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Hutterite Fecundability by Age and Parity: Strategies for Frailty Modeling of Event Histories*

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Effective fecundability declines with age and parity. Furthermore, women differ in their effective fecundability: some women have persistently low or high monthly chances of live-birth conception. Estimates are presented concerning the magnitude of these effects in a natural-fertility population: 406 Hutterite women in North America who had 3,206 births, largely in the 1940s and 1950s. The estimates are based on models that incorporate the effects of persistent heterogeneity and that use the full information provided by multiple-spell duration data. In addition, hazards rather than probabilities are modeled, piecewise linear hazard functions are used, and age and parity effects are decomposed systematically. These methods permit the development of more elaborate models of changing fecundability and of heterogeneity in postpartum amenorrhea.

How does effective fecundability—the monthly probability that a conception will result in a live birth—vary over a woman's reproductive lifetime? How does effective fecundability vary across women? These two questions are of great interest to demographers as well as to couples concerned about infertility and about how long they can wait in postponing childbearing.

In this article we present estimates of how effective fecundability declines with age after age 20 and with increasing parity (i.e., number of previous births). We also present estimates of the degree of heterogeneity among women in their effective fecundability,

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including an estimate of the proportion of fecund women who have persistently low or high monthly chances of live-birth conception.

The results pertain to a very special population: 406 Hutterite women in North America who had 3,206 births, largely in the 1940s and 1950s. We chose this population for the same reasons many other demographers have chosen to analyze it. Most important, the population appears to be a natural-fertility population with no evidence of use of contraception. In addition, the data are readily available and appear to be reliable and there is relatively little missing information about women's reproductive histories . Although the Hutterites are unique, analyses of patterns of fecundability over age and parity among this natural-fertility population may shed some light on possible patterns in other populations.

The Hutterite data can be treated as multiple-spell duration data (Heckman and Walker 1987). The first duration for each woman is the time from marriage until first birth, the second duration is the time from first birth to second birth, and so on for successive durations. Vaupel (1990a, 1990b) developed a maximum-likelihood approach for using such data to estimate a hazard function and a distribution of hidden heterogeneity. This article presents the first application of Vaupel's method.

PRELIMINARIES

General Background

The level of fecundability in a population has been a focus of research interest ever since Gini (1924) first defined fecundability as "the probability for a married woman to conceive during a month, in the absence of any Malthusian or neo-Malthusian practice intended to limit procreation." Many conceptions are lost very early in the pregnancy, and more than 30% of all pregnancies are not carried to term (Wilcox et al. 1988). Very early pregnancy losses might not be recognized, and fetal losses generally are underreported. Consequently it is often not feasible to estimate fecundability, and analysis may be limited to live-birth conceptions to estimate what is known as effective fecundability (Bongaarts 1975).

Demographers are interested in fecundability because it is one of the major determinants of fertility. Recently there has been substantial public interest in information not only about the general level of fecundability, but also about the age trajectory. Successful contraceptive users need to know how late they can postpone childbearing and still be fairly certain that they will be able to reproduce. Furthermore, studies of contraceptive efficacy require accurate assessments of the level of fecundability in natural-fertility populations.

The age pattern of fecundability is not well understood. It is unclear whether a couple's fecundability gradually declines to zero or whether the transition from fecundity to subfecundity to sterility occurs over a short period. Similarly, it is not known whether the decline in aggregate fecundability by age is due largely to an increase in the proportion sterile or to a decline in fecundability among the couples who are still fecund. It is also uncertain whether parity affects fecundability and, if so, whether fecundability declines gradually with parity or markedly at some level of parity. Sheps and Menken (1973) assumed no dependence on parity in their theoretical models of fecundability.

Menken (1975) concluded that "fecundability has proved difficult to measure"(p. 1), and that "a fruitful area of methodological research may be the development of new types of analysis" (p. 170). New types of analysis have been proposed by (among others) Bongaarts (1978, 1982) and Hobcraft and Little (1984). Menken, Huang, and Reinis (1989), however, concluded that "estimates of potential fertility or total fecundity from either procedure are so unreliable that they should be suppressed" (p. 6). In response to Menken we estimate fecundability using a frailty modeling approach that takes persistent heterogeneity and repeated births into account (Vaupel 1990a, 1990b).

The idea that some women are more fecund than others was recognized by Gini (1924). Heterogeneity in fecundability might arise from persistent differences across women over their entire reproductive lifespans as well as from differences that vary from birth interval to birth interval. In either case, an important issue is whether fecundability is so heterogeneous that estimates of patterns of fecundability over age and parity are biased if heterogeneity is ignored. Furthermore, if all women are not endowed with the same fecundability, then knowledge about the degree of heterogeneity might increase understanding of prevailing patterns of fertility.

Studies of fecundability are confronted with the methodological issue of how to model repeated events in a natural-fertility population because most women in such populations have many births. Tuma and Hannan (1984) suggested treating events for the same individual as independent. David and Mroz (1989), Heckman and Walker (1987), Mroz and Weir (1990), and Vaupel (1990a, 1990b) developed approaches that use the information provided by the repeated events; we apply Vaupel's method. The main methodological question we address is this: How can the effects of age and parity on fecundability in a heterogeneous population be decomposed parsimoniously and in a biologically and demographically plausible way?

In contemporary populations, studies of fecundability are hampered by the widespread use of contraception: one difficulty is that couples who do not use contraception may have low fecundability. On the other hand, the age and parity schedules of fecundability in natural-fertility populations, who have on average more than 10 children per couple, may differ markedly from that of contemporary populations, whose total fertility rate is less than two. Also, estimates of fecundability based on historical populations may understate the fecundability of healthier 20th-century populations. Accordingly we applied our analysis of age and parity schedules of fecundability to the Hutterites in this century.

The Hutterites live in North America in scattered areas of the Dakotas, Minnesota, and neighboring parts of Canada (Eaton and Mayer 1953). For religious reasons they practice no form of birth control, and their marital fertility is exceptionally high. Hence we have little reason to suspect any form of deliberate fertility control. In addition, the Hutterites have a communal lifestyle, and there are no evident social or cultural forces that can lead to differential fecundability. Therefore, if heterogeneity is documented, it probably can be ascribed largely to biological factors. Furthermore, the Hutterites have been used as a standard in numerous demographic studies, including the Princeton European Fertility Project (Coale and Watkins 1986), Coale and Trussell's (1978) model of marital fertility and assessment of the degree of fertility control, and Howell's (1979) study of fertility of the Dobe !Kung.

To simplify the analysis and presentation of results, we treat fecundability as an attribute of the woman rather than of the couple. Previous studies showed that biological aging of men has a minor effect on couples' fecundability until the men are older than 60 (Goldman and Montgomery 1990; Mineau and Trussell 1982). Among the Hutterites, the age difference between wife and husband is generally only a few years.

Substantive Background and Previous Findings

Many studies have focused on estimating fecundability: for a general review, see Golden and Millman (1988) and Menken (1975). Here it suffices to note that findings about the level as well as about the age and parity schedule of fecundability are inconsistent.

Fecundability, even in natural-fertility populations, is understood so poorly, that no decisive answer can be given to the question "How long can you wait?" (Menken and Larsen 1986).

Bongaarts (1975) pointed out that estimates of fecundability vary greatly from study to study because of different methods and different definitions of fecundability. Yet, even when the same method and the same definition were applied in a study of several historical populations, fecundability ranged from .18 to .31 (Wilson 1987). We suggest that different age and parity distributions, as well as other unobserved factors such as frequency of intercourse, might contribute to the diversity of fecundability estimates.

Because low fecundability leads to longer intervals between births, studies of birth intervals clarify the effect of age and parity on fecundability. Goldman, Westoff, and Paul (1987) found in selected countries in South Asia, Latin America, Africa, and the Middle East that birth intervals increased substantially above age 35 and above parity 8. Studying birth intervals in a number of Asian, Latin American, and African countries, Rodriguez et al. (1984) and Trussell et al. (1985) found that longer birth intervals were associated with older ages, and that parity was not important when the length of previous birth interval and other covariates were controlled. In contrast, Heckman and Walker (1987) concluded that models of Hutterite fecundability fit the data significantly better when parity was included, whereas controlling for previous birth interval lenghts did not improve the fit.

The Hutterites

The Hutterites are a communally oriented Christian sect. To escape religious persecution, they migrated to the Dakotas in the 1870s from the places to which they had migrated previously in Russia. About half of the sect settled in three colonies; the sample analyzed here is drawn exclusively from one of these colonies, the S-leut. The S-leut increased from 215 persons in 1880 to 5,450 in 1960. This growth was internal because almost nobody has moved into the Hutterite community. There is a fair degree of inbreeding, but this has not affected Hutterite fertility (Mange 1964). The community is very homogeneous; there is no variation in fertility by education, occupation, income, or social status (Eaton and Mayer 1953).

The Hutterites' fertility is exceptionally high. Eaton and Mayer (1953) found a median of 10.4 children per woman over age 45 in 1950, and 10 children was the modal value in the sample we analyzed. None of the women we studied had more than 15 children, and twinning is at the same level as in the general U.S. population. Total Hutterite mortality is comparable to U.S. mortality.

Estimates of Hutterite fecundability have been published in numerous studies, including D'Souza (1974), James (1963), Majumbdar and Sheps (1970), Sheps (1965), and Suchindran (1972). Hutterite fecundability estimates range from less than 1 (James 1963) to .25 (Suchindran 1972) because of different analytical methods, sampling frames, and definitions. D'Souza's (1974) careful study documented a gradual decline in the monthly probability of a live-birth conception from .154 among 25 to 29-year-olds to .123 among 33 to 37-year-olds and a rapid decline at older ages. D'Souza's fecundability estimates fit the data quite well, but the analysis was restricted to women who had at least 4 children by age 50. Thus the estimates probably were too high.

The effective reproductive period spans nearly the same interval for all Hutterites. The husband is generally one to two years older than the wife, and most Hutterites marry in their early twenties. In the sample studied, 60% of the women married between age 20 and 23, and another 24% married at 18 or 19. Only one of the 419 women married before age 18 and only 15% married after age 23. Hence age-specific coital frequencies may vary less among Hutterite couples at the same age than in most other populations, because marriage duration is a strong predictor of coital frequency (Jasso 1985; Kahn and Udry 1986). No data about coital frequency are available. Premarital intercourse is considered very sinful; in our sample, only eight children were born less than seven months after marriage. Divorce and widowhood are rare among couples in the reproductive age span, and by age 45 almost everybody has married. We confined the analysis to the reproductive period spanning the years from age 20 to 47. No woman had a live birth before age 18 or after age 46, and adolescent subfecundity is absent by age 20.

It is unknown how frequently the married Hutterites have intercourse, but it is customary not to have intercourse a few weeks before parturition and for about six weeks afterwards (Eaton and Mayer 1953). Women who do not breast-feed generally start to menstruate six to eight weeks after a delivery, so among the Hutterites the postpartum infecund period is at least as long as the period of abstinence. Huntington and Hostetler (1966) observed that Hutterite women let their babies nurse for very short periods (10 minutes or less). Supplementary food is introduced very early, and at the age of six weeks most infants are fed solid food before they are nursed. The age of weaning varies from less than four months to more than a year, and younger women seem to wean their children earlier than older women. Exact inferences from observations about breast-feeding to the period of amenorrhea cannot be made. Breast-feeding, however, is known to be a strong predictor of the duration of amenorrhea (Bongaarts and Potter 1983; Goldman et al. 1987; John, Menken, and Chowdhury 1987). The link between breast-feeding and amenorrhea is a hormonal reflex initiated by the suckling stimulus, whereby increases in the pituitary hormone prolactin act either on the hypothalamus or directly on the ovaries to prevent ovulation (McNeilly, Howne, and Houston 1980). A woman must nurse rather intensively (at least four times a day and for about 20 minutes each time) to prevent ovulation.

It has been suggested that the period of amenorrhea can be approximated by the difference between the interval from marriage to first birth and the interval from first to second birth. This procedure is flawed, however, because it assumes that the frequency of intercourse is the same in the first and in the second birth interval, that effective fecundability does not decline after the first birth, and that intercourse starts at marriage. In our sample the average first and second birth intervals are 13 and 19 months, suggesting an average period of amenorrhea of about six months. Yet, fully 15% of all live births (excluding first births) occurred less than 15 months after the previous birth. If the six-month estimate of the period of amenorrhea is corrected for the decline in fecundability with age and parity, a figure of perhaps five months may be reasonable. Some 8% of second and higher-order births occurred less than 14 months after the previous birth.

There is no evidence suggesting that the Hutterites practiced any form of birth control; their religion forbids the use of mechanical and pharmaceutical devices. It is possible that a few high parity women had a hysterectomy, which cause no objections if performed for health reasons (Eaton and Mayer 1953). Finally, induced abortion is non-existent in this population.

Hutterite Data

The Hutterite reproductive histories analyzed in this study were gathered as part of a medical genetic study conducted by A. G. Steinberg and associates at Case Western University. The major source was family records listing dates of birth, marriage, and death; verbal accounts allowed a check on the accuracy of the written information. Most records were transcribed onto special forms during the years from 1958 to 1961, although some data were collected as early as in 1953. It is not clear how the sample was drawn, and we cannot exclude sample biases.

The sample available to us included 724 unions. In this sample 10 women had been married twice. We discarded their second unions as well as 175 unions with missing birth, marriage, or death dates. In addition, we excluded all couples married less than five years. Finally, 13 couples who remained childless were excluded: we analyzed data on couples who were fecund at marriage, as demonstrated by at least one subsequent birth. About 3% of all couples never attain the ability to reproduce in any population (Bongaarts and Potter 1983). The resulting sample contained 406 couples who had 3,206 live births. In this data set the Hutterites either underreported the frequency of fetal loss or were not aware of all their wasted pregnancies. Sheps (1965) found that only 9.3% of all reported pregnancies were lost, whereas in general more than 30% of all conceptions do not lead to a live birth (Wilcox et al. 1988). Hence, studies of Hutterite total fecundability are problematic, and we confined our analysis to live-birth conceptions (i.e., effective fecundability).

ANALYSIS

Overview

Our analysis of Hutterite fecundability by age and parity involves three consecutive models. In Model 1, the age schedule of fecundability is determined, and various ways to model heterogeneity in fecundability are explored. In Model 2, the age schedule of conditional fecundability (i.e., among nonsterile women) is analyzed. In Model 3, the simultaneous effects of age and parity on conditional fecundability are examined.

Description of Model 1

Let the hazard[1] of the jth woman's ith live-birth conception at exact age x (among women who are fecund at marriage) be given by

$$h_{ij}(x) = z_j f(x), \tag{1}$$

if the woman is at risk of having her ith live-birth conception at age x, and by

$$h_{ij}(x) = 0 \tag{2}$$

otherwise, where z_j measures persistent differences among women in fecundability and the function f describes how fecundability varies with a woman's age x.

We modeled the frailty variable z in three alternative ways. First, fecundability was assumed to be homogeneous so that z was 1 for all women. Second, z was assumed to be gamma-distributed with mean 1 and variance σ^2. Third, z was assumed to follow a two-point distribution with support points z_1 and z_2 and with mean 1.[2]

We assumed the age schedule of fecundability f(x) to be a piecewise linear function with bends at ages 20, 25, 30, 35, 40, and 45 years. The 13 births conceived before exact age 20 were not used in this analysis. No woman in the sample conceived a live birth after exact age 47, so we set f(47) equal to 0.

Women's ages at marriage and at all births are known to the day, so we treated the observed ages as exact ages on a continuous time scale. Age was measured in months and fractions of months; f(x) should be interpreted as a monthly hazard rate.

The models we used to fit the data are continuous-time models of hazards rather than the discrete-time models of monthly or menstrual probabilities often used in fecundability analyses. The probability, q(x), of a live-birth conception in a period of (say) one month is given by

$$q(x) = 1 - \exp\left(-\int_{x}^{x+1} f(t)dt\right). \tag{3}$$

Because f does not change much over the course of a month, this relationship can be approximated closely by

$$q(x) = 1 - \exp(-f(x+.5)). \tag{4}$$

Thus there is a simple correspondence between q and f; whether q or f is used is a matter of analytical convenience.

In frailty modeling, individuals with frailty z face z times as great a chance of some event as compared to standard individuals with frailty 1. It is convenient to work with hazards because hazards are unbounded, whereas probabilities cannot exceed 1. To handle heterogeneity in the probability of conception, we must use distributions that are restricted to values between 0 and 1; the beta distribution is often used. If hazards are modeled, any nonnegative distribution can be used. In our analysis we use two very different nonnegative distributions, the two-point and the gamma distribution.

We assumed a woman to be at risk of having her first live-birth conception from age X_1, her age at marriage, to age $Y_1 = T_1$-9, where T_1 is her observed age at the birth of her first child (with age measured in months). For a very few women for whom Y_1 was less than X_1, we set $Y_1 = X_1 + .5$. This correction is based on the assumption that Hutterite women who give birth less than nine months after marriage do so because of a short pregnancy rather than because of premarital conception. A woman's age at the time of her first live-birth conception was assumed to be Y_1. A woman was assumed to be at risk of having her ith live-birth conception at age x, i>1, from age $X_i = T_{i-1} + c$ to age $Y_i = T_i$-9, where T_i is her observed age at the birth of her ith child and c is the postpartum infecund period. We assumed for Model 1 that c was two months if the i-1st child died before age one month and that c was five months otherwise. In about 8% of the cases, Y_i was less than X_i: in these cases we assumed that the gestation period was less than nine months and set $Y_i = X_i + .5$. A woman's age at the time of her ith live-birth conception was assumed to be Y_i.

Let I denote a woman's total number of live births. Let $X_{I+1} = T_I + c$ represent the earliest age following a woman's final birth when she is again at risk of a live-birth conception, and let Y_{I+1} denote the last age when a woman is at risk of a live-birth conception. Hence the interval from X_{I+1} to Y_{I+1} is the open interval following the final birth. As noted earlier, we followed some women to the end of their reproductive lives: for them we set Y_{I+1} equal to 47 years. Other women died or were otherwise lost to follow-up at some younger age T^*. In these cases we set $Y_{I+1} = T^*$-9. In the few cases when the husband died or the union was dissolved at a woman's age T^*, we observed the woman to age $Y_{I+1} = T^* + 9$, to allow pregnancies to be carried to term. In the few cases where Y_{I+1} was less than X_{I+1}, we eliminated the open interval by setting X_{I+1} equal to Y_{I+1}.

Following Vaupel (1990a, 1990b) but with somewhat different notation, let M denote the total cumulative hazard for some woman,

$$M = \sum_{i=1}^{I+1} \int_{X_{i-1}}^{X_i} h_i(x)dx, \tag{5}$$

let n denote the total log hazard at the woman's ages at live-birth conception,

$$n = \sum_{i=1}^{I} \log h_i(X_i), \tag{6}$$

and let g†(M,I) denote the integral transform

$$g^t (M,I) = \int_{O}^{\infty} z^I e^{-Mz} \, dG(z), \tag{7}$$

where G(z) is the distribution function of z and the integral is a Lebesque-Stieltjes integral, so that this distribution function can be continuous or discrete. (If the distribution function is discrete, the integral can be interpreted as a summation.) It follows from Vaupel (1990a, 1990b) that the likelihood of the data for a woman is

$$£ = e^n g^t (M,I). \tag{8}$$

The likelihood of the data for all the women is simply the product of these likelihoods for each woman. Vaupel provides the functional forms of g^t for the gamma and two-point distributions needed to compute the value of the likelihood.

Results of Model 1

Table 1 displays the monthly hazard of a live-birth conception at selected ages estimated for Model 1. Figure 1 illustrates the age schedule of Hutterite fecundability when heterogeneity in fecundability is modeled as homogeneous or by a gamma or a two-point distribution. The parameter estimates concern the hazard of live-birth conception, whereas the figure plots the monthly probability of a live-birth conception for a hypothetical woman whose frailty (or relative fecundability) z is 1; as discussed above, we estimated this probability by 1-exp(-f(x + .5)), where x is age in months. All three models yield roughly similar results, and effective fecundability appears to decline in a roughly linear fashion.

We used the likelihood-ratio statistic to determine the best-fitting model: we compared the homogeneous model with the gamma and the two-point distribution model. Both the gamma and the two-point distribution model fit the data significantly better at the .001 level than the homogeneous model (the likelihood-ratio statistics were 334 and 282 respectively with one and two degrees of freedom). These are alternative rather than nested models, but the log-likelihood is higher for the gamma than for the two-point distribution. The gamma distribution, however, has only one free parameter (the variance), whereas the two-point distribution has two free parameters.

As expected, fecundability was generally lower in the homogeneous model than in either of the models where heterogeneity was distributed as a gamma or a two-point distribution. If fecundability varies among women, the more fecund women spend less time at risk of a live-birth conception because they are pregnant or postpartum infecund. This kind of selection biases the estimates of fecundability downward.

In the best-fitting two-point distribution, roughly one-third of women were in the low-fecundability group and two-thirds in the high-fecundability group. The monthly chances of a live-birth conception for the high-fecundability group were 2.5 times as high as for the low-fecundability group; at age 30 the monthly probability of a live-birth conception was about 15% for the more fecund and about 6% for the less fecund. Thus even though the

Table 1. Monthly Hazard of Live-Birth Conception at Selected Ages and Related Statistics for Parous Hutterite Women, for Homogeneous, Gamma, and Two-Point Distributions of Fecundability[a]

	Monthly Hazard of Live-Birth Conception at Age										
Model	20	25	30	35	40	45	sd[b]	p_1[c]	z_1[d]	z_2/z_1[e]	Log-Like-lihood
Homogeneous	.261	.161	.109	.086	.051	.005	0	—	—	—	−9616
	(.016)	(.008)	(.006)	(.006)	(.004)	(.002)					
Gamma	.308	.188	.128	.104	.058	.006	.477	—	—	3.096	−9449
	(.020)	(.009)	(.007)	(.006)	(.004)	(.002)	(.030)				
Two-point	.296	.179	.123	.099	.057	.006	.348	.318	.491	2.520	−9475
	(.019)	(.008)	(.007)	(.006)	(.004)	(.002)		(.104)	(.073)		

[a] Standard deviations of estimates are given in parentheses.
[b] Standard deviation of hazard of live-birth conception.
[c] p_1 is probability mass at z_1.
[d] z_1 is support point for p_1.
[e] z_2/z_1 is for the two-point distribution, the ratio of the hazard of live-birth conception of the more fecund group to that of the less fecund group. For the gamma distribution, $z_2/z_1 = (1+\sigma)/\sigma$ (σ is standard deviation),the hazard of live-birth conception of those one standard deviation above the mean to that of those one standard deviation below the mean.

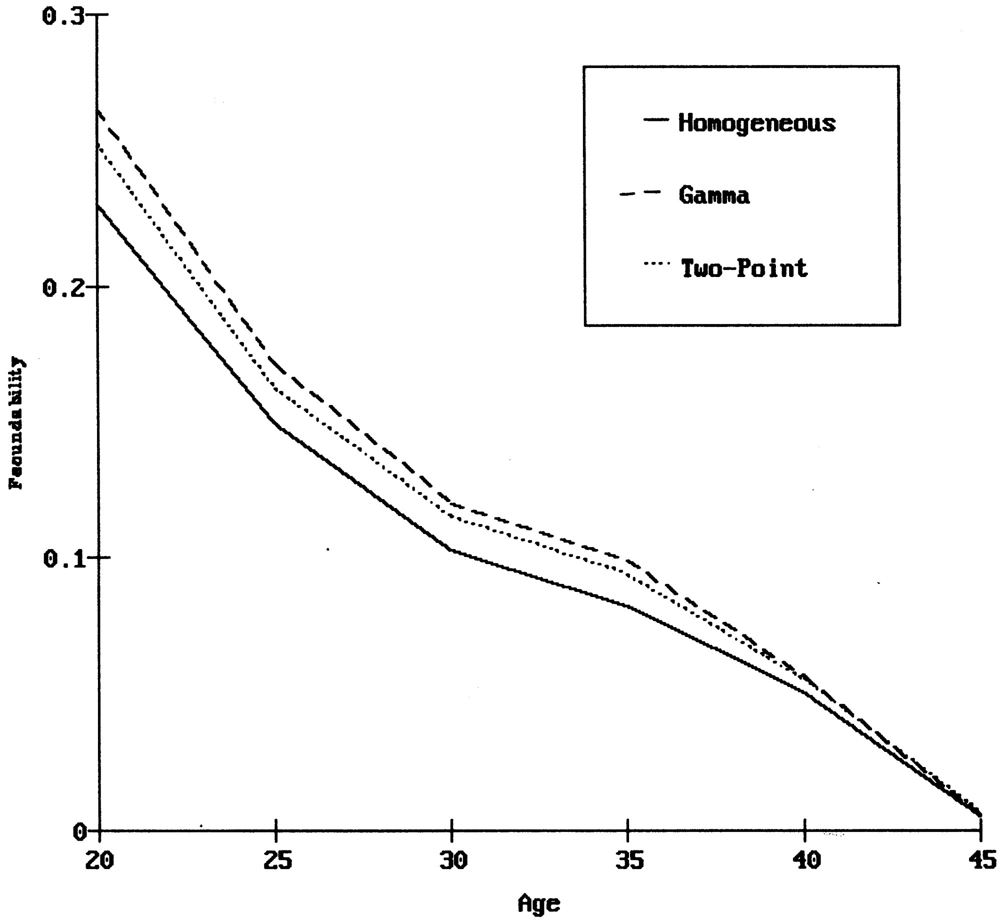

Figure 1. Age-Schedule of Average Fecundability for Parous Hutterite Women, for Homogeneous, Gamma, and Two-Point Distributions of Fecundability. Fecundability is the monthly probability of a live-birth conception for women with average frailty.

age schedule pattern of fecundability shown in Figure 1 does not differ greatly for the homogeneous and the heterogeneous models, heterogeneity in fecundability is not insubstantial. This heterogeneity will influence the distribution of waiting times to conception and the distribution of completed family size.

The best-fitting gamma distribution had a standard deviation of nearly .50, as compared with a standard deviation of about .35 for the two-point distribution. Women one standard deviation above average in the gamma model had just over three times as great a monthly chance of a live-birth conception as women one standard deviation below average.

Description of Model 2

One of the most questionable features of Model 1 is the assumption that women stay at the same level of frailty (i.e., fecundability relative to that of other women of the same age) from marriage until age 47. This assumption is unrealistic because it is known that women who are fecund at younger ages may become sterile at older ages. In Model 2 we circumvent this problem by restricting the analysis at each age to women who are known to be fecund at that age. Women are assumed to be fecund at some age if and only if they have a child subsequently. Hence Model 2 focuses on what might be called conditional fecundability, that is, effective fecundability among fertile women. This approach is a simplification because some women who are fecund at (say) age 45 may not have another child. That is, some women with relatively low fecundability may not be included at ages near the end of their fecund period.

We estimated conditional fecundability $f^*(x)$ in the same fashion as fecundability f(x) in Model 1, but on the restricted data set with all open birth intervals excluded. Because conditional fecundability, by definition, cannot be zero, we set $f^*(47)$ equal to $f^*(45)$.

Results of Model 2

The parameter values estimated for Model 2 are presented in Table 2. The pattern of decline of conditional fecundability with age is similar to the decline indicated in Table 1 and Figure 1, but now it levels off at about .1 rather than declining to zero. This is a consequence of the definition of conditional fecundability; to be included in the data set at age 40, a woman must give birth to a child after age 40. Hence the data set contains only women with nonnegligible monthly chances of live-birth conception.

As in the case of Model 1, both the two-point and the gamma models fit the data significantly better, at the .001 level, than the homogeneous model. Furthermore, the gamma model has the higher likelihood, even though it has one parameter fewer than the two-point model.

In the best-fitting two-point model, 44% of women had low fecundability and 56% had high fecundability; the highly fecund had twice as great a monthly chance of a live-birth conception. The standard deviation of the best-fitting gamma distribution is .37, in contrast to a standard deviation of .32 for the two-point model. Women one standard deviation above the mean in the gamma model had nearly four times as great a monthly chance of a live-birth conception as women one standard deviation below the mean.

Description of Model 3

We designed Model 3 to separate the effects of age and parity on conditional fecundability. Conditional fecundability $f^*(x)$ in Model 2 is modeled by

$$f^*(x) = f^0(x)p(i), \tag{9}$$

where i denotes the number of children a women has had (i.e., her parity), f^0 is the conditional fecundability schedule for first births (at parity 0) and p(i) measures the reduction in fecundability at higher parities; p(0) is set equal to 1. We approximated the conditional parity schedule p(i) by a piecewise linear function with values estimated for p(1), p(4), p(8), and p(14). No woman had more than 15 children.

Results of Model 3

Adding parity to the model of conditional fecundability by age improved the fit significantly at the .001 level for the homogeneous, the two-point, and the gamma models.

Table 2. Monthly Hazard of Live-Birth Conception at Selected Ages and Related Statistics for Fecund Hutterite Women, for Homogeneous, Gamma, and Two-Point Distributions of Fecundability[a]

	Monthly Hazard of Live-Birth Conception at Age										
Model	20	25	30	35	40	45	sd[b]	p_1[c]	z_1[d]	z_2/z_1[e]	Log-Like-lihood
Homogeneous	.254	.172	.130	.113	.080	.094	0	—	—	—	−9045
	(.016)	(.008)	(.006)	(.006)	(.006)	(.011)					
Gamma	.289	.192	.145	.131	.089	.109	.366	—	—	3.732	−8973
	(.018)	(.009)	(.007)	(.007)	(.007)	(.013)	(.027)				
Two-point	.285	.188	.143	.128	.087	.103	.316	.437	.641	1.995	−8981
	(.018)	(.009)	(.007)	(.007)	(.007)	(.013)		(.095)	(.047)		

[a] Standard deviations of estimates are given in parentheses.
[b] Standard deviation of hazard of live-birth conception.
[c] p_1 is probability mass at z_1.
[d] z_1 is support point for p_1.
[e] z_2/z_1 is for the two-point distribution, the ratio of the hazard of live-birth conception of the more fecund group to that of the less fecund group. For the gamma distribution, $z_2/z_1 = (1+\sigma)/\sigma$ (σ is standard deviation),the hazard of live-birth conception of those one standard deviation above the mean to that of those one standard deviation below the mean.

Furthermore, the two-point and the gamma models fit significantly better at the .001 level than the homogeneous model.

Table 3 presents the estimated parameter values. Let us consider first the estimates of relative fecundability at different parities (compared with fecundability at parity 0). For the two heterogeneous versions of the model, these values are about three-quarters at parity 1, with a rough leveling off at a somewhat lower level at higher parities. The pattern is noisy (i.e., with large standard errors for the estimates), but it appears plausible.

In the homogeneous case, on the other hand, a strange pattern emerges whereby relative fecundability declines from 1 at parity 0 to three-quarters at parity 1 and then gradually doubles to 1.5 at parity 15. A reasonable explanation is that Hutterite women are not homogeneous in fecundability and that the most fecund are the most likely to have many children. Thus the value of 1.5 at parity 15 reflects the composition of the group of women who have 15 children—they tend to be relatively fecund—rather than an effect of parity per se.

The general pattern of decline of conditional fecundability with age in Model 3 is similar to that estimated in Model 2, but the degree of decline is greater for the homogeneous case and less for the two heterogeneous cases. In addition, the estimated values of fecundability tend to be higher in Model 3 than in Model 2 at all ages. These two differences exist because Model 3 divides the decline in fecundability into an age and a parity component. The value of fecundability at some age estimated in Model 2 is broadly comparable to the value of relative fecundability in Model 3 at that age multiplied by the average relative fecundability at parities attained at that age.

Because relative fecundability at parities greater than 1 appeared to be roughly level for the gamma and the two-point distributions, we tested the model in which relative fecundability has the same value at all parities greater than 0. The resulting estimates are shown in the first panel of Table 4. The restricted model is nested within Model 3 and can be compared with it by using the likelihood ratio test. For the gamma distribution, the full version of Model 3 was barely better (at a significance level of .1) than the simpler version. For the two-point distribution, there was no statistically significant difference between the full version of Model 3 and the simpler version.

Relative to fecundability at parity 0, fecundability at parity 1 and higher is around three-quarters for both the gamma distribution and the two-point distribution. So sizable a decline in fecundability after one birth may be implausible. To test one possible cause of this sharp decline, we estimated the restricted version of Model 3 under different assumptions about the period of postpartum amenorrhea. This period affects estimates of fecundability at parity 1 and higher but not at parity 0. The results are shown in the lower panels of Table 4.

When the period of postpartum amenorrhea is assumed to be three months, relative fecundability at parities 1 and higher is estimated to be close to .5. In contrast, when the period of postpartum amenorrhea is assumed to be seven months, relative fecundability at parities 1 and higher is estimated to be 1.1, implying that monthly chances of conception increase by 10% after first birth. Both estimates are implausible and probably are artifacts of misestimates of the length of time a woman is exposed to the risk of conception. When the period of postpartum amenorrhea is assumed to be three months, the implied length of exposure is too long; when this period is assumed to be seven months, the implied length of exposure is too short.

When the period of postpartum amenorrhea is assumed to be six months, relative fecundability at parities 1 and higher is estimated to be about .9. This figure seems reasonable; it may be that the typical period of postpartum amenorrhea for Hutterite women is closer to six than to five months. As discussed earlier, however, if this period is taken to be six months, then fully 15% of Hutterite second and higher-order births occurred after a

Table 3. Monthly Hazard of Live-Birth Conception at Selected Ages and Parities and Related Statistics for Fecund Hutterite Women, for Homogeneous, Gamma, and Two-Point Distributions of Fecundability[a]

	Monthly Hazard of Live-Birth Conception at														
	Age						Parity[f]								Log- Like-
Model	20	25	30	35	40	45	1	4	8	14	sd[b]	p_1[c]	z_1[d]	z_2/z_1[e]	lihood
Homogeneous	.291	.226	.156	.115	.068	.071	.759	.765	1.018	1.541	0	—	—	—	−9027
	(.025)	(.025)	(.022)	(.019)	(.013)	(.016)	(.068)	(.098)	(.167)	(.324)					
Gamma	.327	.281	.234	.215	.164	.217	.739	.620	.613	.448	.392	—	—	3.551	−8961
	(.028)	(.030)	(.033)	(.035)	(.032)	(.051)	(.066)	(.077)	(.102)	(.114)	(.031)				
Two-point	.322	.257	.199	.172	.123	.153	.758	.693	.764	.627	.281	.430	.633	2.017	−8972
	(.027)	(.027)	(.026)	(.026)	(.022)	(.033)	(.066)	(.085)	(.121)	(.148)		(.095)	(.050)		

[a] Standard deviations of estimates are given in parentheses.
[b] Standard deviation of hazard of live-birth conception.
[c] p_1 is probability mass at z_1.
[d] z_1 is support point for p_1.
[e] z_2/z_1 is for the two-point distribution, the ratio of the hazard of live-birth conception of the more fecund group to that of the less fecund group. For the gamma distribution, $z_2/z_1 = (1+\sigma)/\sigma$ (σ is standard deviation),the hazard of live-birth conception of those one standard deviation above the mean to that of those one standard deviation below the mean.
[f] Relative to parity 0.

Table 4. Monthly Hazard of Live-Birth Conception at Selected Ages and at Selected Parities and Related Statistics for Fecund Hutterite Women, for Homogeneous, Gamma, and Two-Point Distributions of Fecundability, under Various Assumptions about the Length of Postpartum Amenorrhea[a]

	Monthly Hazard of Live-Birth Conception at											
	Age						Parity[f]					
Model	20	25	30	35	40	45	1+	sd[b]	p_1[c]	z_1[d]	z_2/z_1[e]	Log-Likelihood
Postpartum Infecund Period of 5 Months												
Homogeneous	.290	.222	.168	.146	.104	.121	.770	0	—	—	—	−9038
	(.024)	(.022)	(.017)	(.016)	(.012)	(.018)	(.071)					
Gamma	.338	.264	.200	.181	.124	.151	.721	.372	—	—	3.688	−8964
	(.028)	(.026)	(.020)	(.018)	(.014)	(.023)	(.064)	(.028)				
Two-Point	.329	.250	.191	.172	.117	.137	.744	.316	.429	.635	2.007	−8973
	(.026)	(.024)	(.019)	(.017)	(.014)	(.022)	(.065)		(.096)	(.049)		
Postpartum Infecund Period of 3 Months												
Homogeneous	.275	.232	.188	.169	.127	.160	.553	0	—	—	—	−9690
	(.022)	(.023)	(.019)	(.017)	(.014)	(.022)	(.050)					
Gamma	.299	.258	.210	.192	.143	.186	.516	.244	—	—	5.098	−9671
	(.024)	(.025)	(.020)	(.019)	(.016)	(.025)	(.045)	(.030)				
Two-Point	.295	.255	.207	.188	.141	.178	.517	.175	.146	.574	1.869	−9670
	(.024)	(.025)	(.020)	(.019)	(.016)	(.024)	(.045)		(.121)	(.134)		
Postpartum Infecund Period of 6 Months												
Homogeneous	.298	.216	.160	.135	.093	.104	.922	0	—	—	—	−8676
	(.025)	(.022)	(.017)	(.015)	(.011)	(.016)	(.086)					
Gamma	.359	.266	.195	.173	.112	.131	.883	.437	—	—	3.288	−8555
	(.030)	(.027)	(.021)	(.018)	(.014)	(.021)	(.080)	(.028)				
Two-Point	.346	.249	.185	.162	.105	.118	.913	.375	.469	.601	2.250	−8570
	(.028)	(.025)	(.019)	(.017)	(.013)	(.020)	(.081)		(.073)	(.038)		
Postpartum Infecund Period of 7 Months												
Homogeneous	.300	.216	.154	.127	.085	.092	1.091	0	—	—	—	−8302
	(.025)	(.023)	(.017)	(.015)	(.011)	(.015)	(.106)					
Gamma	.374	.272	.192	.166	.102	.114	1.091	.503	—	—	2.988	−8118
	(.032)	(.029)	(.021)	(.018)	(.013)	(.020)	(.103)	(.028)				
Two-Point	.357	.254	.183	.155	.094	.102	1.119	.432	.488	.558	2.547	−8139
	(.029)	(.026)	(.019)	(.017)	(.012)	(.019)	(.102)		(.057)	(.032)		

[a] Standard deviations of estimates are given in parentheses.
[b] Standard deviation of hazard of live-birth conception.
[c] p_1 is probability mass at z_1.
[d] z_1 is support point for p_1.
[e] z_2/z_1 is for the two-point distribution, the ratio of the hazard of live-birth conception of the more fecund group to that of the less fecund group. For the gamma distribution, $z_2/z_1 = (1+\sigma)/\sigma$ (σ is standard deviation),the hazard of live-birth conception of those one standard deviation above the mean to that of those one standard deviation below the mean.
[f] Relative to parity 0.

pregnancy of eight months or less. The period of postpartum amenorrhea probably varies somewhat from woman to woman and from birth to birth, so that a fixed term of neither five nor six months is valid. Indeed, there is evidence suggesting that duration of postpartum amenorrhea increases with age, perhaps because older Hutterites nursed their babies longer (Huntington and Hostetler 1966; Jones 1988). In any case, as shown in Table 4, the pattern of decline in fecundability with age appears similar whether the period of postpartum amenorrhea is set at five or six months or at three or seven months. The level of fecundability, however, varies with the length of this period. Hence our results may be more useful as a guide to variations in fecundability by age and parity than by levels.

Goodness of Fit

Our approach to modeling is guided by two principles. The first was captured aptly by George Box (1976), who pointed out that all models are wrong but some models are useful. Given enough data, any model can be shown not to fit the data. Reality is very complicated, and models can capture only some aspects of it. The question is not whether a model fits reality—none do—but whether it captures some relevant and significant aspects of reality.

The second principle is distilled in Garry Brewer's admonition "Model simple, think complex" (See Behn and Vaupel 1982, p. 16). Most useful, we believe, are simple models that facilitate complex thought about those aspects of reality which are most important in addressing the research question of interest. Box also argued for this point of view, praising "simple but evocative models" and inveighing against "overelaboration and overparameterization."

These two principles suggest that a model should be compared with the data on which it is based on to determine whether it approximately fits the data along some key dimensions of particular interest. In the analysis of duration data, for instance, if the functional form of the hazard has the wrong shape, even the best-fitting model may not fit the data well enough to be useful.

On the other hand, it would be overfastidious to reject all the models tested and to present no discussion of estimates because none of the models fit the data along a gamut of dimensions. No model is right, but some are useful.

To explore how well our restricted version of Model 3 fit the Hutterite data, we analyzed waiting times to next live-birth conception for women who were 20, 30, and 40 years old. That is, we examined how many months elapsed from the earliest time a woman was susceptible to conception to the time she conceived. We focused on this measure because a primary concern in our analysis is how long women must wait at different ages before they conceive. In taking this approach, we followed Heckman and Walker (1987), who discuss various goodness-of-fit and other criteria for selecting models.

We calculated the actual distribution of waiting times and then simulated the distribution for the homogeneous, gamma, and two-point versions of the restricted Model 3. We ran the simulations 1,000 times each and estimated the standard errors in the estimated values from the variation across simulations. Table 5 displays the mean waiting time, the standard deviation, and the proportions of waiting times of various lengths.

The results show that all three versions of the model capture mean waiting times moderately well, although all the estimates are underestimates. The heterogeneous versions are more successful than the homogeneous version, but the difference is not great.

At age 20, the three versions of the model capture the standard deviation in waiting time fairly well, although now the homogeneous version is more successful and all the estimates are overestimates. At ages 30 and 40, all the estimates are far too high.

The three versions of the model produce roughly similar distributions of waiting times

Table 5. Waiting Times to Next Live-Birth Conception, for Fecund Hutterite Women Age 20, 30, and 40: Actual Cases versus Simulations Based on Restricted Model 3 for Homogeneous, Gamma, and Two-Point Distributions of Fecundability[a]

Model	Mean	sd	Waiting Times in Months						
			<1	1–2	3–5	6–11	12–17	18–23	24+
Age 20 (406 Observations)									
Actual	4.55	6.07	.340	.217	.192	.167	.037	.030	.017
Homogeneous	4.24	6.10	.218	.300	.245	.176	.044	.012	.005
	(.22)	(.38)	(.021)	(.023)	(.022)	(.019)	(.010)	(.005)	(.003)
Gamma	4.27	6.75	.243	.307	.226	.155	.042	.014	.011
	(.27)	(.75)	(.022)	(.023)	(.020)	(.018)	(.010)	(.006)	(.005)
Two-point	4.25	6.49	.238	.306	.230	.158	.044	.015	.009
	(.24)	(.48)	(.021)	(.023)	(.020)	(.018)	(.010)	(.006)	(.005)
Age 30 (265 Observations)									
Actual	8.92	9.38	.106	.125	.230	.336	.106	.045	.053
Homogeneous	8.07	11.49	.118	.195	.216	.248	.115	.055	.053
	(.51)	(.84)	(.020)	(.024)	(.026)	(.026)	(.020)	(.014)	(.014)
Gamma	8.31	12.98	.131	.208	.212	.230	.104	.050	.063
	(.64)	(1.54)	(.021)	(.025)	(.026)	(.027)	(.019)	(.013)	(.015)
Two-point	8.17	12.33	.130	.206	.215	.231	.105	.051	.062
	(.58)	(1.13)	(.021)	(.026)	(.025)	(.026)	(.019)	(.014)	(.015)
Age 40 (74 Observations)									
Actual	12.50	9.27	.081	.095	.108	.216	.284	.122	.095
Homogeneous	11.77	16.31	.078	.142	.172	.243	.147	.089	.128
	(1.32)	(2.03)	(.031)	(.041)	(.045)	(.051)	(.043)	(.034)	(.040)
Gamma	11.81	17.21	.087	.154	.178	.235	.138	.078	.132
	(1.48)	(2.48)	(.033)	(.042)	(.044)	(.050)	(.041)	(.031)	(.041)
Two-point	11.99	17.39	.085	.151	.178	.234	.134	.083	.136
	(1.46)	(2.41)	(.034)	(.041)	(.046)	(.050)	(.040)	(.033)	(.040)

[a] Standard deviations of estimates are given in parentheses.

at the three ages. These estimated distributions, however, deviate markedly from the actual distributions in certain time categories. At age 20, the estimates are too low for the proportion of women who conceive within one month and too high for the proportion who wait one to six months. At age 30, the estimates are too low for the proportion of women who wait six to 12 months. At age 40, the estimates are too low for the proportion of women who wait 12 to 18 months.

Perhaps these discrepancies exist because we made erroneous assumptions in our analysis about premarital intercourse (in the case of the 20-year-olds) and about the duration of postpartum amenorrhea (in the case of the 30- and 40-year-olds). Greater variation in postpartum amenorrhea and an increase in the length of this period with age might account for the distributions among 30- and 40-year-olds.

Comparison with Heckman and Walker

In a well-known study, Heckman and Walker (1987) fit various multiple-spell duration models to Hutterite data. Their paper and this paper thus are related, both in methodology and in application, and our work builds on theirs. The two studies overlap very little, however, they are complementary because we have chosen to focus on different methodological and substantive issues.

Heckman and Walker are concerned mainly with developing approaches to choosing among competing models. They present their parameter estimates in an appendix, with no substantive discussion. Our main concern is estimating how fecundability declines over age and parity.

Heckman and Walker use a computer program called CTM, which was designed for econometric analysis of continuous-time models. We use generic methods of maximum-likelihood estimation applied to a simple expression for the likelihood of multiple-spell duration data that was developed by Vaupel (1990a, 1990b). Our approach may be useful to persons without access to CTM and to those who wish to use more flexible hazard function specifications than permitted in CTM.

Heckman and Walker analyze fairly complex models, with 13 to 85 parameters, which appear to be motivated largely by a methodological concern with exploring a wide range of models. We analyze simple models, with six to 12 parameters, which we designed to capture the main aspects of variation in fecundability over age and parity and across women.

Current age does not appear as a separate covariate in Heckman and Walker's models. Some of the models, with appropriate parameter values, can capture current age as the sum of age at marriage and previous birth intervals, but the estimated parameter values do not permit this interpretation. The trajectory of fecundability over age is modeled partially by requiring the hazard of live-birth conception to follow a Gompertz, quadratic, or Weibull function of time since last birth. The influence of parity is modeled indirectly by estimating different parameter values for each level of parity.

In contrast, we focus on age as the key variable of interest. We employ a flexible specification of the age trajectory of fecundability based on a piecewise linear function determined by the level of fecundability at ages 20, 25, 30, 35, 40, and 45. Similarly, we model the effect of parity by a simple multiplicative term that is determined by a flexible piecewise linear function.

In the models that include heterogeneity in fecundability, Heckman and Walker use an n-point distribution, with n equal to either 2 or 4. In a subsequent analysis of waiting times to first conception (1990), they conclude a two-point distribution is the most appropriate. We model heterogeneity in fecundability by a two-point distribution and by a gamma distribution.

Heckman and Walker ignore the period of postpartum infecundability: "second and higher birth intervals are assumed to begin at the date of the previous birth" (1987, p. 286). We include a postpartum infecund period of five months in most of our analyses and report results for periods of three, six, and seven months.

Finally, none of Heckman and Walker's models fit the data on times between pregnancies well; neither do any of ours. Heckman and Walker reject their various models by using a chi-square test. We follow their approach in simulating waiting times, but instead of presenting χ^2 statistics, we display model predictions versus data (see Table 5). It is apparent that our models do not capture some aspects of the data: χ^2 calculations simply confirm this point in a less informative way. In any case, in both the Heckman and Walker analysis and in ours, models that include heterogeneity fit better than models that do not. In addition, the standard errors for most of Heckman and Walker's parameter estimates tend to be large in relation to the estimates, especially in their more complicated models. The standard errors of our models tend to be relatively small.

DISCUSSION AND CONCLUSION

In this analysis we have presented a variety of estimates concerning the decline in fecundability with age. They can be summarized broadly as follows: the monthly probability of a live-birth conception, for the Hutterite population we studied, is about one-third as high at age 35 as at age 20.

Some of this decline occurs because initially fertile women become sterile. Even if attention is restricted to conditional fecundability, however, the monthly probability of a live-birth conception (among those women who will conceive) declines by a factor of 2 from age 20 to age 35. These results hold whether fecundability is assumed to be homogeneous or to follow a gamma or a two-point distribution. Furthermore, the halving of conditional fecundability from age 20 to age 35 holds approximately, whether the effect of parity is controlled or whether the typical period of postpartum amenorrhea is assumed to be five or six months. We conjecture that the probability of a live-birth conception declines with age, partly because fetal loss becomes more prevalent at the older reproductive ages (beyond age 35). Futhermore, coitus may be less frequent at older ages and at longer marriage durations; as a consequence, fecundability declines with age. The confounding effect of inadequate specification of the postpartum infecund period may be minor because all Hutterite women nurse for relatively short periods. In addition, models with postpartum infecund periods of different lenghts indicate the same age and parity pattern of fecundability. In summary, the present study of Hutterite fecundability suggests that fecundability declines gradually with age. This finding is consistent with previous work on historical populations (see, for example, Menken, Trussell, and Larsen 1986) as well as with mathematical modeling of changes in fecundability with age (see, for example, Wood and Weinstein 1988).

What difference does the decline in fecundability make? For the average Hutterite woman at age 20 who has a child, the waiting time to live-birth conception is about four months (as can be calculated by inverting the hazards given in Table 2). For the average woman at age 35, the waiting time is about eight months. For women of lower-than-average fecundability, a halving of the hazard of live-birth conception also doubles the average waiting time, but for these women the waiting times will be longer. If fecundability is gamma-distributed, then fertile women who are two standard deviations below the mean wait, on average, 13 months at age 20 and 28 months at age 35. Thus, variation in waiting time to next birth is not insubstantial among Hutterite women. This variation may be ascribed largely to biological factors such as fetal loss, because the Hutterites are so homogeneous in socioeconomic and cultural characteristics. Age-specific variation in coital frequency also may explain part of the variation in fecundability across women.

These results must be treated cautiously because our goodness-of-fit analysis shows that the models we used overestimate the standard deviation in waiting times to conception and fail to capture certain features of the distribution of waiting times. In particular, it may be incorrect to assume that all Hutterite women at all ages have a five-month period of postpartum amenorrhea. Some variation may exist among women, and this variation may increase with age, so that by age 40 some Hutterite women may have periods of postpartum amenorrhea much longer than five months. If this is the case, their fecundability is higher than we estimated. Hence conditional fecundability may decline with age at a slower rate than our results suggest. To analyze this possibility, we (together with Anatoli Yashin) are developing models that allow heterogeneity in the period of postpartum amenorrhea. These new models build on the research of D'Souza (1974) and on the models presented above.

We are also developing models that allow women to become sterile between ages 20 and 47. These can be considered models of changing frailty (i.e., fecundability) in that a woman begins at some level of frailty and then can fall to the level of 0 (i.e., to sterility). The changing-frailty models also are direct extensions of the models presented above. They will permit analysis of the incidence of sterility and of the overall change with age and parity in effective fecundability, because effective fecundability is a function of conditional fecundability and sterility.

The main methodological contributions of this paper involve the inclusion of persistent heterogeneity in fecundability analysis and the use of all the information provided by multiple-spell duration data. In addition, hazards rather than probabilities are modeled, piecewise linear hazard functions are used, and age and parity effects are decomposed systematically. These methods permit us to develop more elaborate models of changing fecundability and of heterogeneity in postpartum amenorrhea.

We doubt that any model of fecundability will capture all the details of the distribution of fecundability over age and parity and across women. We hope, however, that the methods described here will lead to more useful models that fit more closely more of the most significant aspects of fecundability distributions.

NOTES

[1] The distinction between the hazard and the monthly probability of live-birth conception corresponds to the distinction, in mortality analysis, between the force of mortality μ, which is a hazard, and the annual probability of death q. Essentially a hazard is a continous measure of the rate of occurence of some event, whereas a probability is a discrete measure pertaining to some specified time interval. Numerous studies of reproductive health use hazard models, including Rodriguez et al. (1984), Sheps and Menken (1973), and Trussell et al. (1985). Even so nearly all studies to date of age and parity patterns of fecundability have relied on probability models rather than hazard models.

[2] Use of the two-point distribution implies that there are two kinds of women, a group with low fecundability and a group with high fecundability. The three parameters of the distribution determine the proportion of women in the first group (the remaining women are in the second group) and the levels of relative fecundability in the two groups. (In our analyses, mean relative fecundability is set to 1, so that there are two free parameters). The gamma distribution implies a continuous range of fecundability level among women. This distribution often is used to model heterogeneity because it is confined to nonnegative numbers (unlike (say) the normal distribution), because it takes a variety of shapes depending on parameter values, and because it is mathematically tractable.

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