Birth Intervals

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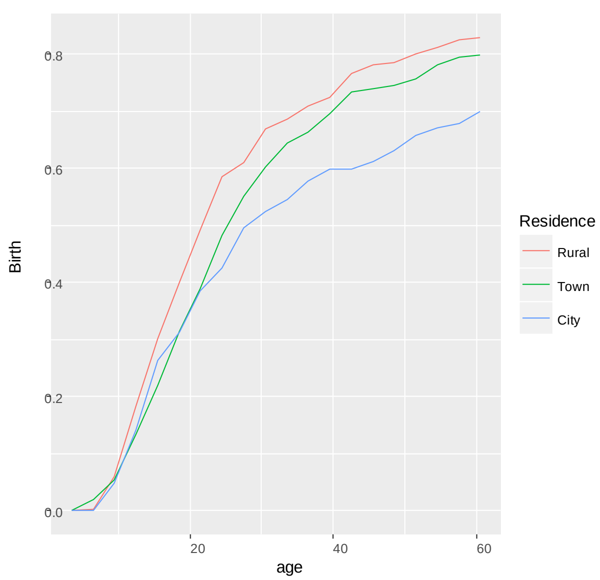
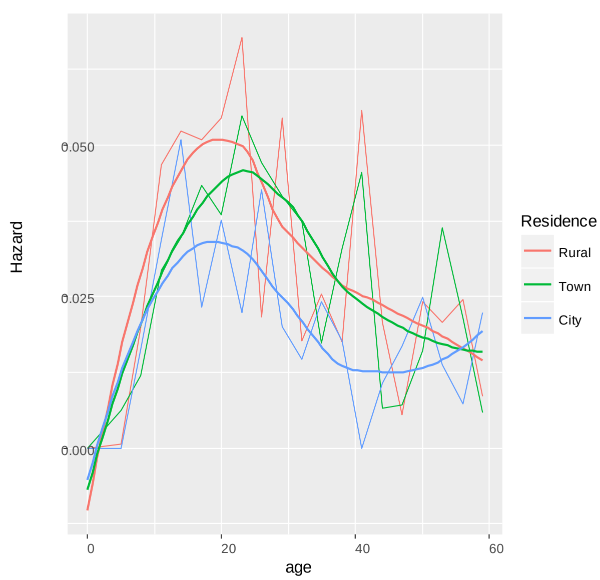
Birth interval analysis provides a more detailed view of the family building process than conventional fertility rates. We discuss briefly life table analysis of birth intervals and models of conception and birth, topics discussed in Section 5.4 of the textbook.

Life Table Analysis of Birth Intervals

Life table techniques can be used to study the progression from one parity to the next. Of interest here is the force of fertility, a hazard function that reflects the risk of moving to the next parity by duration since the last birth, and the *birth function* $B(d)$, or proportion who have moved to the next parity by duration d since the previous birth. (This function is analogous to our old friends $F(a)$, the proportion married by age a, and $1 - l(x)/l(0)$, the complement of the survival function.) The proportion who eventually move on is called the *parity progression ratio.* The average time it takes to move is the *length of the birth interval*.

Hobcraft and I did an illustrative analysis of birth intervals using data from the Colombian World Fertility Survey. The figures below show the birth and hazard functions for the transition from second to third birth by childhood type of place of residence, for women who had a second birth in the ten years preceding the survey. (The original paper used all births, so results are slightly different.)





The birth function shows that women who grew up in cities are less likely to make the transition to a third birth than those who grew up in towns or rural areas. The hazards functions are noisier, as you might expect, but smoothing shows a typical pattern where the hazard rises quickly to reach a maximum after one or two year and then declines. The rise is due to women coming out of the post-partum non-susceptible period, and the decline can be attributed to fertility control and/or selectivity.

Most women who make the transition to the next parity do so within five years, so one can summarize the *quantum* of fertility using the birth function at five years, and the *tempo* using the mean birth interval for those who make the transition within five years. As shown in the summary table on the right, women who grew up in rural areas have much higher parity progression ratios than those who grew up in towns or cities. They also have the shortest birth intervals, but the relationship between interval length and childhood residence is not monotonic, as women who grew up in towns have the longest intervals.

Residence	Quantum	Tempo
Rural	82.3	19.64
Town	79.3	22.06
City	67.7	20.24

The first birth interval is different from the others because it doesn't start with a birth. Traditionally demographers have studied the transition from first marriage to first birth, but this is fraught with difficulties because of premarital births. Ideally one would want a better marker of the start of exposure, but the necessary data are rarely available. A better strategy is to think directly in terms of entry into motherhood. The Coale-McNeil model of age at first marriage has been used successfully to model age at first birth. Birth intervals, like fertility rates, can be based on period or cohort data, with a synthetic cohort interpretation in the latter case. Cohorts can be defined by year of birth, year of entry into motherhood, or the year in which a specific parity is reached.

A side note: in life table analysis of birth intervals we compute rates dividing the number of births of a given order (say second births) by women in the previous parity (those with one birth), who are of course the only ones at risk of making that particular transition (to a second birth). We also index the process by duration since previous birth. Sometimes analysts compute order-specific fertility rates by age, dividing births of a given order to women in an age group by all women in the age group, regardless of parity. These rates are then summed to obtain order-specific TFRs, which are then interpreted as synthetic parity progression ratios. The age-order specific rates have the nice property that they add up to the overall ASFR, but they are not true event-exposure rates. (Clearly women with three children are not exposed to have a second child.) This is the same distinction we encountered before in terms of marriage frequencies and marriage rates, or between death densities and hazards.

Models of Conception and Birth

There is a long tradition of work on mathematical models of conception and birth by Sheps, Menken, Potter, Bongaarts, and others; and some of this work is reviewed in Section 5.4 in the textbook. Here we set aside issues of unobserved heterogeneity to focus on a few key ideas that will be useful later.

A typical birth interval has three components, a non-susceptible period that ends with the resumption of ovulation, a waiting time that ends with conception, and a gestation period that ends with the next birth. The first interval is different in that it doesn't start with a non-susceptible period. The figure below shows these components starting with the waiting time to conception.

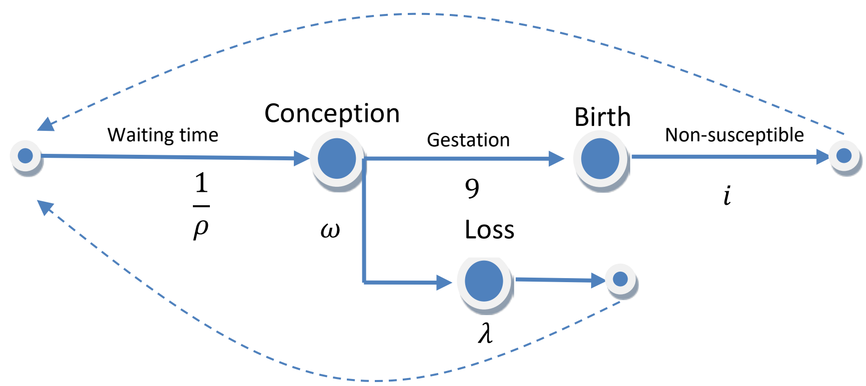


Figure 1. A Simple Model of Conception and Birth

In a homogeneous population with constant fecundability ρ the waiting time to conception is $1/\rho$. (This is a standard result for Bernoulli trials.) If $\rho = 0.2$ it would take an average of 5 months to conceive, and adding a typical gestation period of 9 months would lead to a first birth interval of 14 months. The length of the non-susceptible period depends on such practices as post-partum abstinence and the length of breastfeeding. If this phase lasts i months, then subsequent birth intervals would last on average $1/\rho + 9 + i$ months. If $i = 7.5$ months we get an average birth interval length of 21.5 months.

So far we have ignored pregnancy losses, such as miscarriages and still births. If the probability that a pregnancy will not end in a live birth is ω it takes on average $\omega/(1-\omega)$ losses before a successful live-birth conception. (This is the same standard result as above, but counting the delay, or failures before the first success.) Let λ denote the length of gestation plus the non-susceptible period following a pregnancy loss. (One could separate these two segments, but I follow the textbook in considering them together.) Each loss adds $1/\rho + \lambda$ months to the waiting time to a live-birth conception, the $1/\rho$ months it took to conceive plus gestation and infecundity following the loss. The total length of the birth interval is then

$$\left(\frac{1}{\rho} + \lambda\right)\frac{\omega}{1-\omega} + \frac{1}{\rho} + 9 + i$$

(Combining the two terms on $1/\rho$ yields equation 5.13 in the textbook, which uses s_b and s_ω for the no-susceptible periods following a birth and a loss; the latter includes gestation but the former doesn't, so I prefer using different symbols.) If 20% of pregnancies are wasted, so $\omega = 0.2$, one would average 0.25 losses before a live birth conception. Assuming that gestation plus infecundity takes up $\lambda = 5$ months, each loss would add 10 months (5 to conceive and 5 for gestation and non-susceptibility). The average 0.25 losses would then add a total of 2.5 months to the birth interval. Under these conditions, women would have a first birth after 16.5 months, with another birth following every 24 months.

Birth intervals can be translated into expected number of children by calculating how many intervals fit into the reproductive period. A woman who married at age 15 and had children following our simple model until age 45 (so her reproductive span is 360 months) would have one birth after 16.5 months and then (360-16.5)/24 = 14.3 more, for a total of 15.3 births. (We will encounter this number again later.) If she married at 25 instead she would have 'only' 10.3 children, and we can easily see the effect of delaying marriage.

This model can also be used to estimate the effect of contraception on fertility. We say that a method has *effectiveness* e if the monthly probability of conception ρ is reduced to $\rho(1-e)$; so a 90% effective method reduces fecundability to 10% of what it would be otherwise. It is easy to see that the waiting time to conception is then $1/\rho(1-e)$ instead of $1/\rho$, so the average wait would be 1/0.02 = 50 months instead of 5 with 90% effective contraception. The first birth interval would then be 72.75 months, subsequent birth intervals would be 80.25 months, and our mythical woman would have 4.58 births over 30 years. If she also waited to marry at 25 instead of 15 she would have 3.08 children.

An interesting application of this simple model is to compute births averted by abortion. You'd think an abortion averts exactly one birth, but this ignores two facts: (1) a woman having an abortion would become susceptible much sooner than if she had carried the pregnancy to term, particularly if there is prolonged lactational infecundity, and (2) some of the pregnancies that are aborted would have resulted in a loss anyway, with the fraction depending on the timing of abortion. Under the assumptions used so far and with no contraception, an abortion adds 10 months to the birth interval (5 to conceive and 5 in gestation and infecundity), so it prevents 10/24=0.435 births. Using 90% effective contraception an abortion increases the birth interval from 80.25 to 135.25 months, thus preventing 55/80.25 = 0.685 births.

The textbook notes that an abortion effectively prevents one birth when contraception is very effective and the waiting time to conception dominates the birth interval, but this is only true if there are no other pregnancy losses. Equation 5.15 effectively assumes that abortions occur very early, so a fraction ω are redundant and the best you can do is avert $1-\omega$ births. A more realistic model would distinguish early and late losses and allow for the timing of abortion. A simple solution is to add a delay for recognized losses before the decision to abort of the form $(1/\rho+\lambda_e)\omega_e/(1-\omega_e)$ where λ_e is the gestation and infecundity associated with an early loss (say 4 months) and ω_e is the probability of an early loss (say 0.12 instead of 0.20). This increases the length of an interval with 90% effective contraception from 80.25 to 142.61 and averts 0.777 births. (With 99% effective contraception the original model gives 0.785 and adding an allowance for losses 0.893.)

These calculations are extremely simplistic because they ignore age effects and heterogeneity across women, but they have the advantage that they can be carried out 'on the back on an envelope'. More realistic models require simulation. Potter has looked at births averted when abortion is added to contraception using data from Taiwan and a simulation model called ACCOFERT, which has the added advantage of letting some of the parameters vary with age. He concludes that "if abortions are being performed in the third month of pregnancy upon 30-year-old women who are regularly practicing 98 percent effective contraception, the mean number of births averted per operation is 0.85; but if the same women are not practicing contraception at all, births averted per abortion average only 0.45." Another simulation model you may find interesting is SOCSIM, developed by Hammer and Watcher.