

RESEARCH ARTICLE

Rethinking age-specific fecundability: Selection bias can generate apparent rapid decline with age

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ABSTRACT Age-specific fecundability among conception seekers is frequently treated as evidence of how much individuals should expect their own fecundability to decline. Demographers caution against this practice because of negative selection on fecundability among people seeking to conceive at older ages. We revisit this classic result, using simulation to investigate the plausible degree of selection introduced by two processes: on average, first, those with higher fecundability have more births before seeking to conceive; and second, these individuals achieve their desired births sooner, and thus seek to conceive higher-parity births at younger ages. We simulate full reproductive lives for cohorts in which fecundability is constant with age for individuals but varies across individuals. Thus, any change in the age-specific fecundability of conception seekers comes from selection. Our results demonstrate that selection alone can generate substantial depression in observed fecundability at later ages. We call for greater caution in interpreting age patterns of observed fecundability as straightforward evidence of individual age-related decline.

KEYWORDS Fecundability • Postponement • Microsimulation • Selection bias • Infertility • Reproductive careers

Introduction

Carefully designed modern studies can answer the question: “How much and at what ages does mean fecundability decline *among conception seekers*?” but women want to know the answer to a different question: “How much and when should I expect my own fecundability to decline as I age?”⁴ This paper describes the degree to which the answer to the first

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4 Some terminology for reproductive capacity: We use *fertility* to refer to actual reproductive performance rather than capacity (Demopædia, 2013a) and *fecundability* to refer to the probability of conception per susceptible cycle (Demopædia, 2013b). While agreed upon among English-language demographers, the colloquial and the medical use of these terms differ, and the sister terms in French are false cognates (Demopædia, 2013a). Because behaviour shapes conception and not all conceptions lead to live births, demographers distinguish between *natural fecundability* (per cycle probability of conception, in the absence of contraception), *residual fecundability* (per cycle probability of conception while contracepting) and *effective fecundability* (per cycle probability of conception leading to live birth) (Demopædia, 2013b). We follow the convention that when the word fecundability is used alone, natural fecundability is implied (Demopædia, 2013b). In all cases, fecundability is estimated as the quotient of events over person-months or cycles of exposure.

question (which is observable) might differ from the answer to the second question (which is what matters when we plan our lives). Since the 1960s, demographers have recognised that – as long as fecundability varies across women – the age pattern of observed fecundability is shaped by negative selection on fecundability itself (Heckman and Walker, 1990a, 1990b; Menken et al., 1986; Sheps, 1964; Sheps and Menken, 1973).

There are good biological reasons to expect reproductive capacity to decline with age. Ovarian reserves decline and anovulatory cycles, chromosomal abnormalities and early spontaneous abortions increase with age, among other changes that may be observed as menopause approaches (Balasch and Gratacós, 2012; Broekmans et al., 2006; Farr et al., 2007; Pellestor et al., 2003; Scott et al., 1995). But clinical evidence does not identify when or how rapidly fecundability decline might occur – the type of information those planning their lives require.

Additionally, the intentional nature of modern reproductive lives creates differences between what we can observe and what we wish we knew. In modern contexts, people spend most of their lives avoiding conception. Therefore, the form of fecundability salient to modern reproductive life planning is only observable during windows of conception-seeking. If our purpose is to help women anticipate when and by how much their fecundability will change with age, we would ideally base our estimates of age-specific fecundability on the conception-seeking behaviour of a random sample drawn from the total population at each age. In reality, conception-seeking is part of a life course process of family-building, so it is not true that every individual has the same probability of conception-seeking at every age. Many factors shape when an individual seeks to conceive, and one of these factors is fecundability itself. If some women have higher fecundability, all else being equal, they will, on average, complete their childbearing at younger ages, selecting them out of observability at subsequent ages.

We do not know how much fecundability varies within the population, which makes it hard to estimate how much selection actually shapes the population seeking to conceive at each age. In order to investigate the degree of selection, we use a simulation model and a counterfactual design. We simulate reproductive lives for cohorts in which fecundability varies across individuals but remains constant for each individual as she ages. We conduct simulations in which we vary only the distribution of fecundability in the population and sexual behaviour before conception is sought. This work advances the study of the age pattern of fecundability in two ways. First, we describe and illustrate the two processes by which selection on the population seeking to conceive depresses mean fecundability among conception seekers at older ages. Second, our simulation results demonstrate that selection alone can cause substantial depression of mean fecundability among conception seekers at older ages, even when no individual's fecundability declines with age.

The rest of the paper is organised as follows: the Background section reviews the state of knowledge on fecundability, including evidence of heterogeneity and age patterns. 'How selection on fecundability can influence observed fecundability' presents the mechanisms by which selection occurs. 'Reproductive process model' introduces the reproductive process model we use for simulations. The penultimate section presents results of the simulations, and the final section discusses the findings, limitations and directions for future work.

Background

We focus on evidence that is used to describe or predict individuals' age-related changes in fecundability, regardless of the initial purpose of the analyses. Often these data were collected or analysed to answer other questions, and the authors cautioned against generalisation. Nevertheless, these results are interpreted by influential groups and the public as evidence of contemporary individuals' likely trajectories of age-related change in fecundability. As one example, the American College of Obstetricians and Gynecologists, in a committee opinion on female age-related fertility decline, reproduces a figure depicting historical marital fertility rates from Menken et al. (1986) to support the claim that fecundability declines rapidly in the thirties ([American College of Obstetricians and Gynecologists' Committee on Clinical Consensus—Gynecology, 2025](#)). Menken and colleagues make clear that the figure does not reflect the age pattern of fecundability, but rather the joint effect of age and a variety of other factors. Our purpose is not to criticise the studies that present the evidence, but to ask how consequential it might be that the evidence is interpreted in this way.

Most contemporary evidence on variation in fecundability comes from preconception cohort studies (prospective incident designs), which enrol individuals who are starting to seek to conceive and observe their conception and pregnancy outcomes. In cross-sectional designs, samples are subject to length bias because the probability that an individual is seeking to conceive in any period is inversely associated with their fecundability ([Eijkemans et al., 2019](#); [Keiding et al., 2002](#); [Sheps, 1964, 1966](#); [Weinberg and Gladen, 1986](#)).

In the following subsections, we briefly review the evidence regarding heterogeneity in fecundability, contemporary evidence on age patterns in fecundability and historical evidence on age patterns in fecundability.

Heterogeneity in fecundability

Selection on fecundability requires heterogeneity. Demographers have recognised that fecundability varies across individuals since the earliest studies on fecundability and contraceptive efficacy ([Gini, 1924/1977](#); [Pearl, 1933](#); [Potter, 1960](#); [Sheps, 1964](#); [Tietze, 1959](#)). Substantial effort has been directed towards measuring fecundability when it is heterogeneous ([Bongaarts, 1975](#); [Dunson and Weinberg, 2000](#); [Gini, 1924/1977](#); [Heckman and Walker, 1990a, 1990b](#); [Larsen and Vaupel, 1993](#); [Majumdar and Sheps, 1970](#); [Pearl, 1933](#); [Potter, 1960](#); [Sheps, 1964](#); [Sheps and Menken, 1973](#); [Suchindran and Lachenbruch, 1975](#); [Weinberg and Gladen, 1986](#)).

Prospective studies find substantial differences in fecundability across categories other than age, including education level ([Boxem et al., 2025](#); [Jørgensen et al., 2023](#); [Schrager et al., 2020](#)); health behaviours such as alcohol consumption ([Fan et al., 2017](#)), smoking ([Wootton et al., 2023](#); [Zhou et al., 1996](#)), high caffeine consumption ([Dunson, 2001](#)) and dietary patterns ([Cueto et al., 2022](#); [Willis et al., 2020, 2022](#)); and physical characteristics such as large or small body size ([Loy et al., 2018](#); [McKinnon et al., 2016](#); [Wise et al., 2010, 2013](#); [Wootton et al., 2023](#); [Zhang et al., 2020](#)), higher body mass index

(Boxem et al., 2024), certain menstrual cycle traits (Pedersen et al., 2024; Wesselink et al., 2016; Zhang et al., 2017) and hypertension (Xiong et al., 2024). Likely as a result of heterogeneity itself, observed fecundability is 20–30% higher among women who have had a prior pregnancy or birth than it is among those of the same age who have not, with differences rising above 100% at later ages in some studies (Rothman et al., 2013; Steiner and Jukic, 2016; Wesselink et al., 2017).

Observed contemporary age patterns of fecundability

Preconception cohort studies can provide both crude and adjusted age patterns in fecundability. Adjustment is especially necessary in contexts where the age pattern of childbearing is stratified by levels of advantage, since more advantaged populations tend to exhibit higher fecundability on average. Recent large high-quality preconception studies that have followed pregnancy seekers in North America (Wesselink et al., 2017) and Denmark (Rothman et al., 2013) have found that adjustments for behavioural factors and sociodemographic characteristics changed the estimated age pattern of fecundability, amplifying decline with age compared to crude estimates. Between the early twenties and the late thirties, crude fecundability declined by 25% in the North American study and was flat in the Danish study, while adjusted fecundability declined by 40% and 33% in the North American and Danish studies, respectively. These changes with adjustment illustrate the salience of social and life course processes in determining the ages at which contemporary individuals seek to conceive.

Historical data

One way to avoid the selection problems in contemporary data is to use historical data from pre-demographic transition populations. By focusing on marital fertility among populations in which no fertility timing or limitation was practiced beyond prohibiting intercourse outside of marriage, demographers have sought to identify a variety of biological averages and maxima, including measures of fecundability by age (Eijkemans et al., 2014; Henry, 1961; Larsen and Yan, 2000; Leridon, 2008; Leridon and Menken, 1979; Menken et al., 1986; Menken and Larsen, 1986; Ridley et al., 1969).

A summary of these contributions to age patterns of reproductive capacity and a discussion of their implications for contemporary individuals were provided by Menken and colleagues in the mid-1980s (Menken, 1985; Menken et al., 1986). While they could not measure fecundability directly (because pregnancy loss is not well measured in historical or contemporary vital statistics), the historical data still provide insights into its age pattern. The historical age pattern of effective fecundability offers an upper bound, since as long as the probability of pregnancy loss does not decline with age, effective fecundability declines with age by at least as much as fecundability itself declines. The historical evidence reviewed by Menken and colleagues indicates that effective fecundability was approximately stable until age 35, at which point it declined concave down. Menken and colleagues make

clear that their historical analyses cannot reflect the age pattern of fecundability because they could not determine how much of this decline was caused by reduced fecundability versus other age-related factors, including censoring, disease, coital frequency, pregnancy loss and obstetric injury due to prior childbearing.

Demographers have also examined subsequent fertility by age at marriage to generate estimates of the historical age patterns of sterility (the fraction of brides at each age who never subsequently gave birth). This offers something of a lower bound on the pace of age-related decline in fecundability, since all attempts to conceive among sterile individuals lead to no pregnancies. Reanalysing an earlier study using historical English parish data (Trussell and Wilson, 1985), Menken and coauthors examined subsequent fertility by wife's age at marriage, and estimated that the historical sterility rate was about 5% at age 25 (the youngest age estimated), 20% at age 40 and about 60% at age 45 (Menken et al., 1986). Subsequent reanalyses reported lower rates of sterility by age (Eijkemans et al., 2014; Leridon, 2008).

Ultimately, Menken and colleagues concluded that neither historical nor available contemporary data could provide an unbiased estimate of the age pattern of fecundability. While demographic work on the question continued with historical data (Larsen and Vaupel, 1993; Larsen and Yan, 2000) and more contemporary data with fewer parametric assumptions (Heckman and Walker, 1990a, 1990b; Menken and Larsen, 1986), the question of by how much and when fecundability declines with age remains open.

How selection on fecundability can influence observed fecundability

It is widely established that selection can generate observed patterns in a population hazard that differ from patterns in any subpopulation. Scholarship on frailty documented this phenomenon in human mortality. In a particularly influential paper, Vaupel and Yashin (1985) called the observed population hazards generated by selection “heterogeneity’s ruses” because they can misrepresent the trajectories individuals should actually expect for themselves.

Heterogeneity works somewhat differently in generating fecundability selection. The hazard of death is observable among all living members of a population, so selection operates only by removing individuals from risk when they die. By contrast, in modern populations, fecundability is only observable among those trying to conceive, so selection operates through both entries and exits – i.e. by shaping both when individuals seek to conceive and how long they spend doing so. First, among women whose first sex precedes the age at earliest conception-seeking, it is possible for those with higher fecundability to complete some or all of their desired childbearing without ever seeking to become pregnant. In such cases, women with higher fecundability will seek to conceive fewer times or never seek to do so at all. Second, in a cohort of women who begin seeking to become pregnant together, women with higher fecundability will conceive sooner and become less likely to seek to conceive (or to conceive again) with advancing age.

The first process operates via unsought conceptions. Conceptions due to contraceptive failures or to non-use or irregular use of contraception are more common among individuals with higher fecundability, on average. If at least some of these pregnancies are not terminated by abortion, and if the desired family size is stable for at least some women who carry unsought pregnancies to term, such conceptions will influence how many times and when women seek to conceive, reducing the number of conception-seeking spells and advancing subsequent conception-seeking to younger ages, on average. Thus, unsought conceptions disproportionately (1) remove individuals with higher fecundability from contributing to observed fecundability, and (2) lead individuals with higher fecundability to directly seek higher-parity births at younger ages, thereby disproportionately removing them from observation seeking conception at older ages.

The second process generating increasingly negative selection on fecundability among women seeking to conceive at older ages operates through waiting time to conception. On average, women with lower fecundability must try to conceive for longer periods of time before success. Therefore, compared to women with higher fecundability, all of their spells of conception-seeking after the first spell occur at older ages, on average. When some of their conceptions end in loss, this process becomes even longer.

These processes shape the population initiating a spell of conception-seeking at each age, even in prospective incident designs in which individuals are only recruited if they are initiating the first spell of conception-seeking by parity of birth sought. While prospective incident designs minimise length bias in sampling (Bell et al., 2025; Cox et al., 2022; Eijkemans et al., 2019; Menken, 1985; Menken and Larsen, 1986; Sheps, 1964), such designs cannot eliminate selection on the population seeking to conceive by age.

In summary, on average, among members of a birth cohort, at every age, those with higher fecundability have already had more births from conceptions they did not seek; spend less time seeking to conceive and thus start trying to conceive pregnancies for births of each parity at younger ages; and are more likely to have already completed their family-building at every age. We can expect especially strong negative selection when there is more opportunity for unsought pregnancy (e.g. when desired fertility is especially delayed vis-à-vis sexual debut; contraceptive efficacy is low or variable; or ambivalence about pregnancy is high), and when unsought pregnancies are more likely to lead to births (e.g. abortion is stigmatised or abortion access is limited).

Reproductive process model

Below, we describe how we investigate how selection on fecundability depresses observed fecundability at older ages. In the next subsection, we describe the model we designed for this paper. In the ‘Simulation design’ subsection, we describe the rationale for our simulation design. In the ‘Assignment of characteristics and parameters’ subsection, we describe how we assign individual characteristics and universal parameters in our baseline model. In the ‘Simulations’ subsection, we describe the alternative simulations we conduct. In the ‘Analysis’ subsection, we describe our analysis of simulation results.

Conception Abortion Miscarriage Birth Simulation (CAMBS) model

To illustrate how selection can depress observed fecundability at later ages, we designed a life course reproductive process model – the Conception Abortion Miscarriage Birth Simulation (CAMBS) model.⁵ It builds on the long history of mathematical and simulation models that have been deployed since the mid-20th century (e.g. Ciganda and Todd, 2022; Gottard et al., 2015; Greulich and Toulemon, 2023; Horvitz et al., 1971; Potter, 1960; Ridley and Sheps, 1966; Sheps and Menken, 1973, 1971, 1971; Sheps et al., 1969, 1969; Tietze, 1959; Udry and Poole, 1974).

In these models, individuals spend their reproductive lives in one of the following states: susceptible to pregnancy, pregnant, or non-susceptible to pregnancy due to a recent prior pregnancy (postpartum infecundability). The state of being susceptible to pregnancy is subdivided into periods of seeking and not seeking to conceive. The state of being non-susceptible to pregnancy is subdivided into periods of being non-susceptible after a live birth and being non-susceptible after a pregnancy ends in miscarriage or abortion (non-live birth). Each reproductive event is a state transition, and the probability of each event varies according to the state (e.g. the probability of a new conception is zero for the duration of a pregnancy, while the probability of a miscarriage is non-zero only during pregnancy). Some probabilities vary according to the duration in the state (e.g. the probability of a miscarriage is higher earlier in pregnancy).

The discrete time model we use is based on those in Sheps and Menken (1973) and is illustrated in Figure 1. States are shown as boxes and arrows represent transitions.

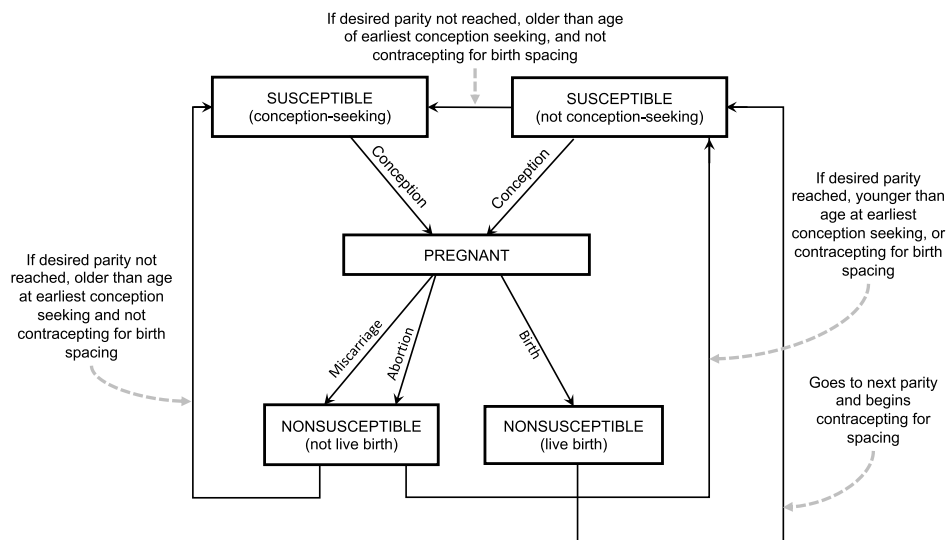
Each arrow is associated with the probability of the event that the transition represents. Transitions include: conception, miscarriage, abortion, birth, end of a non-susceptible period, and initiation of conception-seeking. Our model is weekly, with ovulation occurring every four weeks, though similar results are produced by monthly models.

Individuals stay in their state until a transition occurs, so an individual who seeks to conceive remains in the susceptible, conception-seeking state until conception is achieved. We do not model transitions out of sexual activity, so we do not include a state of non-susceptibility due to celibacy. We model celibacy before the onset of sexual activity as absence from the model. Those individuals who are not seeking to conceive are modelled as contracepting.

Simulation design

Simulations using reproductive process models can generate full reproductive life courses for individuals and populations, given input parameters. To investigate how selection shapes conception-seeking, we conduct simulations in which fecundability varies across a cohort of individuals but is constant for every individual as they age. We present results in which only the fecundability distribution and celibacy before the age at earliest

5 Materials to replicate our simulation results with the CAMBS model are available at <https://doi.org/10.17605/OSF.IO/ZXPQE>

Figure 1 A simplified illustration of the discrete time model with age- and parity-specific contraception

Notes: Individuals remain in their current state each week unless a transition occurs. In the model presented here, the state “not exposed to the risk of pregnancy” is represented by absence from the model because we do not model transitions into and out of sexual activity. Women enter the state SUSCEPTIBLE (not conception-seeking) at first exposure to the risk of pregnancy

conception-seeking vary. Assumptions for all transitions are described below. We analyse the resulting life course histories.

By observing the population initiating conception-seeking at each age in a counterfactual condition in which no individual experiences age-related decline in fecundability, we isolate the effect of selection on observed age-specific fecundability. This allows us to investigate the possible magnitude of such selection.

Assignment of characteristics and parameters

For each simulation, a cohort of individuals is assigned individual-level traits drawn from independent population-level distributions. Their transitions between states are determined by universal transition parameters.

Individual-level traits that remain constant over the lifetime are: fecundability, sexual activity before conception-seeking, contraceptive efficacy, age at earliest conception-seeking (the individual contracepts to delay conception or remains celibate prior to this age) and desired lifetime parity (parity at which the individual starts or resumes the use of contraception to avoid conceiving). Universal parameters include duration-dependent probabilities of abortion and miscarriage; durations of non-susceptibility to pregnancy after a miscarriage, an abortion or a birth; duration of pregnancy; and duration between birth and

initiation of conception-seeking for the next desired birth. See Supplementary material available online (<https://doi.org/10.1553/p-p7d2-d2hz>) for more details on individual-level traits (Table S.1) and universal parameters (Table S.2).

Simulations

We assign individual-level traits to each individual in a 50,000-woman cohort and then simulate each individual's weekly reproductive life course from the week she enters the model in the state SUSCEPTIBLE (not seeking conception) (age 15 in the baseline case) until the week she turns age 50.

In the main text, we report results from simulations across which only two factors vary: population-level heterogeneity in fecundability and whether individuals engage in sexual activity before reaching their age at earliest conception-seeking.

Population-level distribution of fecundability

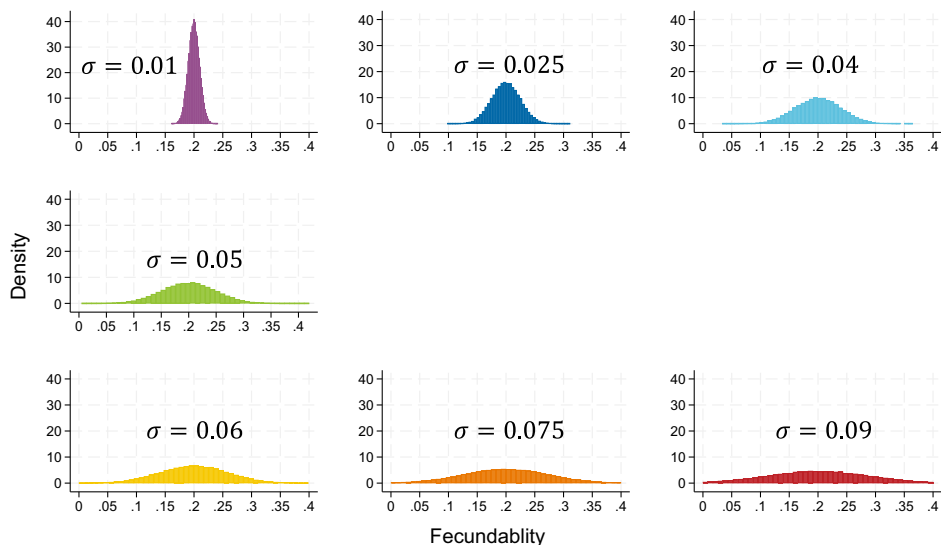
In all simulations, each individual's fecundability is constant as she ages, but fecundability varies across the population. In all simulations, the population-level distribution of fecundability is truncated normal centred at $\mu = 0.2$ with range $[0, 0.4]$, consistent with recent demographic work (Ciganda and Todd, 2022) and similar to the observed fecundability in young non-contracepting or pregnancy-seeking populations (Bongaarts and Potter, 1983; Leridon, 2004; Rothman et al., 2013; Wesselink et al., 2017).

In our baseline simulation, fecundability is distributed across individuals in the population with $\sigma = 0.05$. This is less variable than empirical estimates (Dunson, 2001; Zhou et al., 1996). We choose this relatively mild degree of population-level heterogeneity as our baseline to generate a conservative estimate of negative selection on fecundability. We report results from simulations in which population-level heterogeneity in fecundability is lower ($\sigma = 0.01, 0.025, 0.04$) or higher ($\sigma = 0.06, 0.075, 0.09$). Figure 2 displays these distributions (baseline in green).

Sexual activity and contraceptive use before the age at earliest conception-seeking

Sexual and contraceptive behaviour are often highly variable within and across individuals before conception is first sought, particularly at younger ages (Lindberg et al., 2021). We use two more extreme assumptions to illustrate the sensitivity of our results to these factors. In our baseline simulation, all individuals are sexually active and contracept from age 15 to their age at earliest conception-seeking (which is selected from a normal distribution centred at age 25 and truncated at age 20). Contraceptive efficacy assigned to each individual is randomly selected to be .90, .95 or .99. In alternative simulations, all individuals are celibate until reaching their age at earliest conception-seeking.

Figure 2 Alternative population-level distributions of fecundability centred at $\mu = 0.2$ with seven different levels of heterogeneity (σ)



Notes: The distribution chosen as baseline is in green. All distributions are truncated with minimum = 0 and maximum = 0.4

Age at earliest conception-seeking

We assign to each individual an age at earliest conception-seeking from a population distribution. Whenever they are susceptible before this age, individuals contracept to delay a birth. In our baseline simulation, each individual's assigned age is taken from a truncated normal distribution with $\mu = 25$, $\sigma = 4$ and range $[20, 40]$. We chose a relatively early age pattern for our baseline case because younger ages at earliest conception-seeking allow for longer observation after conception is sought.

Desired lifetime parity

We assign to each individual a desired parity drawn from a uniform distribution between one and four children.

Sampling variation

While our results are not intended to represent any general population, and thus we do not present confidence intervals, as simulations, our results are subject to the influence of sampling variation via pseudorandom number generation. We include 50,000 individuals in each simulation, but the complexity of reproductive lives means that at some ages

relatively few events of a specific definition occur. To minimise our risk of interpreting artefacts caused by chance, we focus on estimates based on 50 or more events in our interpretation of the results. To illustrate the role of sampling variation in our results, we present in [Supplementary Material Figure S.2](#) the main result from our baseline simulation (mean fecundability among those initiating a spell of conception-seeking by age at last birthday) under three different initial states (or seeds) from which pseudorandom number generation proceeds.

Analysis

Our analysis takes the form of reporting on the results of our simulations. For each age at last birthday, we calculate mean fecundability among those who initiate a spell of conception-seeking at that age. We calculate this mean directly based on individuals' assigned age-invariant fecundability, and call the resulting statistic mean observed fecundability at that age. We focus on initiators at each age to minimise length bias. For further details on the target population for whom mean fecundability is observed at each age and simulation results under alternative population definitions, see [Supplementary Material section S2.1](#).

Because the degree of population-level heterogeneity is unknown and directly salient to the selection process, we begin by displaying mean observed fecundability for our baseline simulation and the six alternative simulations of greater or lesser heterogeneity. This provides a sense of the possible magnitude of depression in mean observed fecundability caused by selection on fecundability.

To illustrate the role of births conceived before conception is ever sought (unsought births), we compare results from simulations in which all individuals are sexually active and contracept starting at age 15 with results from simulations in which all individuals are celibate until reaching their age at earliest conception-seeking. We repeat these simulations for the baseline and higher and lower heterogeneity of fecundability distributions.

Finally, we look within our baseline simulation to summarise the reproductive experiences of individuals with different fecundabilities. These results illustrate the mechanisms by which fecundability influences ages at conception-seeking.

To illustrate the changing composition of those initiating conception-seeking by fecundability, we display the relative risk of initiating a spell of conception-seeking by age last birthday and fecundability.

To illustrate how the timing of parity-specific conception-seeking varies by fecundability, we report the mean ages at which individuals begin seeking to conceive by parity and fecundability.

To provide an overview of the sensitivity of the selection process to individual-level traits, we also provide a summary figure displaying mean fecundability among those initiating spells of conception-seeking at ages at last birthday of 35–39 by trait. This figure shows how much mean observable fecundability declines by ages 35–39 by level of contraceptive efficacy, age at earliest conception-seeking and desired lifetime parity.

Results

We display mean observed fecundability among those individuals initiating a spell of conception-seeking by age from simulations varying in heterogeneity of fecundability ('Effects of degree of heterogeneity in fecundability' subsection) and by sexual activity prior to reaching the age at earliest conception-seeking and heterogeneity of fecundability ('Effects of sexual activity prior to the age at earliest conception-seeking' subsection). Because fecundability is constant with age for all individuals in our simulations and no deaths occur, decline with age in observed mean fecundability among those initiating spells of conception-seeking is solely caused by the influence of selection on the timing of conception-seeking. We compare observed means at each age with the underlying all-individual mean fecundability, which is constant $\mu = 0.2$ at all ages in all simulations.

In the subsections 'Effect of fecundability on the age at conception-seeking – baseline simulation', 'Effect of fecundability on unsought births – baseline simulation' and 'Conception-seeking by parity – baseline simulation', we compare the reproductive experiences of individuals with different fecundabilities within our baseline simulation. In the 'Summary' subsection, we summarise our results regarding the magnitude of depression in mean observed fecundability at ages 35–39 due to selection.

Effects of degree of heterogeneity in fecundability

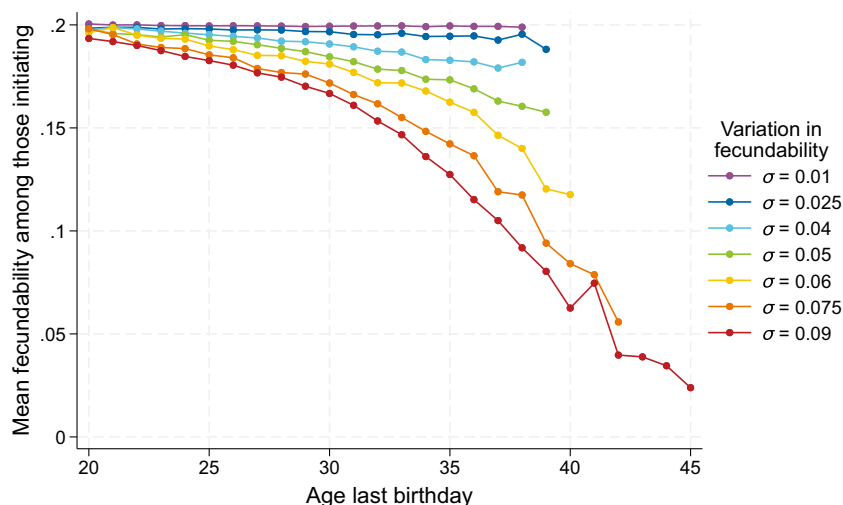
Figure 3 displays mean fecundability among those initiating spells of conception-seeking by single year of age at various levels of population-level heterogeneity in fecundability. In these simulations, all individuals are sexually active and contracepting starting at age 15. Population-level heterogeneity in fecundability (see Figure 2) ranges from $\sigma = 0.01$ to $\sigma = 0.09$, and the underlying all-individual mean is $\mu = 0.2$, constant across ages.

The greater the heterogeneity in fecundability in the population, the greater the depression in observed mean fecundability as age advances. Observed mean fecundability changes little with age when $\sigma = 0.01$. Consider only ages 35–39: As we take 6 steps, increasing heterogeneity from $\sigma = 0.025$ to $\sigma = 0.09$, observed mean fecundability decreases: 0.19, 0.18, 0.16, 0.15, 0.12, 0.10. Despite population mean fecundability constant at 0.20 in all cases, increased heterogeneity leads to increased selection among women initiating a spell of conception seeking and observed mean fecundability at our highest heterogeneity is depressed to about half the population level by ages 35–39.

Effects of sexual activity prior to the age at earliest conception-seeking

In Figure 4, we illustrate the effect of sexual activity before the age at earliest conception-seeking on observed fecundability by age. We compare results from simulations in which no one has sex before they seek to conceive with results from simulations in which everyone has sex starting at age 15 and contracepts unless seeking to conceive. For simplicity, we offer pairs of such simulations at three levels of population-level heterogeneity in

Figure 3 Mean fecundability among those initiating spells of conception-seeking by age at last birthday for alternative levels of population heterogeneity in fecundability

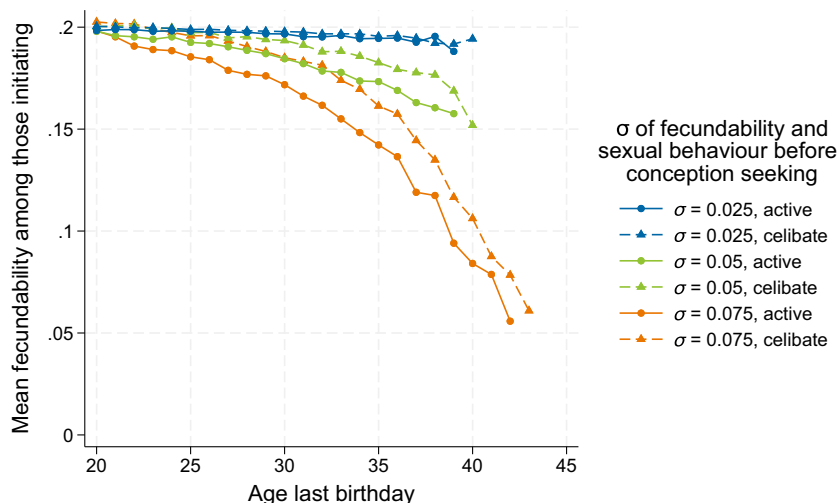


Notes: Each line is based on a simulation of 50,000 individual reproductive lives under the specified parameters. All individuals begin sexual activity at age 15 and contracept until reaching their age at earliest conception-seeking. Mean fecundability is reported only for years of age at which 50 or more initiations of conception-seeking occurred

fecundability, $\sigma = 0.025$, $\sigma = 0.05$ and $\sigma = 0.075$. All other factors remain the same as in our baseline simulation. For each level of heterogeneity, dashed lines reflect results of simulations in which no one has sex before reaching their age at earliest conception-seeking, and solid lines reflect the results in which sex begins at age 15.

In all six simulations, the observed mean fecundability at older ages is less depressed in the simulation with celibacy before conception-seeking than in the simulation in which all individuals are sexually active from age 15. We illustrate this by comparing across the sexual activity conditions at the same population level heterogeneity in fecundability and expressing observed means in terms of their depression from the underlying all-individual mean at ages 35–39. For example, when $\sigma = 0.05$, in the abstinent simulation the observed mean is depressed by 11% of the underlying all-individual mean, compared with a depression of 18% in the sexually active from age 15 simulation. And when $\sigma = 0.075$, the observed mean in the abstinent simulation is depressed by 28%, compared with a depression of 39% in the sexually active from age 15 simulation. While the overall magnitude of the depression in the observed means is small when $\sigma = 0.025$, the depression in the simulation with celibacy is similar to the depression in the sexually active from age 15 simulation (3.0% vs 3.5% of the all-individual mean). In general, the depressions of the observed mean in the simulations with full celibacy before conception-seeking are about 70% of the depressions of the observed mean in the simulations with extensive sexual activity before conception was sought.

Figure 4 Mean fecundability among those initiating spells of conception-seeking, by sexual activity before the age at earliest conception-seeking, at three levels of population-level heterogeneity in fecundability



Notes: Each line is based on a simulation of 50,000 individual reproductive lives under the specified parameters. Mean fecundability is reported only for the years of age during which 50 or more initiations of conception-seeking occurred

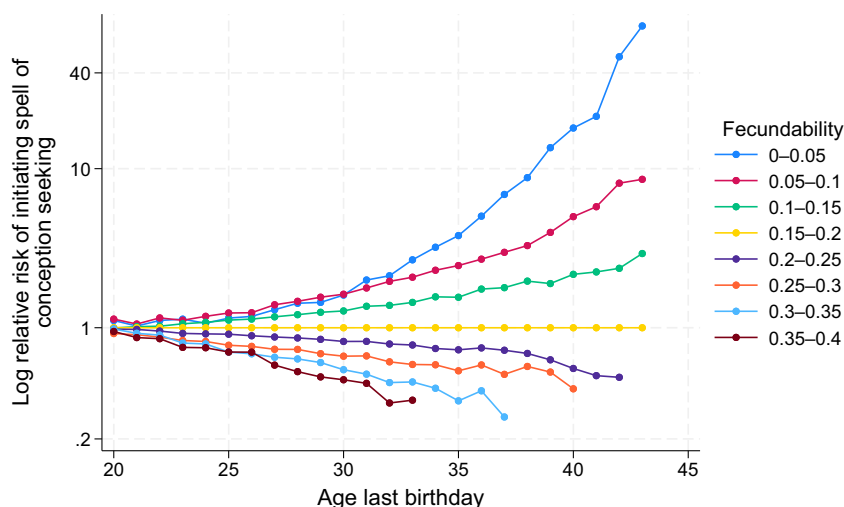
Effect of fecundability on the age at conception-seeking – baseline simulation

Next, we turn away from patterns of mean observed fecundability by age to focus on how fecundability shapes individuals' ages at conception-seeking, generating the selection driving the patterns described above.

Figure 5 shows how the risk of initiating a spell of conception-seeking varies according to fecundability itself. These results are drawn from our baseline simulation, so all individuals are sexually active before reaching their age at earliest conception-seeking. We group individuals into ranges of fecundability 1σ -wide and use the group with fecundability 0.15–0.2 as a comparison. For each group, we plot the log relative risk of initiating a spell of conception-seeking by age at last birthday, comparing individuals in each range to those whose fecundability is 0.15–0.20. We display relative risks only if both the index group and the comparison group had at least 50 initiations in the year of age.

The downward slope of the lines for groups with fecundabilities greater than the comparison demonstrates that individuals with higher fecundability are increasingly less likely to initiate conception-seeking with advancing age. The upward slopes of the lines for groups with fecundabilities lower than those of the comparison group demonstrate that groups with lower fecundability are increasingly more likely to initiate conception-seeking with advancing age. By the late twenties, differences begin to emerge. By age 27, the relative risks are 1.2 and 0.87 for the groups just above and just below the comparison, respectively. The divergence accelerates in the thirties, with the relative risks being 1.56 and 0.74 for the

Figure 5 Log relative risk of initiating a spell of conception-seeking by age at last birthday and fecundability, index group fecundability 0.15–0.2



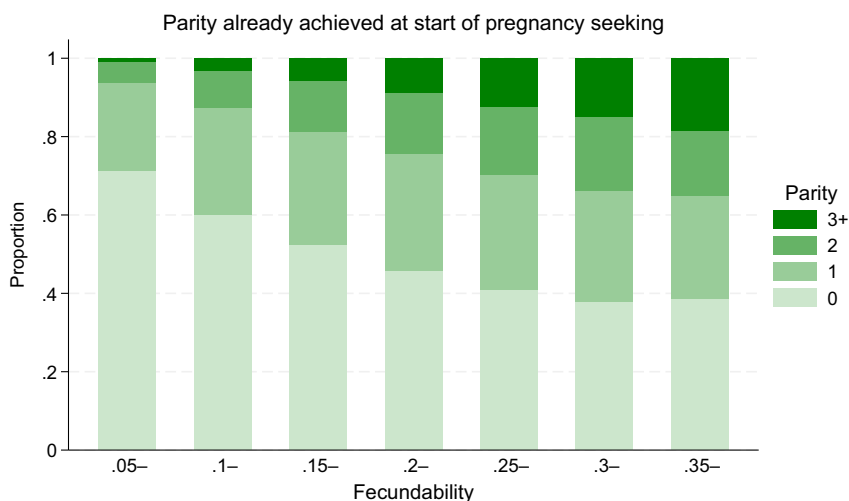
Notes: Log relative risk is reported only for years of age in which 50 or more initiations of conception-seeking occurred in both groups. Source: Baseline simulation – all individuals are sexually active and contracepting from age 15 to the age of earliest conception-seeking

same groups at age 34. After age 35, the divergence continues to increase, particularly for the groups with lower fecundability. At age 40, the relative risk of initiating a spell of conception-seeking is 2.1 and 0.55 for the groups just above and just below the comparison, respectively.

Effect of fecundability on unsought births – baseline simulation

Figure 6 illustrates parity before the age at earliest conception-seeking by level of fecundability, using results from our baseline simulation. Each column in Figure 6 describes a 1σ -wide range of fecundability, like the lines in Figure 5. The parity composition of individuals in that range of fecundability at the earliest age at which they would seek to conceive is reflected by the colours of the bars. The lightest green reflects the fraction of individuals who had no births before they would ever seek to conceive, with darker colours reflecting one, two and three or more births. The proportion of individuals at parities one, two and three or more increases as fecundability increases because all the pregnancies leading to these births occurred due to contraceptive failures, and such failures are proportional to fecundability. Over half of those in all groups with fecundability of over 0.2 had had at least one birth before reaching their age at earliest conception-seeking, with only 37% and 30% of the groups with the highest fecundability having zero births by the time they reached the earliest age at which they would seek to conceive.

Figure 6 Unsought births prior to reaching the earliest age at conception-seeking by fecundability, when sexual activity starts at age 15



Note: Baseline simulation – all individuals are sexually active and are contracepting from age 15 to the earliest age at conception-seeking

These unsought births disproportionately prevent individuals with higher fecundability from being able to contribute conception-seeking to observation, and disproportionately remove individuals with higher fecundability from observation altogether. The decline in the proportion of individuals reaching their age at earliest conception-seeking with no births is especially notable. We also note (results not shown) that some individuals reached their desired lifetime parity through unsought births before reaching their age at earliest conception-seeking. Therefore, they could never be observed initiating conception-seeking. Less than 10% of those with fecundability below 0.1 reached their desired lifetime parity via unsought conceptions. This fraction increased roughly linearly across the fecundability groups, with 29% of those with fecundability above 0.3 reaching their desired lifetime parity before reaching their age at earliest conception-seeking and therefore being unobservable as ever having tried to conceive. In relative terms, this means that those individuals with fecundability above 0.3 were three times as likely to be excluded from the observation of fecundability at any age compared with those individuals whose fecundability was below 0.1.

Conception-seeking by parity – baseline simulation

Table 1 displays the mean ages of individuals initiating spells of conception-seeking by parity of the birth sought and fecundability. Darker colours in the table reflect older mean ages. Lower fecundability is associated with older mean ages at the initiation of

Table 1 Mean age at the start of conception-seeking spells by parity and fecundability

Fecundability	Seeking first birth	Seeking second birth	Seeking third birth	Seeking fourth birth
0–0.05	26.42	30.27	33.98	
0.05–0.1	25.61	27.95	30.08	32.34
0.1–0.15	25.54	27.18	29.13	31.04
0.15–0.2	25.43	26.78	28.42	30.21
0.2–0.25	25.36	26.40	27.91	29.58
0.25–0.3	25.28	26.12	27.39	29.10
0.3–0.35	25.21	25.72	26.92	28.45
0.35–0.4	25.05			

Notes: Baseline simulations – all individuals are sexually active and contracepting from age 15 to the age at earliest conception-seeking. Values are suppressed if fewer than 50 spells of conception-seeking are observed

conception-seeking for parities two and greater. For example, the mean age at the initiation of conception-seeking for the second birth is 0.78 years greater at fecundability 0.1–0.15 than at fecundability 0.2–0.25. The differences are even starker between adjacent parity groups at fecundabilities below 0.15. The differences increase as parity increases. The difference in the mean age between fecundability 0.05–0.1 and 0.3–0.35 increases from 2.23 years when seeking to conceive for the second birth, to 3.16 years when seeking to conceive for the third birth and to 3.89 years when seeking to conceive for the fourth birth.

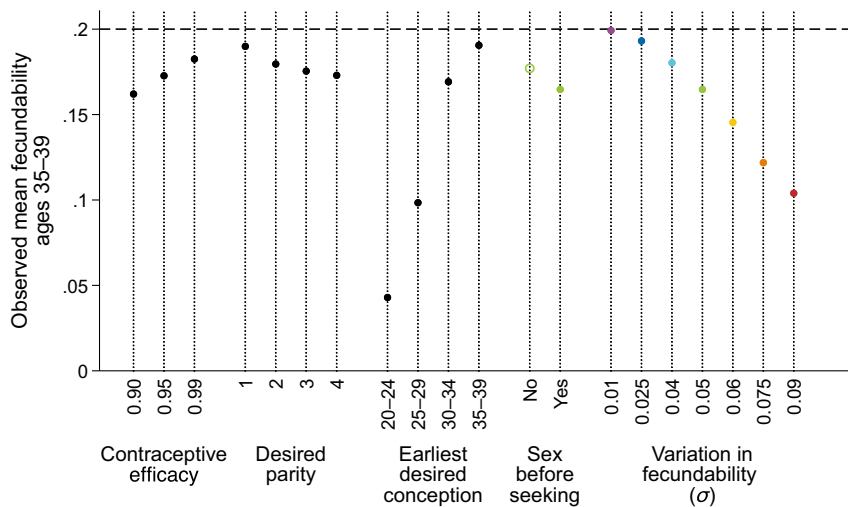
Summary

In [Figure 7](#), we present a summary of selection across a variety of traits and factors using mean fecundability among those initiating attempts to conceive at ages 35–39. This summary compares selection across levels of contraceptive efficacy, desired lifetime parity and age at earliest conception-seeking based on the baseline simulation, as well as selection across our specifications of sexual behaviour before the age at earliest conception-seeking and heterogeneity in fecundability across simulations.

Dots that are lower on the plot reflect greater negative selection on fecundability, since the underlying all-individual mean of every group is 0.2. Black dots reflect means among individuals with specified traits. These results are not presented elsewhere. For comparison, we also summarise selection in the same way for simulations with the seven degrees of population-level heterogeneity fecundability from [Figure 3](#) and the two simulations with $\sigma = 0.05$ in [Figure 4](#). We follow the colour conventions from [Figures 3](#) and [4](#) for the markers displaying results derived from the same simulations.

[Figure 7](#) reflects that higher contraceptive efficacy and lower desired parity are associated with less selection on fecundability. Those individuals for whom contracepting is more effective have fewer contraceptive failures on average and are thus less negatively selected via that mechanism. Moreover, those individuals who want fewer births are impacted by

Figure 7 Summary of selection on fecundability of those initiating conception attempts at ages 35–39, by three individual-level traits in the baseline simulation and two factors modified across simulations



selection due to waiting time to conception to either a smaller degree or not at all (if they want only one birth) compared to those who want more births. Much greater variation in selection is exhibited across ages at earliest conception-seeking. This is because fewer individuals who initially seek to conceive at younger ages remain in the pool of possible conception seekers by ages 35–39. For example, less than 0.01% of those who desired conception starting at ages 20–24 and 1.2% of those who desired conception starting at ages 25–29 were observed initiating a spell of conception-seeking at ages 35–39. Thus, while selection is very great, few of the observed initiations at later ages are from individuals who initially sought to conceive over a decade earlier. For a comparison of the magnitude, substantial variation in selection as population-level heterogeneity in fecundability increases is displayed in the figure, as is the more modest decrease in selection when all individuals practice celibacy until reaching the age at earliest conception-seeking.

Conclusion

Demographers have long known that selection contributes to the observed age pattern of fecundability. In this paper, we use a reproductive process model, CAMBS, to investigate the extent to which selection might shape observed age-specific fecundability and to explicate the two forces at play in that selection: first, individuals with higher fecundability have more contraceptive failures and thus more births before they seek to conceive; and second, when seeking to conceive, these individuals also achieve pregnancy more quickly than those with lower fecundability, which means that their periods of conception-seeking for

higher parity births occur at younger ages. Our results illustrate that under a variety of conditions, selection on fecundability via these two forces can cause substantial depression of mean observed fecundability among women seeking to conceive at older ages, even when no individual's fecundability declines with age.

Our counterfactual design addresses a fact that demographers have long recognised: if observed fecundability declines with age, this may be caused by declining fecundability in individuals as they age, by negative selection or by a combination of the two (Heckman and Walker, 1990a; Sheps and Menken, 1973, p. 69). By simulating the experiences of cohorts in which no individual's fecundability declines with age, we begin to explore how much selection might be depressing observed fecundabilities at older ages. By comparing the reproductive experiences of individuals with different fecundabilities, we illustrate the mechanisms by which fecundability influences the ages at conception-seeking.

We find that selection alone can induce substantial depression in observed fecundability at older ages. In our baseline simulation, which includes extensive pregnancy risk before conception is sought, we find that selection depresses the mean observed fecundability at ages 37–39 by 20% of the underlying all-individual mean. This represents 50% of the decline in adjusted fecundability observed by that age range in a recent large prospective study (Wesselink et al., 2017). We show that this selection is caused both by unsought births before conception was ever attempted and by the inverse relationship between fecundability and waiting time to conception. Using simulations in which all individuals are abstinent until they seek to conceive, we isolate selection via the inverse relationship between fecundability and waiting times to conception. We find that under our simulation assumptions, at least half of the total depression in mean observed fecundability generated by the two types of selection together is caused by longer waiting times to conception alone.

We illuminate the mechanisms through which heterogeneity in fecundability and contraceptive failure affect observed fecundability. By comparing the reproductive experiences of individuals with different fecundabilities in our baseline simulation, we see that even relatively small differences in fecundability could generate large differences in the risk of initiating conception-seeking at older ages. By examining parities before conception is ever sought, we see how contraceptive failures cause large fractions of those with high fecundability to seek fewer or no conceptions. Moreover, by comparing the mean ages at conception-seeking by fecundability and parity, we observe that those with higher fecundability seek births of the same parity at younger ages, and that these differences are amplified as parity increases.

We do not argue that all or most real-world observed age-related declines in fecundability are caused by selection. Physiological changes with age, such as diminished ovarian reserves and egg quality, are well-documented. However, if we lived in the world of our simulations, it is easy to see how our observed pattern of mean fecundability by age could lead us to infer that fecundability declines as individuals age. We only argue that the forces that would induce this erroneous conclusion in a counterfactual world also shape observed fecundability in our real world. By revisiting demographers' concerns about selection bias in contemporary observed age-specific fecundability, we hope to consider their implications for our interpretations of modern experiences.

One important implication is that the population seeking to conceive or initiating conception-seeking at each age is unlikely to be representative of the general population. For women planning their lives, this means that the observed age patterns in fecundability may misrepresent an individual's actual likely trajectory of fecundability with age. Another implication is that social forces alone do not shape the ages at which we seek to conceive. Biological forces like fecundability matter, too. The focus on age as the primary determinant of variation in fecundability may obscure other biological sources of variation in fecundability, including the timing of conception-seeking and births.

One reason it is important to interpret observed age patterns in fecundability in light of possible selection is that social forces likely shape the degree to which selection on fecundability affects those seeking to conceive at later ages. For example, if women who wished to delay childbearing used more effective contraception to prevent unsought births, selection could be reduced, since a lower risk of unsought conceptions would mean that fewer individuals with high fecundability would be eliminated from conception-seeking. Conversely, if abortion is restricted or stigmatised, selection may increase, since unsought conceptions disproportionately prevent conception-seeking among those with higher fecundability. Changes in the distribution of desired family size could operate in the same way to increase or decrease the number of conception-seeking spells people initiate, on average, and thus the ages at which people with higher fecundability seek to conceive.

In a population in which these forces are stable over time, the observed age pattern of fecundability could be informative for individuals' lives; that is, the average person who reaches age 35 without achieving their desired family size would be similar in terms of fecundability to those on whom the data are based. Even in this case, however, people who are well under the age of 35 may base their partnering, education and career decisions on assumptions about this perceived deadline. But when social conditions are changing, the behavioural determinants of the life course family-building process that generates selection on fecundability will also change. This should make us especially cautious when interpreting observed fecundability by age as evidence of a biological ageing process.

The notion of the "biological clock" expresses the tension between women's social and biological lives (Friesen et al., 2006), and the issue of the age-related decline in female fecundability has attracted broad popular, medical and social-scientific interest (American College of Obstetricians and Gynecologists' Committee on Clinical Consensus–Gynecology, 2025; Blum, 2025; Heffner, 2004; Mahdawi, 2021; Menken, 1985; Menken et al., 1986; Practice Committee of the American Society for Reproductive Medicine, 2022; Soules, 2003). We interpret a classic result in reproductive demography as a warning regarding the fit between the questions women ask about their own reproductive futures and the available evidence.

This fit is important for individuals who must plan their lives, but it also has implications for broader social processes and concerns. In the contemporary United States, fertility postponement continues to drive fertility change and falling birth rates are fuelling a surge in pronatalist politics. Some proposals that seek to reduce women's participation in civic and economic life use age-related decline in fecundability as their rationale. For example, there have been calls for reductions in women's participation in higher education and for financial

incentives to encourage marriage and childbearing before specific ages in order to facilitate earlier births (Abbamonte, 2025).

A more demographically rigorous understanding of what we can and cannot know on the basis of the observed age pattern of fecundability, and a more robust discussion of the role of individual variation in fecundability, may provide a helpful counterbalance to narratives pressuring women to have children as early as possible. In service of our aim to illustrate the possible role of selection in shaping the observed age patterns of fecundability, our models make many simplifying assumptions. Actual partnering and family building trajectories are much more complex than those expressed here. For example, our model uses two extreme specifications of sexual behaviour before conception-seeking: (1) universal sex and contraception use from age 15 until the age at earliest conception-seeking and (2) abstinence until conception is sought. Using these two extremes, we aim to demonstrate a plausible range of sensitivity to this complex determinant. Our treatment of the age at earliest conception-seeking and fecundability as independent is also implausible, since the evidence indicates that advantaged women have higher fecundability and delay childbearing to a greater degree (Gottard et al., 2015; Greulich and Toulemon, 2023; Ní Bhrolcháin and Beaujouan, 2012). Furthermore, childbearing desires change in response to life circumstances, a fact our model does not capture. Similarly, neither desired lifetime parity nor the age at earliest conception-seeking are static predetermined traits in actual practice (Behrman, 2024; Bhrolcháin and Beaujouan, 2019; Guzzo, 2022; Trinitalpoli and Yeatman, 2018). It is also not true that everyone wants a minimum birth interval of 21.5 months, as is assumed in our model. We assume an earlier distribution of the earliest ages at which conception would be sought than is likely in most rich nations, which we do to conservatively minimise selection attributable to unsought conceptions. Finally, people's childbearing desires, intentions and behaviours are not always as clear-cut as "trying" and "avoiding", as ambivalence about pregnancy is common (Higgins et al., 2012; Miller et al., 2018; Rocca et al., 2022; Samari et al., 2020; Weitzman et al., 2017). However, we do not aim to simulate real-world reproductive lives, but rather to illustrate that selection on fecundability could contribute substantially to observed age-related declines in fecundability.

Even if there is no age-related change in individual fecundability, but there is heterogeneity among individuals, selection on fecundability will depress observed fecundability at older ages. Therefore, observed age-related declines in fecundability do not imply that individual fecundability follows that same pattern.

This is particularly concerning because the observed age-related fecundability decline is interpreted as evidence of the schedule on which individual women should expect their own fecundability to change. Further efforts towards estimating population-level heterogeneity in fecundability could help us to better understand the age-related decline in reproductive capacity. In addition, demographers could call for strategies for measuring fecundability by age to be informed by selection – for example, by focusing on those seeking first births. Even in the absence of new data, demographers should more thoroughly investigate the possible role of heterogeneity and selection in generating real-world observed fecundabilities by age. We should caution against interpreting the age pattern of fecundability among those seeking to conceive or initiating conception-seeking as representative of individual

age patterns of fertility. We can begin by undertaking broader simulation studies than the example provided here and should continue with analyses of existing data in light of these life course processes.

Supplementary material

Supplementary file S1. Software for Conception Abortion Miscarriage Birth Simulation (CAMBS) Model in which fecundability is constant with age. Available online at <https://doi.org/10.17605/OSF.IO/ZXPQE>



Supplementary file S2. Additional details on assumptions and distributions in the Conception Abortion Miscarriage Birth Simulation (CAMBS) Model (S1) and supplementary results (S2). Available online at <https://doi.org/10.1553/p-p7d2-d2hz>



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