	123,427.81	123,099.65	123,415.07	123,094.61	122,826.48
BIC	123,521.61	123,201.27	123,516.69	123,204.04	122,967.17
F Statistic	1,769.55	1,679.22	1,624.53	1,551.10	1,220.22
R^2	.52	.52	.52	.52	.53
R^2, Adjusted	.51	.52	.52	.52	.53

Notes: Model 1: Linear model controlling for birth year, age, age squared, sex, and race/ethnicity. Model 2: Adds maternal education to Model 1. Model 3: Adds lifespan overlap between the mother and the child to Model 1. Model 4: Adds maternal education and lifespan overlap with the mother to Model 1. Model 5: Adds controls for own education and household income to Model 4. All models control for household clustering in the standard error estimation.

†$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

statistical significance ($p > .05$) when controls for maternal education and lifespan overlap (Model 4) are introduced. Controls for own socioeconomic status (Model 5) attenuate the associations for young maternal age. These controls also remove the effect associated with maternal education but not with lifespan overlap.

Sensitivity Analyses

The sensitivity analyses listed in this section are available in Online Resource 1.

Our key result of no effect of advanced maternal age up to age 45 on health or mortality after controlling for maternal education and lifespan overlap was robust to

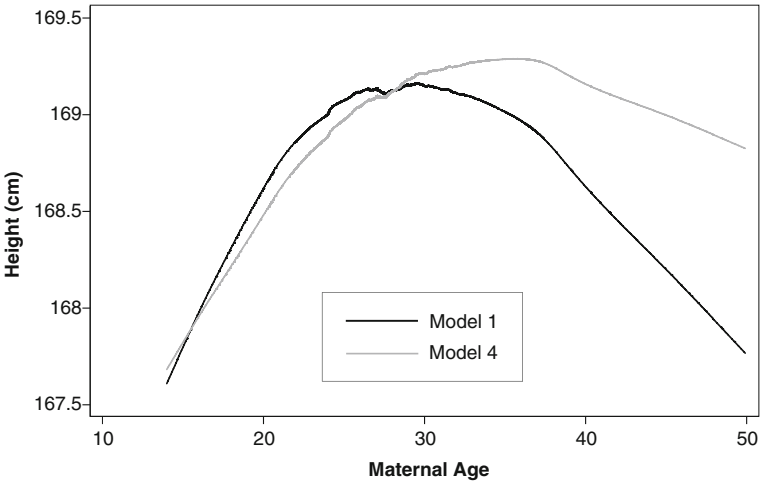

Fig. 3 Maternal age and height. Estimates are based on a semiparametric lowess model. Black line corresponds to Model 1 and controls for only demographic characteristics birth year, age, age squared, sex, and race/ethnicity. Gray line corresponds to Model 4 and adds as controls maternal education and lifespan overlap with the child and the mother

changes in the categorization of maternal age—in particular, to changing the reference group to 25–29 or to combining ages 40–44 and 45–49 to increase statistical power.

The results were robust to the following alternative specifications of the dependent variables and functional forms of the regression models: frailty index excluding mental health problems or cancer, ordered logistic instead of linear specification of self-rated health, linear instead of binary obesity measure of body mass index, and logistic instead of Cox proportional hazard model for mortality with the dependent variable a binary indicator for survival (dead/alive after 10 years of follow-up).

We studied the robustness of our results to an alternative specification of the lifespan overlap variable so that lifespan overlap was categorized to 10-year intervals and capped at 40 or more years. The results did not change significantly.

We studied how paternal age might influence our results. We did not control for paternal age because this correlates strongly with maternal age, increasing multicollinearity problems, and because information on paternal age was available for less than two-thirds of our sample. However, paternal age is negatively associated with health (Liu et al. 2011); thus, omission of the variable may result in slight overestimation of the negative advanced maternal age–offspring health association. Our key result is that even without controls for paternal age, the maternal age–offspring health association is weak up to maternal age 45 when maternal education and lifespan overlap are controlled for. Thus, the potential bias arising from omission of paternal age strengthens our key result. Moreover, Online Resource 1 documents that our results hold when the analyses are replicated for a subset for which paternal age is available and controlled for.

We had limited information on birth order. For the 18,335 subjects in our data, only 6,738 had information on birth order. Analyses for this subset with controls for birth order did not change our results: net of maternal education and lifespan overlap,

Table 5 Maternal age and odds ratio for obesity—Logistic model, with obesity is defined as body mass index BMI (kg/m^2) at 30 or above: Health and Retirement Study

	Model 1	Model 2	Model 3	Model 4	Model 5
Maternal Age (ref. = 25–34)					
14–19	1.330***	1.328***	1.355***	1.351***	1.295***
20–24	1.099*	1.103*	1.115**	1.117**	1.100*
35–39	1.167*	1.138*	1.132†	1.109	1.112
40–44	1.161	1.126	1.104	1.078	1.068
45–49	1.171	1.109	1.075	1.029	0.988
Birth Year	1.034***	1.035***	1.035***	1.036***	1.041***
Age at First Interview	1.110**	1.110**	1.110**	1.110**	1.109**
Age^2 at First Interview / 100	0.929**	0.929**	0.929**	0.929**	0.932*
Female	1.299***	1.295***	1.294***	1.291***	1.261***
Race/Ethnicity (ref. = white)					
African American	1.831***	1.764***	1.804***	1.744***	1.663***
Other	0.989	0.921	0.983	0.919	0.900
Maternal Characteristics					
Mother's education 8+ years		0.822***		0.830***	0.937
Mother alive when ego aged 40			0.843***	0.855***	0.871**
Own Education (ref. = high school)					
Less than high school					1.143**
Some college					0.841***
BA or higher					0.703***
Own Household Income (log)					0.944***
Observations	18,335	18,335	18,335	18,335	18,335
AIC	20,407.22	20,383.13	20,393.61	20,372.08	20,285.95
BIC	20,501.02	20,484.75	20,495.23	20,481.51	20,426.65
Log Likelihood	−10,191.61	−10,178.57	−10,183.81	−10,172.04	−10,124.97
Likelihood Ratio Chi-square	439.98	466.07	455.59	479.12	573.25
Pseudo-R^2	.02	.02	.02	.02	.03

Notes: Model 1: Logistic model controlling for birth year, age, age squared, sex, and race/ethnicity. Model 2: Adds maternal education to Model 1. Model 3: Adds lifespan overlap between the mother and the child to Model 1. Model 4: Adds maternal education and lifespan overlap with the mother to Model 1. Model 5: Adds controls for own education and household income to Model 4. All models control for household clustering in the standard error estimation.

$^{\dagger}p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

young maternal age (<25) continued to be associated with adverse health outcomes, but advanced maternal age (up to age 45) was not.

Our results were similar for both men and women. We estimated all models with maternal age–sex interactions, and these were not statistically significant ($p > .05$) for any of the outcomes.

Discussion

An expanding literature has documented that advanced maternal age is associated with negative offspring health outcomes. The interpretation often relies on

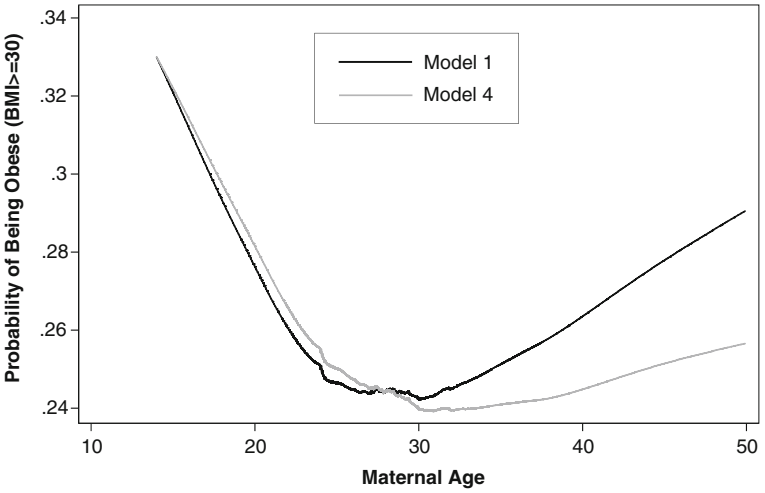

Fig. 4 Maternal age and obesity. Estimates are based on a semiparametric lowess model. Black line corresponds to Model 1 and controls for only demographic characteristics birth year, age, age squared, sex, and race/ethnicity. Gray line corresponds to Model 4 and adds as controls maternal education and lifespan overlap with the child and the mother

physiological processes related to reproductive aging, such as deterioration of the reproductive system and decreasing quality of the placenta or oocytes. We used a large, population-based sample to analyze the roles of selection and lifespan overlap in the maternal age–offspring adult health association. We found that mortality, self-rated health, height, obesity, and the number of diagnosed conditions are strongly associated with maternal age: those with maternal age below 25 or above 35 have markedly worse adult health than those with maternal age 25–34. Controls for maternal education and age at which the child lost the mother eliminate the effect for advanced maternal age up to age 45. Maternal age 45–49 may be associated with negative health net of these confounders, but the small sample size precludes strong conclusions. The results suggest that maternal aging matters for offspring health only insofar as it predicts the age at which the child loses the parents, and does not leave a physiological imprint in the offspring that predisposes it to poor health outcomes in adulthood. The associations for young maternal age, however, are robust and strengthen as we control for maternal education and lifespan overlap.

The negative health outcomes associated with advanced maternal age can be largely explained by nonphysiological maternal characteristics that are correlated with maternal age. Our results show that maternal socioeconomic status, measured by education, is a confounder in the maternal age–offspring health association. The results also show that controlling only for socioeconomic status is not enough because the age at which the child loses the parent adds an additional layer of confounding. The age at which the parent is lost may reflect shared frailty between the child and the mother or the amount of parental investment.

The attenuating effects of maternal education and lifespan overlap help explain the mechanism behind the advanced maternal age–offspring health association. Consider first maternal education. Childhood socioeconomic circumstances, measured by parental education, are negatively associated with adult health and mortality

Table 6 Maternal age and all-cause mortality hazard ratio (HR)—Mortality hazard ratios estimated using the Cox proportional hazard model: Health and Retirement Study

	Model 1	Model 2	Model 3	Model 4	Model 5
Maternal Age (ref. = 25–34)					
14–19	1.132*	1.130*	1.169**	1.164**	1.102†
20–24	1.072	1.077†	1.097*	1.100*	1.079†
35–39	1.143*	1.109	1.094	1.067	1.062
40–44	1.114	1.080	1.027	1.006	0.989
45–49	1.538**	1.431*	1.377*	1.298†	1.216
Birth Year	0.909***	0.910***	0.910***	0.911***	0.918***
Age at First Interview	1.027	1.027	1.026	1.026	1.030
Age^2 at First Interview / 100	0.971	0.970	0.972	0.972	0.972
Female	0.618***	0.615***	0.616***	0.613***	0.585***
Race/Ethnicity (ref. = white)					
African American	1.565***	1.493***	1.525***	1.462***	1.337***
Other	1.400***	1.286*	1.374**	1.270*	1.198†
Maternal Characteristics					
Mother's education 8+ years		0.796***		0.807***	0.958
Mother alive when ego aged 40			0.791***	0.805***	0.829***
Own Education (ref. = high school)					
Less than high school					1.255***
Some college					0.781***
BA or higher					0.622***
Own Household Income (log)					0.913***
Observations	18,335	18,335	18,335	18,335	18,335
AIC	58,026.93	57,993.44	57,999.69	57,970.32	57,768.46
BIC	58,112.91	58,087.24	58,093.49	58,071.94	57,901.35
Log Likelihood	−29,002.47	−28,984.72	−28,987.85	−28,972.16	−28,867.23
Likelihood Ratio Chi-square	1,466.92	1,502.41	1,496.16	1,527.53	1,737.39

Notes: Follow-up is from first interview to last interview (year 2008) or death. Model 1: Cox Proportional Hazards model controlling for birth year, age, age squared, sex, and race/ethnicity. Model 2: Adds maternal education to Model 1. Model 3: Adds lifespan overlap between the mother and the child to Model 1. Model 4: Adds maternal education and lifespan overlap with the mother to Model 1. Model 5: Adds controls for own education and household income to Model 4. All models control for household clustering in the standard error estimation.

†$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

(Galobardes et al. 2004; Hayward and Gorman 2004; Kuh et al. 2002; Strand and Kunst 2007). In the current period, old parents, especially old mothers, have above-average socioeconomic status and resources (Bray et al. 2006). This, however was not the case for cohorts in early twentieth-century America. In our nationally representative sample of U.S. adults born in the first half of the twentieth century, maternal education is inversely correlated with advanced maternal age and confounds the maternal age–offspring health association. Controlling for maternal education markedly reduces the negative association between advanced maternal age and offspring health.

Controlling for maternal education did little to attenuate the associations for young maternal age. Our control was completed education, not maternal education at birth.

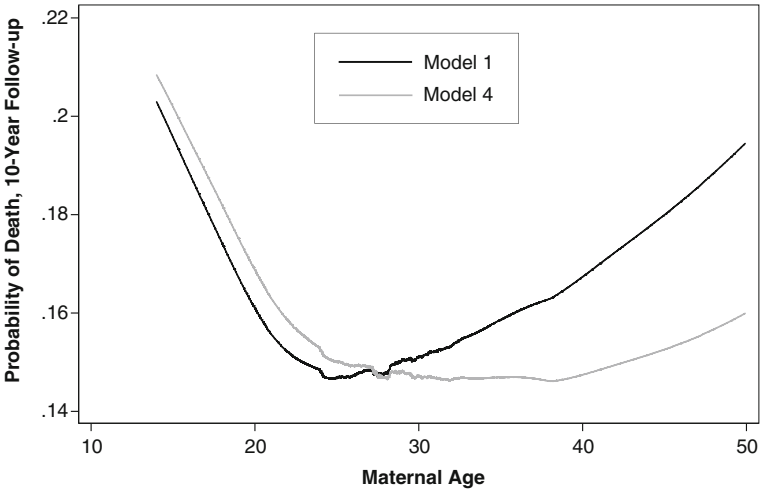

Fig. 5 Maternal age and mortality. Estimates are based on a semiparametric lowess model. Black line corresponds to Model 1 and controls for only demographic characteristics birth year, age, age squared, sex, and race/ethnicity. Gray line corresponds to Model 4 and adds as controls maternal education and lifespan overlap with the child and the mother

Had our data allowed controlling for maternal education at the time of birth, the magnitude of the young maternal age effect would most likely have been larger. Resources and parenting skills—which may be correlated with maternal education—may change over the ages at which the young maternal age effect was observed, from age 14 to 25. These changes are not reflected in the attained level of education.

Controlling for lifespan overlap with the mother in addition to maternal education reduced all the advanced maternal age effects up to age 45 to a statistically and substantively small level. The relative importance of lifespan overlap and maternal education in attenuating the advanced parental age effect depended on the outcome. For height, which is determined early, lifespan overlap mattered relatively little, and maternal education had a stronger attenuating effect. For frailty and mortality, lifespan overlap was a more important attenuator than maternal education. This may be because frailty and mortality are influenced by later-life conditions, for which lifespan overlap may matter more than it does for outcomes that are determined very early in life.

There are several potential mechanisms through which lifespan overlap influences the maternal age–offspring health association. First, lifespan overlap may proxy within-family shared frailty, which may have genetic, epigenetic, or behavioral origins. Lifespans of mothers and their children are correlated. Long-lived mothers may also have children at older ages so that maternal age and longevity are correlated. Although it is not clear whether late reproduction increases longevity, these correlations confound the advanced maternal age–offspring health association. On the other hand, late reproduction may signal age-independent problems in fecundity, which may be correlated with general level of health. If some of these factors that produce poorer health are shared within the family, such correlations confound the maternal age–offspring health association. These shared-frailty-based mechanisms are not connected to the biological mechanism, such as declining quality of oocytes or

weakening of the placenta, that are sometimes hypothesized to be responsible for the maternal age–offspring health association.

Second, lifespan overlap measures exposure to a live mother. Thus, it is broadly understood as a proxy for intergenerational social and economic transfers. If the mechanism proxied by lifespan overlap is intergenerational transfers, late motherhood may have a causal effect on adult health, particularly in high-mortality populations in which those born to older mothers are at high risk of losing their mothers at a young age. Our results, however, suggest that only a small fraction of the mechanism is attributable to such transfers: the regression coefficient for lifespan overlap was attenuated by only 10 %–30 % when we introduced controls for own socioeconomic status.

Third, lifespan overlap may reflect age-related differences in the magnitude of the psychological shock that is related to parental loss. Again, this mechanism is not related to the physiological health of the parents' reproductive systems.

Extensive analysis of the mechanism proxied by lifespan overlap is beyond the scope of this study. What is more important is that controlling for lifespan overlap markedly weakens the association between advanced maternal age and offspring health, challenging the standard interpretation for the association. In particular, controlling for lifespan overlap suggests that the maternal age–offspring health association largely reflects factors other than reproductive aging; among these factors, within-family frailty is a candidate. Future research could focus on the mechanism through which lifespan overlap between the mother and the child influences the health outcomes.

Our results on the weak or nonexistent effect of advanced maternal age on offspring health are consistent with some recent research on maternal age effects on health. Tymicki (2009) studied Polish data from the eighteenth to the twentieth centuries and found no association between child survival and parental age. Robine et al. (2003) found no association between parental age and the probability of surviving to age 100. Hubbard et al. (2009) analyzed twentieth-century Canadian cohorts and found no maternal age effects on health. Westendorp and Kirkwood (2001), in an analysis of British historical aristocracy, also failed to find any maternal age effects on longevity. Smith et al. (2009), however, found that maternal age above 35 is associated with 8 % increased adult mortality for sons when compared with maternal age 20–29. The difference between our findings and the associations documented by Smith et al. may be partially due to differences in age categories; they used age category 35 and older, which includes ages 45–49, for which we observed weak associations with health.

Some of the seeming inconsistency between our results and the literature documenting poor health outcomes for those with advanced maternal age may be because previous studies inadequately controlled for maternal socioeconomic characteristics or lifespan overlap. There are also other mechanisms that might result in such seeming inconsistency.

First, our findings are not inconsistent with the strong evidence suggesting that advanced maternal age is associated with negative birth outcomes (Andersen et al. 2000; Cohen and Lilienfeld 1970; Misra and Ananth 2002). Adult health is characterized by complex, multidimensional etiology, while negative birth outcomes such as malformations and chromosomal abnormalities typically reflect less complex disease

processes. In addition, many negative birth outcomes that are associated with advanced maternal age may have only a small effect on adult population health because the conditions are rare to start with and are associated with high mortality at younger ages. For example, the incidence of Down syndrome, the most common chromosomal abnormality, is below 1 % at maternal age 40 (Hook and Lindsjö 1978), and in the 1940s, when much of our sample was born, life expectancy with Down syndrome was 12 years (Bittles et al. 2007). Low prevalence at birth and selection before eligibility to HRS likely lead to differing results from those examining early life outcomes. However, because we are interested in adult health and mortality, it would not be optimal to adjust for selection of the weakest among our adult sample.

Second, many post-birth and adult conditions (schizophrenia, autism, bipolar affective disorder, and childhood cancer) that have been linked with advanced maternal age may be too rare to have a large impact on population health. It is possible that results for specific conditions are different from general measures for health.

Third, prebirth selection may explain some of the differences between our results for adult health and what others have found for birth outcomes. Because of spontaneous abortions and stillbirths, the force of selection is strongest in utero and increases with maternal age (Andersen and Osler 2004; de La Rochebrochard and Thonneau 2002). This maternal-age-dependent quality control may partially explain why health differences among adults by maternal age are small.

Our results focus on a population that was born before the widespread use of assisted reproductive technology (ART) and prenatal screening, both of which may change the future of the parental age–offspring adult health association. ART helps less fecund couples reproduce, particularly at older ages. This may contribute to the advanced parental age–offspring health association because ART itself may have effects for the development of the offspring. The evidence, however, is mixed, precluding strong conclusions (Wilson et al. 2011). ART may also influence the parental age–offspring adult health association indirectly if the use of ART is inversely correlated with health. If these health characteristics are passed on to the next generation thanks to ART, the new technology may accentuate the negative advanced parental age–offspring health association. On the other hand, prenatal screening removes some of the maternal-age-dependent negative birth outcomes. This may attenuate, or even reverse, the negative advanced maternal age–offspring adult health association. To shed light on these questions, more research is needed on the link between parental age and adult outcomes for cohorts that are now in their 20s and 30s.

There are limitations in our study. First, our follow-up starts at age 40, so we do not observe mortality selection that occurs in childhood and in early adult ages. However, because we are focusing on adult and old-age health, being able to control for such selection would not alter our findings. Second, our data do not allow us to specify what lifespan overlap proxies. Further research should provide a detailed analysis of the factors represented by lifespan overlap. One intriguing possibility would be to use within-siblings comparisons to analyze the contribution of factors that are shared within the family on the maternal age–offspring health link. Third, our controls for family socioeconomic status are rather crude, being based on a binary indicator for educational attainment. The results, however, suggest that even our crude controls perform well for the purposes of this study. Fourth, the associations we observe between advanced maternal age and offspring adult health may be a lower

limit for the effect of the physiological aging of the reproductive system. Powell et al. (2006) suggested that older parents transmit more economic, cultural, and social resources to their children than do younger parents. These positive factors may offset some of the biological-aging-induced negative effects. Finally, we are unable to explain the negative association between young maternal age and offspring outcomes. The robust and strong association warrants further investigation.

Thus, while advanced maternal age is associated with negative early life outcomes, including increased risk of miscarriage and Down syndrome, the impact at older ages seems not to be driven by biological aging of the parents. Instead, at least in our study population, a representative sample of U.S. adults born in the first half the twentieth century, the association is driven by old parents having less education and fewer years of overlap with their children than parents aged 25–35. The educational difference is a pure selection effect, whereas the difference in the overlap of lives could signal many factors, including shared frailty or decreased parental investment. The majority of today's parents' lives will overlap with their offsprings' lives for many decades. Thus, it seems unlikely that the health of the offspring of today's old parents is strongly influenced by short lifespan overlap resulting from late childbearing.

On the other hand, the results suggest that children born to young parents might have been better off if the parents had waited a few years. The robustness of the young parent–negative offspring outcome suggests that changing parental characteristics from very young parenthood to less extreme young parenthood have beneficial effects for the offspring. Our models are unable to directly account for the factors responsible for the young parent disadvantage. The association may be related to the physiological, mental, or resource-related immaturity of the younger parents who are less able than older parents to provide their offspring necessary skills and resources.

In summary, net of some obvious confounders, only maternal ages below 25 and above 45 are associated with negative offspring health outcomes. As only 0.8 % in our sample (and 1.1 % in the U.S. cohorts born in 2000) have mothers aged 45 or older, advanced maternal age appears to only be a minor public health concern. Almost half of our sample (46.5 %), and 36.8 % of U.S. cohorts born in 2000, have mothers younger than 25 (Martin et al. 2002). The public health concern regarding maternal age should focus on young, not old mothers.

Acknowledgements We would like to thank Joshua R. Goldstein, Samuel H. Preston, and James W. Vaupel for helpful comments. Previous versions of this research have been presented at the Lund University Center for Economic Demography and the University of Pennsylvania Population Studies Center colloquiums.

References

American Society for Reproductive Medicine. (2003). *Age and fertility: A guide for patients*. Birmingham, AL: American Society for Reproductive Medicine.

Andersen, A.-M. N., & Osler, M. (2004). Birth dimensions, parental mortality, and mortality in early adult age: A cohort study of Danish men born in 1953. *International Journal of Epidemiology, 33,* 92–99.

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

Andersson, T., Hogberg, U., & Åkerman, S. (1996). Survival of orphans in 19th century Sweden—The importance of remarriages. *Acta Paediatrica, 85,* 981–985.

Armstrong, D. T. (2001). Effects of maternal age on oocyte developmental competence. *Theriogenology, 55,* 1303–1322.

Barker, D. J. P. (2002). Fetal programming of coronary heart disease. *Trends in Endocrinology and Metabolism, 13,* 364–368.

Bell, A. G. (1918). *The duration of life and conditions associated with longevity. A study of the hyde geneology.* Washington, DC: Genealogical Record Office.

Benzies, K. M. (2008). Advanced maternal age: Are decisions about the timing of child-bearing a failure to understand the risks? *Canadian Medical Association Journal, 178,* 183–184.

Billari, F. C., Kohler, H.-P., Andersson, G., & Lundstöm, H. (2007). Approaching the limit: Long-term trends in late and very late fertility. *Population and Development Review, 33,* 149–170.

Bittles, A. H., Bower, C., Hussain, R., & Glasson, E. J. (2007). The four ages of Down syndrome. *European Journal of Public Health, 17,* 221–225.

Bottini, E., Meloni, G. F., MacMurray, J., Ammendola, M., Meloni, T., & Gloria-Bottini, F. (2001). Maternal age and traits of offspring in humans. *Placenta, 22,* 787–789.

Bradley, T., Cupples, M. E., & Irvine, H. (2002). A case control study of a deprivation triangle: Teenage motherhood, poor educational achievement and unemployment. *International Journal of Adolescent Medicine and Health, 14,* 117–123.

Bray, I., Gunnell, D., & Davey Smith, G. (2006). Advanced paternal age: How old is too old? *Journal of Epidemiology and Community Health, 60,* 851–853.

Brion, M.-J. A., Leary, S. D., Lawlor, D. A., Smith, G. D., & Ness, A. R. (2008). Modifiable maternal exposures and offspring blood pressure: A review of epidemiological studies of maternal age, diet, and smoking. *Pediatric Research, 63,* 593–598.

Case, A., Paxson, C., & Ableidinger, J. (2004). Orphans in Africa: Parental death, poverty, and school enrollment. *Demography, 41,* 483–508.

Cohen, B. H., & Lilienfeld, A. M. (1970). The epidemiological study of mongolism in Baltimore. *Annals of the New York Academy of Sciences, 171,* 320–327.

Croen, L. A., Najjar, D. V., Fireman, B., & Grether, J. K. (2007). Maternal and paternal age and risk of autism spectrum disorders. *Archives of Pediatrics & Adolescent Medicine, 161,* 334–340.

De La Rochebrochard, E., & Thonneau, P. (2002). Paternal age and maternal age are risk factors for miscarriage: Results of a multicentre European Study. *Human Reproduction, 17,* 1649–1656.

D'Onofrio, B. M., Donahue, K. L., Coyne, C. A., Van Hulle, C. A., Rodgers, J. L., Waldman, I. D., & Lahey, B. B. (2009). Early maternal age at childbearing and offspring functioning during adolescence: A sibling-comparison study of sexual behavior and depression. *Behavior Genetics, 39,* 647–647.

Durkin, M. S., Maenner, M. J., Newschaffer, C. J., Lee, L.-C., Cunniff, C. M., Daniels, J. L., . . . Schieve, L. A. (2008). Advanced parental age and the risk of autism spectrum disorder. *American Journal of Epidemiology, 168,* 1268–1276.

Eichenlaub-Ritter, U. (1998). Genetics of oocyte ageing. *Maturitas, 30,* 143–169.

Ekbom, A., Hsieh, C. C., Lipworth, L., Adami, H. O., & Trichopoulos, D. (1997). Intrauterine environment and breast cancer risk in women: A population-based study. *Journal of the National Cancer Institute, 89,* 71–76.

Fang, F., Kamel, F., Sandler, D. P., Sparen, P., & Ye, W. (2008). Maternal age, exposure to siblings, and risk of amyotrophic lateral sclerosis. *American Journal of Epidemiology, 167,* 1281–1286.

Fessler, D. M. T., Navarrete, C. D., Hopkins, W., & Izard, M. K. (2005). Examining the terminal investment hypothesis in humans and chimpanzees: Associations among maternal age, parity, and birth. *American Journal of Physical Anthropology, 127,* 95–104.

Fraser, A. M., Brockert, J. E., & Ward, R. H. (1995). Association of young maternal age with adverse reproductive outcomes. *The New England Journal of Medicine, 332,* 1113–1117.

Frejka, T. & Sobotka, T. (2009). Fertility in Europe: Diverse, delayed and below replacement. In T. Frejka, T. Sobotka, & J. Hoem (Eds.), *Childbearing trends and policies in Europe* (pp. 15–46).

Gale, E. A. M. (2010). Maternal age and diabetes in childhood. *BMJ, 340,* c623.

Galobardes, B., Lynch, J. W., & Davey Smith, G. (2004). Childhood socioeconomic circumstances and cause-specific mortality in adulthood: Systematic review and interpretation. *Epidemiologic Reviews, 26,* 7–21.

Gavrilov, L. A., & Gavrilova, N. S. (2000). Human longevity and parental age at conception. In J.-M. Robine, T. B. L. Kirkwood, & M. Allard (Eds.), *Sex and longevity: Sexuality, gender, reproduction, parenthood* (pp. 7–31). Berlin, Heidelberg: Springer-Verlag.

Gavrilov, L. A., Gavrilova, N. S., Semyonova, V. G., Evdokushkina, G. N., Kroutko, V. N., Gavrilova, A. L., . . . Lapshin E. V. (1997). Maternal age and offspring longevity. *Proceedings of the Russian Academy of Sciences* [Doklady Akademii Nauk]*, 354,* 569–572. English translation published in *Doklady Biological Sciences, 354,* 287–289.

Geronimus, A. T., & Korenman, S. (1992). The socioeconomic consequences of teen childbearing reconsidered. *Quarterly Journal of Economics, 107,* 1187–1214.
Hayward, M. D., & Gorman, B. K. (2004). The long arm of childhood: The influence of early-life social conditions on men's mortality. *Demography, 41,* 87–107.
Heffner, L. J. (2004). Advanced maternal age: How old is too old? *The New England Journal of Medicine, 351,* 1927–1929.
Hemminki, K., & Kyyrönen, P. (1999). Parental age and risk of sporadic and familial cancer in offspring: Implications for germ cell mutagenesis. *Epidemiology, 10,* 747–751.
Hook, E. B., & Lindsjö, A. (1978). Down syndrome in live births by single year maternal age interval in a Swedish study: Comparison with results from a New York State study. *American Journal of Human Genetics, 30,* 19–27.
Hubbard, R. E., Andrew, M. K., & Rockwood, K. (2009). Effect of parental age at birth on the accumulation of deficits, frailty and survival in older adults. *Age and Ageing, 38,* 380–385.
Jacobsson, B., Ladfors, L., & Milsom, I. (2004). Advanced maternal age and adverse perinatal outcome. *Obstetrics and Gynecology, 104,* 727–733.
Jalavisto, E. (1959). Parental age effects in man. In G. E. Wolstenholme & C. M. O'Connor (Eds.), *The lifespan of animals, Ciba Foundation Colloqium on Ageing* (Vol. 5, pp. 21–31). Boston, MA: Little, Brown & Company.
Johnson, K. J., Carozza, S. E., Chow, E. J., Fox, E. E., Horel, S., McLaughlin, C. C., . . . Spector, L. G. (2009). Parental age and risk of childhood cancer: A pooled analysis. *Epidemiology, 20,* 475–483.
Kaytor, M. D., Burright, E. N., Duvick, L. A., Zoghbi, H. Y., & Orr, H. T. (1997). Increased trinucleotide repeat instability with advanced maternal age. *Human Molecular Genetics, 6,* 2135–2139.
Kemkes-Grottenthaler, A. (2004). Parental effects on offspring longevity—Evidence from 17th to 19th century reproductive histories. *Annals of Human Biology, 31,* 139–158.
Kuh, D., Rebecca, H., Langenberg, C., Richards, M., & Wadsworth, M. E. J. (2002). Mortality in adults aged 26–54 years related to socioeconomic conditions in childhood and adulthood: Post war birth cohort study. *BMJ, 325,* 1076–1080.
Lansing, A. I. (1947). A transmissible, cumulative and reversible factor in aging. *Journal of Gerontology, 2,* 228–239.
Lansing, A. I. (1948). Evidence for aging as a consequence of growth cessation. *Proceedings of the National Academy of Sciences, 34,* 304–310.
Leridon, H. (2004). Can assisted reproduction technology compensate for the natural decline in fertility with age? A model assessment. *Human Reproduction, 19,* 1548–1553.
Levine, J. A., Emery, C. R., & Pollack, H. (2007). The well-being of children born to teen mothers. *Journal of Marriage and Family, 69,* 105–122.
Liu, Y., Zhi, M., & Li, X. (2011). Parental age and characteristics of the offspring. *Ageing Research Reviews, 10,* 115–123.
Lokshin, M. (2006). Difference-based semiparametric estimation of partial linear regression models. *The Stata Journal, 6,* 377–383.
Martin, J. A., Hamilton, B. E., Venture, S. J., Menacker, F., & Park, M. M. (2002). *Births: Final data for 2000 (National Vital Statistics Reports 50(5))*. Hyattsville, MD: National Center for Health Statistics.
Menezes, P. R., Lewis, G., Rasmussen, F., Zammit, S., Sipos, A., Harrison, G. L., . . . Gunnell, D. (2010). Paternal and maternal ages at conception and risk of bipolar affective disorder in their offspring. *Psychological Medicine, 40,* 477–485.
Menken, J., Trussell, J., & Larsen, U. (1986). Age and infertility. *Science, 233,* 1389–1394.
Misra, D. P., & Ananth, C. V. (2002). Infant mortality among singletons and twins in The United States during 2 decades: Effects of maternal age. *Pediatrics, 110,* 1163–1168.
Nassar, A. H., & Usta, I. M. (2009). Advanced maternal age. Part II: Long-term consequences. *American Journal of Perinatology, 26,* 107–112.
Ní Bhrolcháin, M. (2001). Flexibility in the marriage market. *Population—An English Selection, 13*(2), 9–47.
Pencina, M. J., Larson, M. G., & D'Agostino, R. B. (2007). Choice of time scale and its effect on significance of predictors in longitudinal studies. *Statistics in Medicine, 26,* 1343–1359.
Powell, B., Steelman, L. C., & Carini, R. M. (2006). Advancing age, advantaged youth: Parental age and the transmission of resources to children. *Social Forces, 84,* 1359–1390.
Preston, S. H., Hill, M. E., & Drevenstedt, G. L. (1998). Childhood conditions that predict survival to advanced ages among African-Americans. *Social Science & Medicine, 47,* 1231–1246.
Priest, N. K., Mackowiak, B., & Promislow, D. E. L. (2002). The role of parental age effects on the evolution of aging. *Evolution, 56,* 927–935.

Robine, J.-M., Cournil, A., Henon, N., & Allard, M. (2003). Have centenarians had younger parents than the others? *Experimental Gerontology, 38,* 361–365.

Rocca, W. A., Van Duijn, C. M., Clayton, D., Chandra, V., Fratiglioni, L., Graves, A. B., et al. (1991). Maternal age and Alzheimer's disease: A collaborative re-analysis of case–control studies. Eurodem Risk Factors Research Group. *International Journal of Epidemiology, 20*(Suppl. 2), S21–S27.

Scholl, T. O., Hediger, M. L., Huang, J., Johnson, F. E., Smith, W., & Ances, I. G. (1992). Young maternal age and parity. Influences on pregnancy outcome. *Annals of Epidemiology, 2,* 565–575.

Smith, K. R., Mineau, G. P., Garibotti, G., & Kerber, R. (2009). Effects of childhood and middle-adulthood family conditions on later-life mortality: Evidence from the Utah population database, 1850–2002. *Social Science & Medicine, 68,* 1649–1658.

Strand, B. H., & Kunst, A. (2007). Childhood socioeconomic position and cause-specific mortality in early adulthood. *American Journal of Epidemiology, 165,* 85–93.

Tarín, J. J., Brines, J., & Cano, A. (1998). Long-term effects of delayed parenthood. *Human Reproduction, 13,* 2371–2376.

Tymicki, K. (2009). The correlates of infant and childhood mortality: A Theoretical Overview and New Evidence from the Analysis of Longitudinal Data of the Bejsce (Poland) Parish Register Reconstitution Study of the 18th–20th Centuries. *Demographic Research, 20*(article 23), 559–594. doi:10.4054/DemRes.2009.20.23

Van Noord-Zaadstra, B. M., Looman, C. W., Alsbach, H., Habbema, J. D., te Velde, E. R., & Karbaat, J. (1991). Delaying childbearing: Effect of age on fecundity and outcome of pregnancy. *BMJ, 302,* 1361–1365.

van Poppel, F. (2000). Children in one-parent families: Survival as an indicator of the role of the parents. *Journal of Family History, 25,* 269–290.

Westendorp, R. G. J., & Kirkwood, T. B. L. (2001). Maternal and paternal lines of familial longevity. *Population: An English Selection, 13,* 223–235.

Wilson, C. L., Fisher, J. R., Hammarberg, K., Amor, D. J., & Halliday, J. L. (2011). Looking downstream: A review of the literature on physical and psychosocial health outcomes in adolescents and young adults who were conceived by ART. *Human Reproduction, 26,* 1209–1219.

Yip, B. H., Pawitan, Y., & Czene, K. (2006). Parental age and risk of childhood cancers: A population-based cohort study from Sweden. *International Journal of Epidemiology, 35,* 1495–1503.