

Supplementary Material

Supplement to: Stevenson, A. J., Root, L., and Menken, J. (2026). Rethinking age-specific fecundability: Selection bias can generate apparent rapid decline with age. *Vienna Yearbook of Population Research*, 24, <https://doi.org/10.1553/p-p7d2-d2hz>

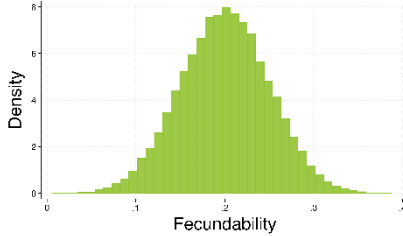
This supplementary material contains additional details on assumptions and distributions in the Conception Abortion Miscarriage Birth Simulation (CAMBS) Model and supplementary results.

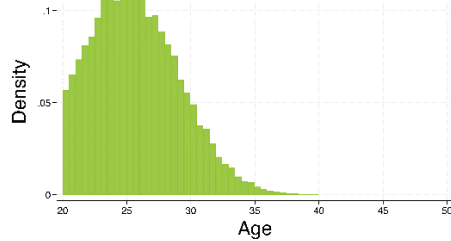
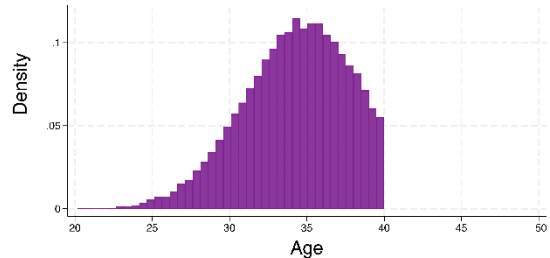
In section S1, we present the reproductive process model we developed for this paper. We describe the population-level distributions from which individual traits are drawn in Table S.1 and the universal transition parameters in the model in Table S.2. Then we provide a brief narrative summary of the life course progression through the simulation. In section S2, we present three supplementary results. First, in section S2.1, we present mean observable fecundability by age under a wide variety of definitions of the target population, based on our baseline simulation. Next, in section S2.2, we present mean observed fecundability by age from three different implementations of our baseline simulation. Finally, in section S2.3, we compare our baseline simulation results with results from a simulation in which population-level mean age of earliest conception seeking is a decade later than baseline.

S1 Additional Model Details

The CAMBS model we developed in this paper relies on individual traits (which can vary across individuals) and universal transition parameters (which are the same for all individuals in a simulation). In this section we provide additional details on the population distributions of individual-level traits and values of universal parameters used in this paper.

Table S.1 Time-invariant individual-level traits assigned in CAMBS, with distributions.

Characteristic	Notation	Population-level distribution from which individual-level values are drawn	
		Baseline simulation	Alternative simulations
Fecundability <i>monthly probability of conception in the absence of contraception</i>	ρ_i	 Each individual i is assigned a value ρ_i from a truncated normal distribution $\mu = 0.2, \sigma = 0.05$, with a minimum = 0 and a maximum = 0.4. Probability of conception at each ovulation when susceptible and not contracepting is ρ_i.	See main text Figure 2 for alternative population-level distributions of ρ_i and Figure 3 for results.
Sexual activity before conception seeking <i>age at which sexual activity generating conception risk begins</i>	S_i	Each individual i is assigned $S_i = 15$, indicating they are sexually active starting at age 15. All individuals enter simulation (begin their reproductive lives) at age 15 as susceptible and not conception seeking.	Each individual is celibate and not in the model until their age at first conception seeking. Individual i is assigned $S_i = A_i$ (A_i defined below). Individuals enter the simulation (begin their reproductive lives) as susceptible and conception seeking at age A_i. See main text Figure 4 for results.
Contraceptive efficacy <i>proportional decline in fecundability when contracepting</i>	ϵ_i	Each individual i is assigned a value ϵ_i from [0.90, 0.95, 0.99] following a discrete uniform distribution. Monthly probability of conception while contracepting is $(1 - \epsilon_i)\rho_i$.	None

Characteristic	Notation	Population-level distribution from which individual-level values are drawn	
		Baseline simulation	Alternative simulations
Age of earliest conception seeking <i>earliest exact age at which individual would intentionally seek conception (determines when individual contracepts to delay)</i>	A_i	 Each individual i is assigned a value A_i from a truncated normal distribution $\mu = 25, \sigma = 4$ with a minimum = 20 and a maximum = 40. All individuals contracept with efficacy ϵ_i when susceptible and age is less than A_i.	 Each individual i is assigned a value A_i from a truncated normal distribution $\mu = 35, \sigma = 4$ with a minimum = 20 and a maximum = 40. All individuals contracept with efficacy ϵ_i when susceptible and age is less than A_i. See Figure S3 for results.
Desired lifetime parity <i>parity after which the individual resumes contracepting (determines when individual contracepts to stop)</i>	P_i	Each individual i is assigned a value P_i from [1,2,3,4] following a discrete uniform distribution. All individuals are conception-seeking when susceptible and not contracepting for spacing if their parity is less than P_i.	None

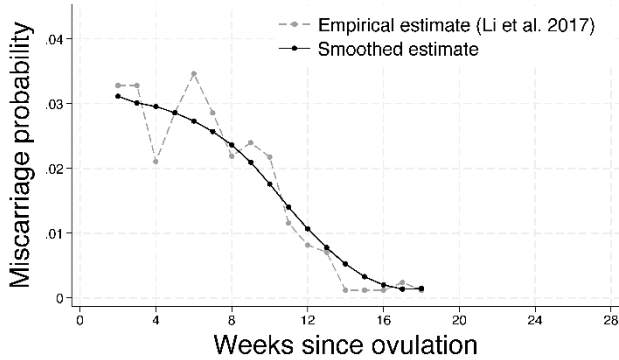
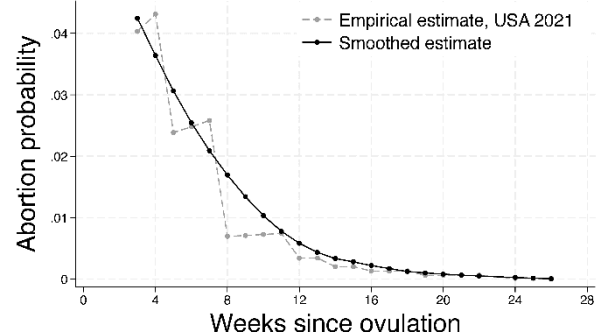
Note: Rationale for population-level distributions of fecundability and sexual behavior before conception seeking are discussed in main manuscript. Contraceptive efficacy, age of earliest conception seeking, and desired lifetime parity are discussed below.

Level of contraceptive efficacy. We assign each individual a level of contraceptive efficacy which we apply to their assigned fecundability to generate the probability of pregnancy in weeks when ovulation occurs while they are susceptible and not seeking conception. Selection on fecundability is greater when contraceptive efficacy is lower, so to be conservative we selected a distribution with mean efficacy higher than the mean observed among recent non-permanent contraceptors in the United States, accounting for the fact that our probabilities are monthly rather than annual (Hatcher et al. 2011; Polis et al. 2025).

Age of earliest conception seeking. We assign to each individual an age at which they would first seek conception if susceptible and they have not yet achieved their desired parity. Whenever they are susceptible before this age, individuals contracept to delay first birth. We assign each individual such an age from a population distribution. 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 earlier ages of conception seeking allow for longer observation after conception is sought. To illustrate how this choice influences the age pattern of observed mean fecundability, in an alternative simulation we adopt a relatively late distribution of ages of conception seeking, drawing from a truncated normal with $\mu = 35, \sigma = 4$ and range $[20, 40]$.

Desired lifetime parity. We assign a variety of desired lifetime parities to reflect a range of effects of this factor, since it is not immediately obvious whether (a) lower desired parity would lead to more bias because of negative selection due to unsought births or (b) greater desired parity would increase the negative selective effect of waiting time to conception.

Table S.2 Universal transition parameters in CAMBS.

Parameter	Values	Source
Weekly miscarriage probability		Lifetables using US national vital statistics on birth, late pregnancy loss, and vital registration (Kortsmit et al. 2022; Li et al. 2017; Maddow-Zimet and Gibson 2024; Mukherjee et al. 2013, 2013; Nobles et al. 2024; United States Department of Health and Human Services (US DHHS), Centers for Disease Control and Prevention (CDC) National Center for Health Statistics (NCHS), Division of Vital Statistics (DVS). n.d.)
Weekly abortion probability (always zero for pregnancies conceived while individual was seeking conception)		Lifetables prepared by first author using US national vital statistics on birth, late pregnancy loss, and vital registration (Kortsmit et al. 2022; Maddow-Zimet and Gibson 2024; Mukherjee et al. 2013, 2013; Nobles et al. 2024; United States Department of Health and Human Services (US DHHS), Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS), Division of Vital Statistics (DVS). n.d.).
Post-pregnancy non-susceptibility after miscarriage or abortion	5 weeks	Sheps and Menken (1973)
Pregnancy duration ovulation to live birth	38 weeks	Sheps and Menken (1973)

Parameter	Values	Source
Postpartum non-susceptibility	20 weeks	Sheps and Menken (1973)
Duration between birth and initiation of conception seeking for next desired birth	44 weeks (20 weeks of infecundability + 24 weeks of contraception for spacing)	To produce expected interbirth interval of 102 weeks or ~25 months, since expected waiting time to conception is 20 weeks when $\rho = 0.2$. $44 + 20 + 38 = 102$

Note: All probabilities included in replication code (available online at <https://doi.org/10.17605/OSF.IO/ZXPQE>).

Additional details on progression through simulation

Delaying – Before age of earliest conception seeking: When an individual is susceptible before ever seeking conception, they are modeled as contracepting at their assigned level of contraceptive efficacy. For an individual with fecundability ρ_i , the probability of conception at each ovulation while contracepting is $(1 - \epsilon_i)\rho_i$.

Family building – Seeking conception: Starting with the first week after an individual's exact age of earliest conception seeking (A_i), individuals who have not yet achieved their desired parity are modeled as “seeking conception” when susceptible and not spacing before seeking pregnancy for a desired birth. Their probability of conception at each ovulation is their fecundability, ρ_i .

Family building – Spacing: Individuals who have not yet achieved their desired parity are modeled as contracepting for spacing for 24 weeks of susceptibility after postpartum infecundability ends (for a total duration between birth and initiation of conception seeking for next parity birth of 44 weeks or 11 months). For an individual with fecundability ρ_i , the probability of conception at each ovulation while contracepting is $(1 - \epsilon_i)\rho_i$. This establishes a minimum target interbirth interval of 86 weeks, composed of 20 weeks of postpartum infecundability after index birth, 24 weeks of contraception for spacing, 4 weeks for first ovulation after infecundability ends, immediate conception, and 38 weeks of the subsequent pregnancy. The expected interbirth interval (when $\rho_i = \mu = 0.2$) is 102 weeks, longer by 16 weeks as expected waiting time to conception is 20 weeks.

Stopping – After desired parity is reached: Once an individual returns to susceptibility following postpartum infecundability after the birth bringing them to their desired parity, they are thereafter modeled as not seeking pregnancy when susceptible, so their probability of conception at each ovulation is $(1 - \epsilon_i)\rho_i$. The simulation ends in the week individuals turn exact age 50.

S2. Supplementary Results

S2.1 Definition of target population.

In this paper we investigate the degree to which the age pattern of fecundability among conception seekers (which can be observed and may be defined in different ways) is a biased measure of the age pattern of fecundability among all individuals (which cannot be observed but is of great interest). Among the many options, we choose to define observed fecundability at each age as the fecundability of the population who initiate spells of conception seeking at that age. We make this choice because this definition follows the practices of modern prospective studies which aim to minimize bias due particularly to length-biased sampling (e.g. Rothman et al. 2013; Wesselink et al. 2017). If one's purpose were different (e.g. to describe conception-seeking experiences or observe health system factors) other definitions would be appropriate. For example, all those who ever seek conception at a given age would have observable natural fecundability at that age and might be appropriately included in some study designs.

To illustrate how our definition of observed fecundability compares with other possible definitions, in Figure S1 we present mean fecundability by age from our baseline simulation under different definitions of the target population: all individuals, individuals initiating a live-birth-seeking spell for any parity,

individuals initiating a conception-seeking spell (the population whose fecundability we consider observed in our analysis), and individuals in a conception-seeking spell weighted by duration of spell at this age.

Spells of conception seeking are periods during which an individual is susceptible and not contracepting because they are seeking conception. If an individual conceives, experiences a pregnancy loss, and then starts seeking conception again, that second period of conception seeking is a new conception-seeking spell. Spells of live birth seeking are periods during which an individual is seeking a live birth. These periods begin when an individual first seeks conception for a desired birth of a given parity and end when the birth occurs. Live birth seeking spells can contain multiple conception-seeking spells if one or more pregnancies end in loss before birth is achieved.

Because all individuals maintain constant fecundability as they age in our simulations, mean fecundability is constant with age when the target population is all individuals (dotted line with circle markers). In each of the alternative definitions of the target population in Figure S1, depression in mean fecundability at later ages is caused by selection.

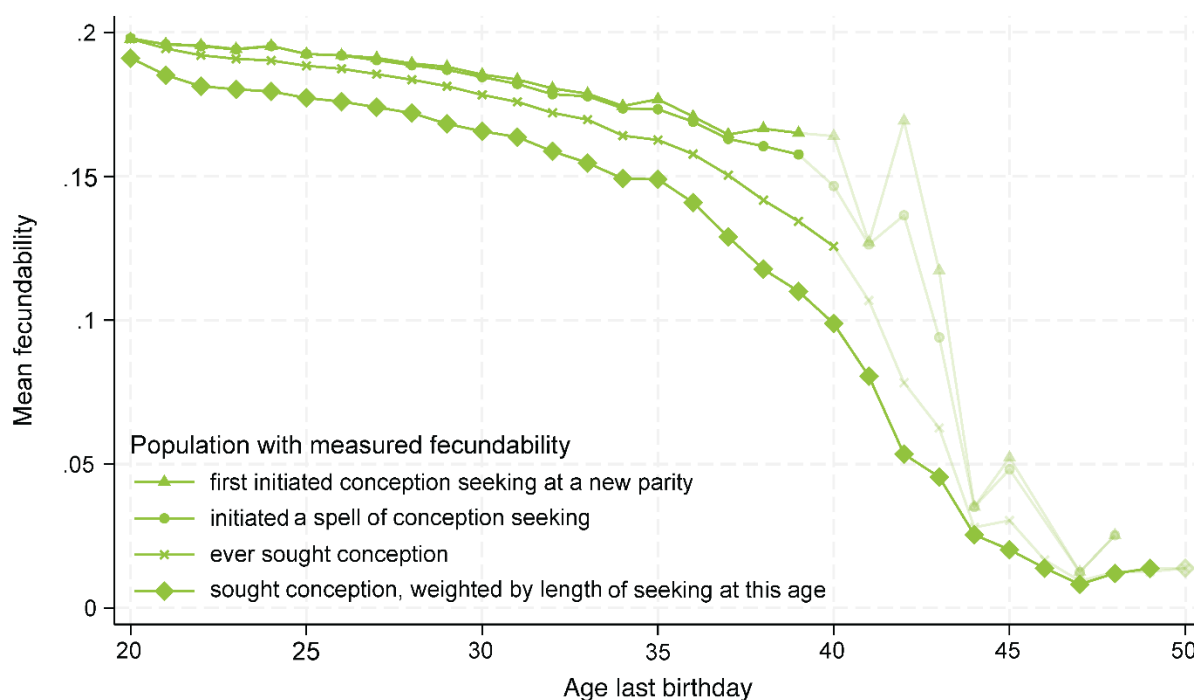
The force of selection on mean fecundability is most pronounced in the least restrictive definition of the target population: all individuals who sought conception weighted by the length of their seeking at that age (solid line with diamond markers). Under this definition, by age 40, mean observed fecundability is depressed to 50% of the mean among all individuals. This reflects a cross-sectional sampling design in which individuals are eligible if they are seeking conception at a point in time and ineligible if they are not. Means among this target population are subject to length-biased sampling by definition.

If the target population is all individuals who ever seek conception during a range of ages (in this case an age last birthday, solid line with X markers), selection causes less depression in mean fecundability at later ages. Under this definition, by age 40, mean observed fecundability is depressed to 66% of the mean among all individuals.

Our target population is those who initiated a spell of conception seeking during a range of ages (age last birthday, solid line with circle markers.) The mean among members of this population declines similarly to the mean for a more restrictive target population – those initiating a live birth seeking spell (solid line with triangular markers), though there is some indication that the restriction to those initiating a live birth seeking spell generates slightly less depression in the observed mean at later ages.

We choose to use those who initiate any spell of conception seeking rather than the more restrictive definitions based on spells of live birth seeking because spells of conception seeking are easier to define behaviorally and are commonly used in modern studies.

Figure S.1. Mean fecundability under different definitions of target population, baseline case.

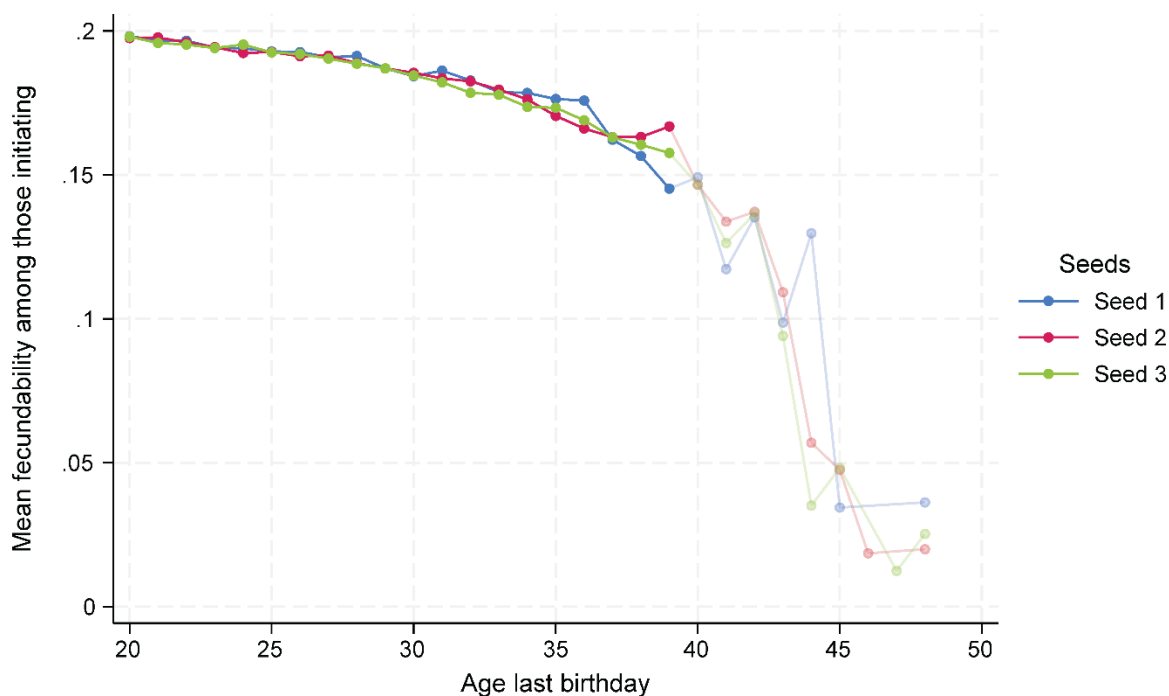


Note: See above for target population definitions. Each line is based on a simulation of 50,000 individual reproductive lives under the specified parameters. All individuals begin sexual activity at age 15 and contracept until seeking conception. Mean fecundability is opaque in years of age at which 50 or more initiations of conception seeking occurred and transparent in years of age at which fewer than 50 initiations of conception seeking occurred.

S2.2 Sampling variation.

In Figure S2 we present mean fecundability among those initiating a spell of conception seeking by age last birthday from our baseline simulation under three different initial states (or seeds) from which pseudorandom number generation proceeds.

Figure S.2 Mean fecundability among those initiating spell of conception seeking by age last birthday in baseline simulation under three different initial states of pseudorandom number generation.



Note: 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 seeking conception. Mean fecundability is shown as transparent in years of age at which fewer than 50 initiations of conception seeking occurred.

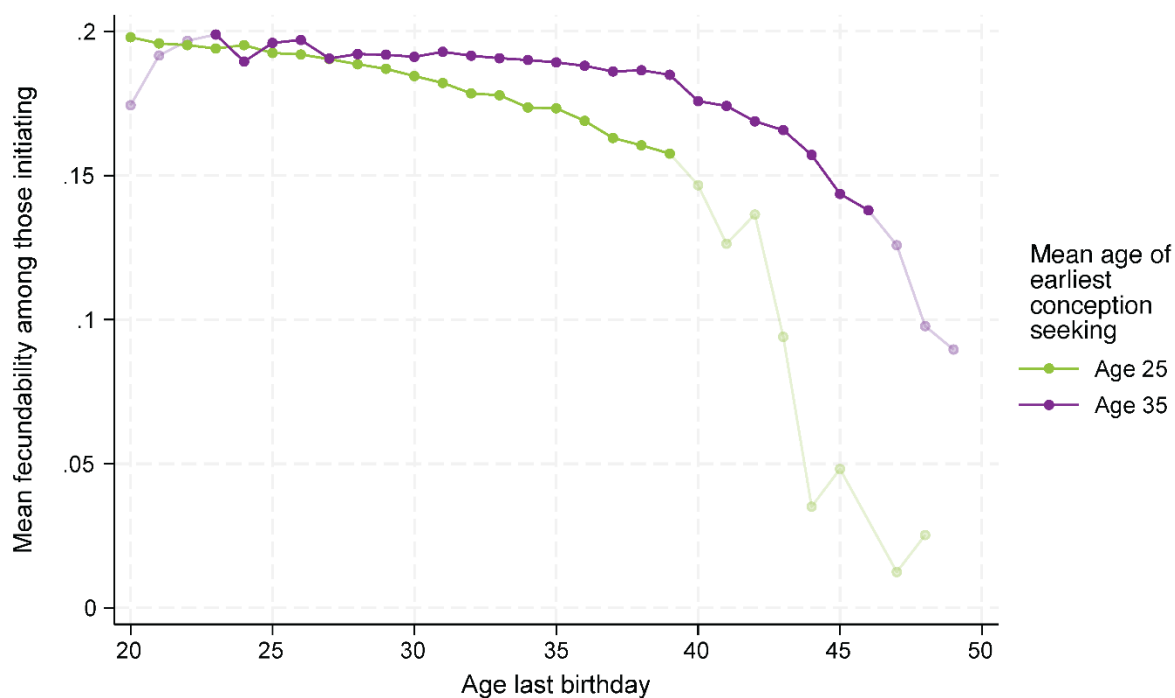
S2.3 Effect of mean age of earliest conception seeking.

To illustrate how the population-level distribution of ages at which childbearing would be sought shapes the ages at which observed mean fecundability deviates from the underlying all-individual mean, we compare mean observed fecundability by age in our baseline simulation and an alternative simulation using a relatively late distribution of ages of conception seeking.

In Figure S3 we illustrate the relationship between population-level differences in preferences for ages of childbearing and age patterns of depression in observed mean fecundability. We compare observed mean fecundability by age among those initiating spells of conception seeking in our baseline simulation (green) with observed mean fecundability by age among those initiating spells of conception seeking in an alternative simulation in which the mean age of earliest conception seeking is ten years later (purple).

In the alternative simulation, observed mean fecundability remains near the all-individual mean until the late 30s, after most individuals have begun seeking conception. Mean observed fecundability in the baseline simulation is 0.17 across ages 35-39, while in the alternative simulation the observed mean does not reach that level until ages 43-44. Overall, in both simulations, observed means are depressed relative to the underlying all-population mean only after the family building process is underway for most of the population.

Figure S.3 Mean fecundability among those initiating spell of conception seeking by age last birthday in baseline simulation and alternative simulation with later mean age of earliest age of conception seeking.



Note: 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 seeking conception. Mean fecundability is opaque in years of age at which 50 or more initiations of conception seeking occurred and transparent in years of age at which fewer than 50 initiations of conception seeking occurred.

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