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A MACROSIMULATION APPROACH TO THE INVESTIGATION OF NATURAL FERTILITY

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Abstract—This paper is part of a long-term investigation known as the Mormon Historical Demography Project. It examines the capability of a simulation model, originally proposed by John Bongaarts (1976), to fit the natural fertility pattern which characterized the mid-nineteenth century Mormon population. Application of this model permits estimates to be made of the historical timing and age-incidence of fertility limitation. A sensitivity analysis of the model's parameters demonstrates that simple changes in the model's proximate determinants of fertility, excluding contraceptive practices, would be insufficient to account for later transition effects. Thus the results successfully capture the dynamics underlying the Mormon natural fertility pattern as well as offer a framework for future modeling of the transition away from natural fertility.

INTRODUCTION

The study of human populations and their vital rates is ultimately directed towards explanatory causal models which account for the properties and changes of demographic variables. A preliminary effort to address this issue is presented within this paper, which is part of a long-term investigation identified as the Mormon Historical Demography Project. The development of a general modeling strategy for a population in transition from natural to controlled fertility is proposed, and the first step in developing the strategy—the modeling of the natural fertility limiting case—is presented.

The basic theoretical and methodological advantage in developing a modeling strategy from a population which initially represents a pattern of natural fertility is the considerable uniformity in its age-specific marital fertility patterns (Coale, 1971, 1972; Henry, 1961). Within natural fertility populations, the levels of fertility, expressed in the total number of children ever born or total marital fertility rates, may differ considerably. This serves to demonstrate that biological and social-behavioral determinants of natural fertility—independent of contraceptive practice or induced abortion—are not uniform across populations. In addition, it is reasonable to believe that the salience of these determinants may change over time within a single population, even though no changes may be observed in levels or patterns of fertility. The explanatory modeling of natural fertility populations over time can then serve to identify the relative role of these proximate determinants[1] of fertility in the specific configuration of marital age-specific fertility levels within the population. Once a strategy for modeling natural fertility populations is derived, the strategy can be applied to the population following the onset of fertility limitation to provide a heuristic standard of "expected" fertility in the absence of control. To provide such capacities requires the use of models which enable one to investigate the relationships between age-specific fertility levels, their proximate determinants, and changes in parameters over time.

An approach capable of meeting the requirements above is suggested by the increasing utilization of various simulation techniques.[2] In view of the fact that macrosimulations are well suited to investigation of the general social demographic relationships with entire populations and subgroups, we utilize a macrosimulation model developed by John Bongaarts (1976).

In this paper the Bongaarts model is employed to investigate the existence of natural fertility among the Mormon (members of The Church of Jesus Christ of Latter-day Saints) population of the nineteenth century, to document the timing and extent of emerging fertility control, and to test the sensitivity of general fertility levels of various model parameters. Our primary objective is not that of producing a case study of the fertility transition in the Mormon population, but rather to create a generalizable strategy of modeling human fertility whose performance will be evaluated against the extensive longitudinal data available for the Mormon population. The following sections will describe our population and data set, the macrosimulation model being utilized, and the specification of the parameters measured and estimated. Following a presentation of the results, we outline the subsequent steps necessary to test the applicability of this approach to explanatory model building and the development of a generalizable modeling strategy for the transition to controlled fertility.

POPULATION DATA SET

The data utilized in this paper are derived from a set of approximately 180,000 computerized Utah genealogies. Initially this project, which is part of a larger medical genetics research effort, selected these family group sheets because they met the criterion of at least one individual recorded on a group sheet having experienced a birth or death on the Mormon pioneer trail or in Utah. These sheets provide birth date and place, marriage date and place, and death date and place for each spouse along with the names of the parents of each spouse. The sheets also include the birth date and place, marriage date and spouse's names, and death date for each child of the marriage. The data repository from which the family group sheets were selected, the nature of the data set, its utilization, and strengths and weaknesses have been described in a number of other publications; the details presented elsewhere will not be repeated here (Bean et al., 1978; Skolnick et al., 1978; Skolnick et al., 1979; Mineau et al., 1979; Mineau, 1980).

Families selected for this analysis consist of once-married couples (husband and wife married only once). This requirement was made to limit our analysis to marital fertility, consistent with the concept of natural fertility, and to avoid the confounding affects of polygyny which was practiced by the Mormons during most of the latter half of the nineteenth century. The interruption of marriage by divorce or death followed by remarriage is often difficult to detect in longitudinal family data for historical populations, and, of course, that difficulty is further compounded if the remarriage involved polygamy. We have eliminated the problem of remarriage by restricting our population to once-married couples; moreover, limiting our analysis in this way we produce a group which is comparable to other historical research which typically deals with either first marriages of individuals or once-married couples. Additionally, we have selected only those couples within which the wife's birth date was between 1840 and 1899. This selection provides a set of birth cohorts which span the period of natural fertility through the introduction of control and produced an initial file of about 42,000 couples. The introduction of a series of additional restrictions and quality controls reduced this file by 25 percent.[3] Our final data file consisted of 31,500 once-married couples, in which the woman was known to have married between the ages of 10 and 49 and was known to have survived at least to the age of 49.[4]

In order to ascertain the beginning of exposure, numbers of births, and timing of births by mother's age, we have had to exclude from the analysis some cases for which dates of some events were missing. However, there are some cases where it is possible to estimate data and retain cases in the file. In this analysis two estimations are utilized at the family level. If a couple is missing a marriage date but their first child has a birth date, a marriage date is estimated for the couple.[5] Second, if only one child in the family is missing a birth date and it is not the last child, a birth date is estimated.[6] These procedures are possible because children are listed on the family group sheet in their correct ordinal position, whether their birth date is given or not, and the listing of all births appears to be unusually complete. Unlike family reconstitutions (where estimations might be unwise), family group sheets are based upon many sources of information, both personal (family bibles, correspondence, etc.) and public; therefore children are not likely to be omitted just because their family moved.

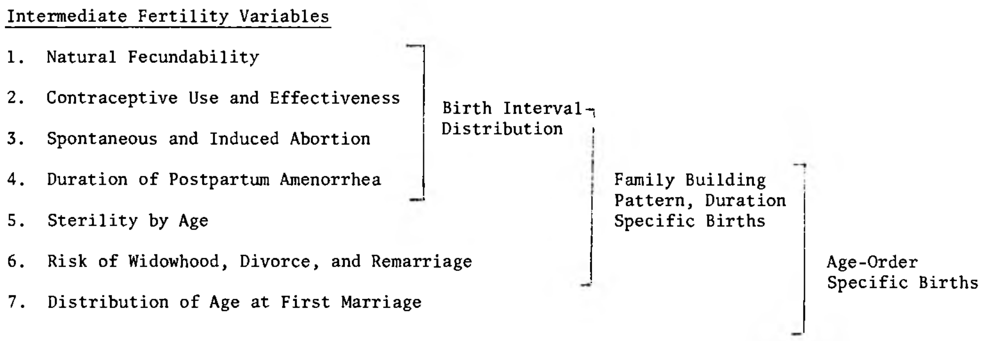
THE SIMULATION MODEL

A demonstration of the Bongaarts (1976) model's ability to replicate observed fertility patterns is given by Bongaarts for eighteenth century Canadian women who also represent a natural fertility population. Our use of the Bongaarts model is primarily for the purpose of generating a set of "expected" or natural fertility schedules in which contraceptive use and abortion are assumed to be nonexistent. Comparison with our observed data then provides the opportunity for an additional test of the ability of Bongaarts's model to replicate natural fertility schedules.

Bongaarts's own verification of this model was limited by several factors: the relatively small size of the simulated population (512 marriages), the restriction of his analysis to a single marriage cohort (1700–1750), and the restriction to a natural fertility population. In this paper we have made steps toward a verification of the macrosimulation model by application of the model to a series of twelve large sequential five-year age cohorts which specify the timing and the magnitude of the shift from a natural fertility to a control fertility schedule.

The Bongaarts model is a macrosimulation routine which, in contrast to microsimulation models, applies events and processes to entire groups of individuals at one time. It is thus a deterministic model describing average relationships or results, based upon a number of simultaneous differential equations. This approach is more restrictive than detailed microsimulation models, but its greater computational efficiency and the relative ease with which deterministic equational results may be interpreted make the model particularly suited to repetitive applications and theoretical deliberations, respectively. While the mathematical structure of the model is relatively simple, the major problem in its application stems from the measurement of the various input parameters. We will outline only in general terms the structure of the model and later describe in more detail our parameter measurement and estimation procedures.

The Bongaarts model requires seven distributions of intermediate fertility variables as exogenous inputs. These intermediate fertility variables represent the most immediate intervening determinants of fertility through which other biological and socioeconomic factors are assumed to affect fertility patterns. These distributions and their interactions in the Bongaarts model are given in Figure 1. The first four intermediate dis-



Source: J. Bongaarts. "A Dynamic Model of the Reproductive Process," Population Studies 30 (3) 1976.

Figure 1.—Schematic of the Bongaarts Model

tributions are used to determine the birth interval distribution for the population. This birth interval distribution in conjunction with the onset of natural sterility and marital disruption schedules results in a schedule of marriage duration-specific birth rates. In the final simulation stage, these duration-specific birth rates are coupled with the exogenous distribution of age at first marriage to determine the age-order and age-specific birth rates.

SPECIFICATION OF PARAMETERS

The parameters required by the model can be divided into four general categories according to the waiting-time process which they describe: the time spent in an unmarried state, the time spent in a fecundable state, the time spent in an infecundable state, and the time from marriage to a state of marital disruption. The empirical estimation and specification of non-trivial parameters is best discussed within the framework of these four processes.

Prior to the discussion of initial parameter estimates, it is important to note the occurrence of trivial starting or input values which arise in the application of Bongaarts's model to natural fertility populations in general and the Mormon frontier setting in particular. The selection of a once-married, predominantly religious, and pronatalist population results in a number of assumed starting values. For a once-married population subgroup, the proportion ever marrying is fixed at unity, and the risk of remarriage is fixed at zero. Given the strong religious prescriptions within the frontier Mormon population, induced abortions and the risk of divorce were assumed to be negligible. In addition, the strong pronatalist religious stance suggested setting the desired number of births at an arbitrarily high value (20) and the number of unwanted births at a zero value. Consistent with the concept of natural fertility, the contraceptive use and efficacy within the population were artificially specified as nonexistent. Specification of remaining parameters is discussed below.

Unmarried State

Bongaarts's simulation model utilizes a variant of Coale's marriage model to determine the first age at marriage distribution (Coale and McNeil, 1972). Three input parameters are provided—initial age at first marriage, mean age at first marriage, and proportion of the population ever marrying. The last of these parameters has previously been discussed as a unitary value. Empirical estimates of the remaining marriage parameters are presented in Table 1. Initial age at first marriage was obtained through the simple observation of the youngest age at which any woman in the birth cohort married. For most cohorts these cases are likely outliers and less robust than some heuristic alternative. The mean age at first marriage was simply computed for each birth cohort.

Fecundable State

Age-specific fecundability is computed within the Bongaarts model according to the trapezoidal distribution first proposed by Henry (1961). Within the simulation, fecundability follows a linear onset from ages 11 to 20, is constant over ages 20 to 34, and declines linearly from age 34 to age 49. Mean fecundability values at ages 20 to 34 were calculated using Bongaarts' tabled values which provide a means of estimating fecundability from ratios of births in months 9–11 after marriage to all first births (see Table 4 in Bongaarts, 1975). These tabled values were derived from five historical populations (Gautier and Henry, 1958; Charbonneau, 1970; Henry, 1956; Henripin, 1954; and Ganiage, 1960). The estimate can be corrected for differing risks of spontaneous abortion and coefficients of variation of the fecundability distribution if such estimates are avail-

Table 1.—Initial Age at First Marriage and Mean Age at First Marriage by Wife's Birth Cohort, 1840–1899

Birth Cohort	Initial Age at First Marriage	Mean Age at First Marriage	Standard Deviation	N
1840-44	12	20.85	4.27	811
1845-49	10	20.35	3.82	1025
1850-54	12	20.06	3.79	1468
1855-59	11	20.14	3.45	2125
1860-64	10	20.47	3.54	2682
1865-69	10	20.76	3.64	2933
1870-74	10	21.31	3.73	3266
1875-79	10	21.76	3.63	3496
1880-84	10	21.70	3.54	3742
1885-89	11	21.71	3.55	3665[a]
1890-94	13	21.88	3.64	3352[a]
1895-99	10	21.57	3.56	2931[a]

[a]Because families in which both husband and wife were missing death dates were excluded from the analysis, the N size in the last three cohorts declines. The majority of those probably represent individuals who had not died at the time that the family group sheet was completed, and the family group sheet was not updated since their death. Some small proportion of these individuals are still alive.

able. For initial simulation purposes the appropriate tabled values from these five historical populations were used without such corrections and are presented in Table 2.

One of the advantages of the Bongaarts model is that it provides for the specification of heterogeneous cohorts within the population. Consequently Bongaarts, in his analysis of the Canadian population, was able to vary the fecundability level for various subcohorts, and we have also tested the same procedure by the specification of three equal-sized subcohorts with fecundabilities of 50, 100, and 150 percent of the levels specified above.

Infecundability

Three parameters of infecundability are utilized by the simulation. The first is the time spent in a postpartum infecundable state and is represented in the simulation model by a Pascal distribution. The simulation requires only the input of the mean duration of postpartum infecundability for women aged 20-40 years. Empirically derived estimates of postpartum infecundability in the Mormon population are presented by five-year birth cohorts in Table 2. These were calculated by subtracting the mean birth interval following an infant death at less than two weeks from the mean interval if

Table 2.—Estimated Mean Fecundability and Estimated Mean Duration of Postpartum Infecundability in Months, by Wife's Birth Cohort, 1840–1899

Cohort	Births in Months 9, 10, 11 After Marriage	All First Births	Estimated Mean Fecundability	Mean Postpartum Infecundability[a]
1840-44	258	758	.179	8.16
1845-49	353	956	.200	8.88
1850-54	501	1368	.198	9.24
1855-59	791	1939	.232	10.08
1860-64	1043	2433	.250	9.00
1865-69	1179	2687	.259	8.40
1870-74	1313	2985	.260	9.36
1875-79	1413	3193	.263	9.00
1880-84	1520	3429	.263	9.00
1885-89	1384	3331	.238	9.24
1890-94	1300	3047	.248	7.80
1895-99	1067	2661	.226	8.88

[a]In the computation of postpartum infecundability, the population is restricted to those cases where both spouses survive until the wife's 45th birthday, and the interval between the last and penultimate birth is omitted.

the previous child survived to be two years old or older. The birth interval following an infant who lived only 0 to 13 days would not be significantly affected by a period of lactation, while the birth interval following a child who survives to at least two years would allow the normative pattern of breast feeding to be fully operative. Thus the difference between these average intervals will be used as the estimate of the period of postpartum infecundability.

The second parameter is the level of infecundability associated with sterility. We employed the estimated pattern of age-specific sterility derived by Henry, ranging from 97.0 percent nonsterile at age 12 to 0.0 percent at age 50. This schedule was also used by Bongaarts in his simulation of Canadian fertility patterns.

Duration of infecundability following spontaneous abortion is the third parameter and is determined according to the geometric waiting-time distribution derived by Bongaarts. The initial specification of the mean risk of spontaneous abortion was set at the .24 level which was derived for an Hawaiian population by French and Bierman (1962) and utilized by Bongaarts for his simulation of eighteenth-century Canadian fertility patterns.

Marital Disruption

As discussed above, the characteristics of our selected population simplify a number of the simulation parameter specifications. Under the presumption of negligible effects of divorce, the only disruption of marriage in a once-married surviving female population is due to the risk of widowhood. Average yearly risks of widowhood can be input into the simulation in one of two ways. First, a male model life table may be entered with the determined mean number of years age difference between husbands and wives. The mortality rates are then converted into widowhood rates for married women through adjusting the age denominator of the rate by the mean difference in ages and applying the rate to married women. This option was used in Bongaarts's simulation of the Canadian population. Second, the direct estimates of age-specific risk of widowhood can be entered. This second option was selected for the purpose of the Mormon simulation. Average yearly risks of widowhood were calculated and averaged over five-year age groups. To further improve the stability of estimates, outliers were excluded, and cohort estimates of risk of widowhood utilized in the simulation are presented in Table 3.

Table 3.—Estimated Mean Yearly Risk of Widowhood per 1,000 and Number Widowed by Wife's Birth Cohort (Grouped), 1825–1899

Cohorts	< 14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50
1825-1849	0.0	3.00	0.82	1.55	2.84	5.29	7.58	10.42	11.17
Number	0	7	8	22	50	85	109	162	36
1850-1874	0.0	1.78	0.78	1.34	2.38	4.11	6.60	9.86	11.63
Number	0	11	34	76	133	257	397	570	131
1875-1899	0.0	1.83	0.95	1.20	2.02	3.57	5.69	9.10	10.60
Number	0	11	48	96	175	309	469	645	162

The relatively low risks of widowhood within the population are in part a consequence of the selection criteria employed in our population. Selection of a once-married population excludes all cases of widowhood which were followed by a subsequent remarriage. Similarly, the death of the husband might for various reasons be associated with an earlier death on the part of the wife; however, non-surviving women are excluded from our selected population. In addition, the relatively high risk of widowhood for those aged 15 through 19 arises from a small number of cases in which the wife was widowed at a very young age, survived to age 50, yet did not remarry. Due to both the small number of women affected by these rates and the insensitivity of the model to the widowhood schedule (see sensitivity results below), the affect of high risks of widowhood within the age group 15-19 is negligible.

Thus three sources of information have been used to develop the parameters: those which were empirically estimated, those which were logically specified, and those utilizing procedures developed for more modern populations often using relatively new biometric procedures. To distinguish the types of measurements used in the simulation, a summary is provided in Table 4. Following the presentation of the initial results, we report several sensitivity tests which suggest that the estimation procedures utilized are unlikely to have introduced any significant bias in the results.

SIMULATION RESULTS

Given the initial parameter assignments above, fertility rates were simulated for 12 five-year birth cohorts. Corresponding observed rates were obtained for comparative purposes through computing marital age-specific fertility rates and inflating these according to the proportion married. To facilitate the comparative interpretation of simulated and observed fertility rates, these two rates for each cohort are plotted against each other. Four of the plots equally spaced in time were selected for presentation in Figure 2. The simulated rates of early cohorts, 1840–1859, generally agree with the observed rates for these cohorts. This agreement with rates simulated under the presumption of no contraceptive use is clearly suggestive of a natural fertility setting. In contrast, the cohorts beginning in 1860 and thereafter display a progressive truncation of fertility rates at the older ages relative to simulated values; this increasing divergence or lack of fit provides a visual perception of the extent of fertility limitation. The age-specific estimates of control (average percentage reduction in ASFR's) are displayed in Figure 3 for the 1875–79 and 1890–94 cohorts. These substantiate the increase in fertility control and the higher level of control at older ages in the latest born cohorts.

A formal testing of "goodness of fit" between the simulated and observed results is hampered by the fact that comparisons must be performed on rates with no underlying denominator corresponding to a real population. Since chi-square tests are inappropriate, a simple test for a significant mean difference was employed. The results of these tests are presented in Table 5 and confirm simple visual interpretations. In other papers we have noted that the population with which we are dealing represents a natural fertility schedule for the birth cohorts prior to 1860 (Mineau et al., 1979; Mineau, 1980). These results are confirmed by the simulation procedure in that there is no significant difference between the simulated and the observed fertility schedules for the four earliest cohorts (see Table 5). Cohorts after 1860 begin to control fertility, and the difference between the observed and simulated values increases systematically thereafter.

In utilizing macrosimulation methods for natural fertility standards, and measuring the extent of fertility limitation, it should be clear that empirically estimated model parameters are desirable if not

Table 4.—Summary of Initial Parameter Specification

Variable	Value	Comment	Trend Summary
Proportion ever marrying	1	Defined by sample (once-married)	N/A
Risk of remarriage	0	Defined by sample	N/A
Number of desired births	20	Assumed	N/A
Number of unwanted births	0	Assumed	N/A
Contraceptive use and efficacy	nil	Assumed for a natural fertility pronatalist population	N/A
Initial age at first marriage	See Table 1	Observed	Random fluctuation
Mean age at first marriage	See Table 1	Observed	Moderately increasing
Mean fecundability	See Table 2	Calculated from observed data	Rapidly increasing
Mean duration of post-partum infecundability	See Table 2	Observed	Random fluctuation
Mean infecundability associated with sterility	Range from 3% at age 12 to 100% at age 50	Pattern based on work of Henry (1961)	N/A
Mean infecundability following spontaneous abortion	g = .40	Geometric distribution specified by Bongaarts (1975)	N/A
Mean risk of spontaneous abortion	.24	Based on French & Bierman's Hawaiian study (1962)	N/A
Marital disruption: divorce	nil	Assumed to be negligible	N/A
Marital disruption: widowhood	See Table 3	Calculated from observed data	Moderately decreasing

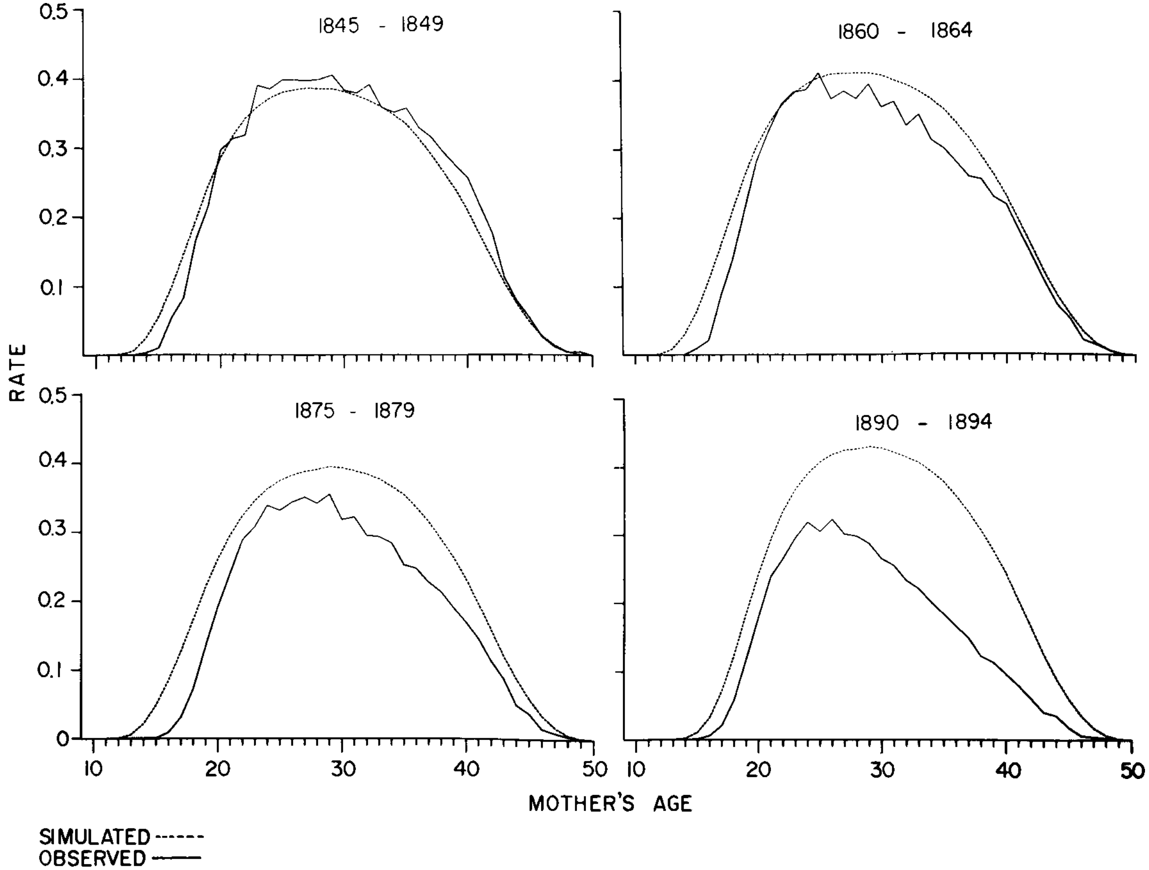


Figure 2.—Observed and Simulated Age-Specific Fertility Rates by Wife's Birth Cohort, Selected Intervals

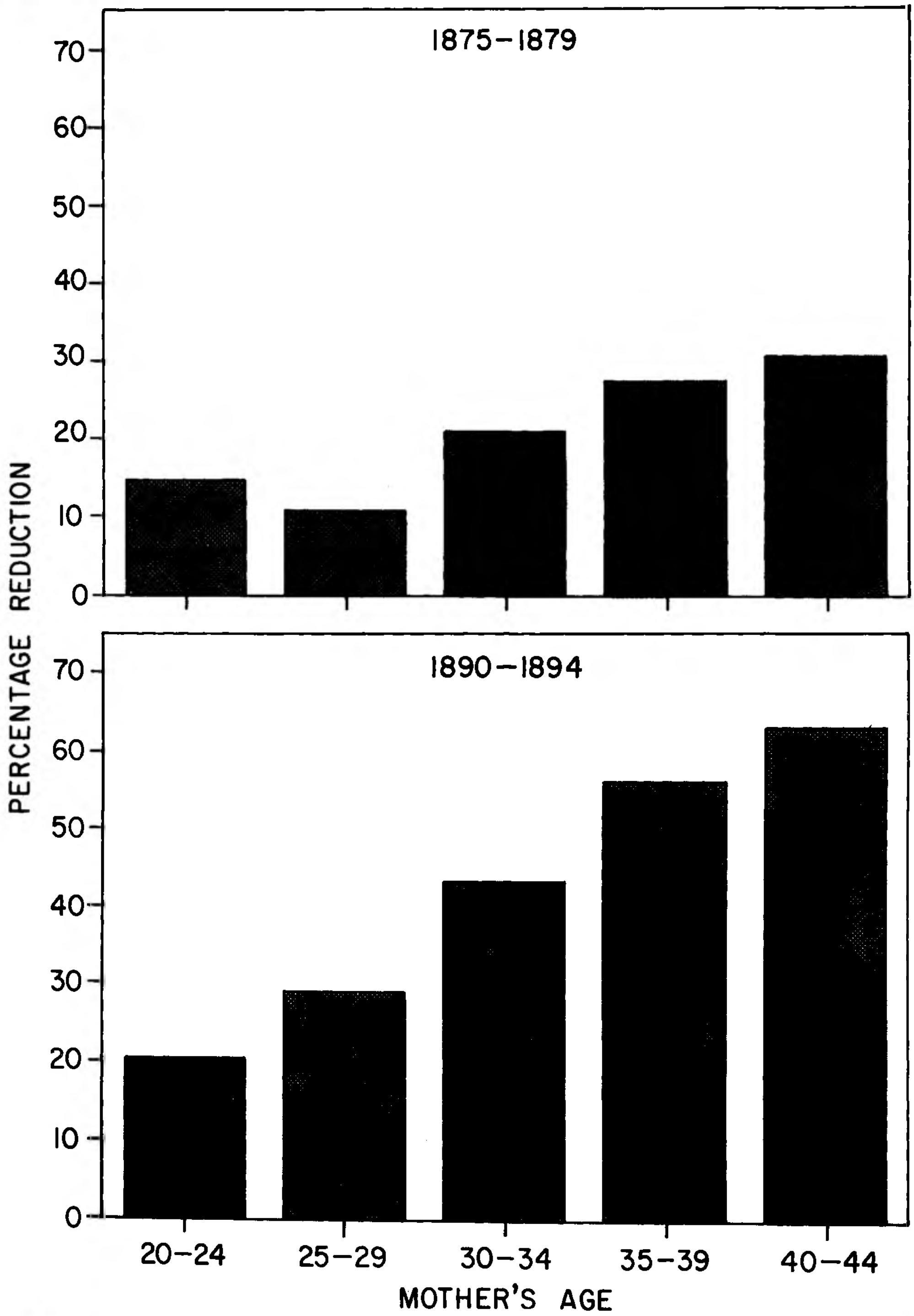


Figure 3.—Average Percentage Reduction in Age-Specific Fertility Rates for Cohorts 1875–79 and 1890–94.

essential. In our simulation of the frontier Mormon population, we followed Bongaarts in accepting sterility and spontaneous abortion estimates derived from similar populations. In subsequent work, Bongaarts (1980) has demonstrated a relatively low variability of sterility and spontaneous abortion risk across varying populations, combined with a low sensitivity of fertility levels to these factors. With the exception of these two parameters, the artificial specification of no contraceptive use, and subcohort structures, the parameters of this simulation were empirically estimated from the population data base.

The large sample sizes and relative homogeneity of the Mormon population used in the simulations tend to understate the variability of these parameters. Thus we have specified conservative ranges about the observed parameters to conduct our sensitivity tests. The parameter sensitivities for the initial specifications in the 1860-64 cohort are given in Table 6. The results of this analysis concur with those of Bongaarts in the relatively high sensitivity of fertility estimates to the mean age at marriage (proportions married) and the duration of postpartum amenorrhea. The sensitivity of estimates to natural fecundability appear moderate, while remaining sensitivities are minimal. These results indicate the general influence which parameters within the model have upon total fertility rates. However, some model parameters may vary more widely in cross-cultural settings than is implied in Table 6. In particular, initial age at first marriage is determined from distributional 'tails' or 'outliers,' and may vary widely across

Table 5.—Paired Mean Difference Tests on Observed and Fitted Age-Specific Fertility Rates by Wife's Birth Cohort, 1840–1899

Cohort	Mean Difference	Standard Deviation	*t*-test	Significance[a]
1840-44	-.00412	.02447	-1.07876	non-signif.
1845-49	-.00407	.02378	-1.09678	"
1850-54	-.00059	.01575	-0.23791	"
1855-59	.00361	.01719	1.34438	"
1860-64	.02598	.02475	6.72131	significant
1865-69	.03676	.02768	8.50291	"
1870-74	.03710	.02522	9.41953	"
1875-79	.04793	.03221	9.52874	"
1880-84	.05673	.03848	9.44042	"
1885-89	.06222	.04272	9.32499	"
1890-94	.08654	.06816	8.12888	"
1895-99	.08763	.06492	8.64285	"

[a]Significant difference between observed and simulated ASFRs at 95 percent two-tailed confidence level with d.f.=40.

Table 6.—Parameter Sensitivities, 1860–64 Cohort[a]

Parameter	Initial Value	TFR	Lowest Value	TFR	TFR % Change	Highest Value	TFR	TFR % Change
Natural fecundability	.25	9.03	.23	8.82	-2.33	.28	9.31	+3.10
Spontaneous abortion risk	.24	9.03	.26	8.91	-1.33	.22	9.16	+1.44
Duration postpartum amen.	9.00	9.03	9.90	8.75	-3.10	8.10	9.34	+3.43
Sterility by age	--	9.03	--[b]	8.85	-1.99	--[c]	9.22	+2.10
Risk of widowhood	--	9.03	--[c]	9.02	-0.11	--[b]	9.05	+0.22
Mean age at first marriage	20.47	9.03	22.52	8.16	-9.63	18.42	9.94	+10.08
Initial age at first marriage	10.00	9.03	10.00	9.03	--	12.00	9.06	+0.33

[a]All parameters were varied over a range of 10 percent plus or minus, with the exception of initial age at marriage which was varied from the initial value to a value of plus 20 percent.

[b]Each age-specific value reduced by 10 percent.

[c]Each age-specific value increased by 10 percent.

populations. Additional simulation tests support the low sensitivity of the model to initial age at first marriage. While trimming of outliers may greatly increase the value of this parameter, only the fertility rate of those few women married at very young ages are substantially affected. Thus, the variability, which may arise out of the way in which initial age at first marriage is defined, is largely offset by the insensitivity of the model to this parameter.

In part, performing the sensitivity analysis on an early transition cohort clarifies the steps necessary to simulate the transition in later cohorts. The limited sensitivity of simulated fertility rates to the parameters presented in Table 6 suggests that these fertility determinants alone cannot account for the population's increasing fertility limitation. This situation would be expected under our specification of no contraceptive utilization. Yet to simply adjust contraception parameters until an adequate fit is obtained does not result in the type of explanatory power which we have suggested a general strategy should provide. To investigate adequately the changing role of contraceptive use requires an empirical identification of subcohorts initiating contraceptive use and the diffusion of patterns of control through other segments of the population. Because the Bongaarts model provides the capacity to simulate subcohort behavior, a method for the empirical identification of subcohorts and necessary parameters within such groups should be considered the first requirement in extending the analysis presented to the later cohorts in which fertility limitation is present.

SUMMARY AND CONCLUSIONS

In previous papers related to the Mormon Historical Demography Project, we have demonstrated that during the nineteenth century this pronatalist, western frontier population represented a natural fertility group. Even though pronatalism remains a dominant ideology of the Mormon religion and the present birthrate of the state of Utah, which is predominantly Mormon, is roughly twice the national average of the United States as a whole, it is evident that there is a fair degree of fertility control being practiced (Hastings et al., 1972). Part of our project involves the identification of the timing and age-specific extent of the introduction of fertility control within the Mormon population.

Several alternative approaches currently exist to evaluate the shift of a natural fertility population to controls. Various indices have been utilized by Henry (1961) and Knodel (1979), and the *m* values developed by Coale and Trussel have been widely used. The ability to utilize such indices, however, reflects primarily the fact that natural fertility populations tend to assume a characteristic age distribution of marital fertility rates. Specifying the shift with respect to various index numbers or *m* values is useful primarily as a descriptive device rather than as an explanatory system which leads to the evaluation of certain theoretical arguments.[7]

In attempting to develop a reasonable theoretical model of historically-based fertility changes, we suggest that a general model should (a) contain a certain parametric specification yielding what we term "natural fertility" as a limiting case, (b) account for the independent and interactive effects of changes in the proximate determinants of fertility, and (c) specify the population subgroups within which the timing and sequences of changes in parameters, and thereby fertility, occur. The data requirements in developing such a model are extensive. First, a natural fertility population, one in which married couples practice neither contraception or induced abortion (Henry, 1961, 1979), must be identified and observed over sufficient time to encompass the change from natural to controlled fertility levels. Second, the data must contain sufficient information to determine the changes in fertility levels attributable to various sets of intermediate, or proximate, variables affecting fertility. Finally, the data must include information which allows social heterogeneities to be determined and linked to changes in these proximate determinants of fertility. Once these data requirements have been met, a second set of problems arises from the selection of a proper research strategy.

In developing our modeling strategy, we have attempted to test the applicability of an explanatory macrosimulation model developed by Bongaarts. The nature of the sample on which the simulation was conducted allowed a number of parameters to be easily specified. In addition, the content and quality of the Mormon demographic data have allowed many of the important simulation parameters to be empirically estimated.

Through our application of the simulation model, we have confirmed the capability of the Bongaarts model to simulate natural fertility patterns. Maintaining the parameters which fit the natural fertility pattern over time has enabled us to confirm the timing of the onset of fertility limitation. The increasing divergence between the natural fertility pattern and the observed fertility pattern among our later cohorts allows us to derive more specific estimates of the age-incidence of fertility limitation. Additinally, the sensitivity tests conducted for a cohort evidencing increased patterns of control demonstrate the fact that the onset of fertility limitation is not due to simple change in the proximate determinants of fertility under the specification of no contraception utilization. Additional analysis of individual level data is therefore suggested to identify heterogeneous cohorts theoretically distinguishable in terms of propensities to adopt fertility limitation behavior.

NOTES

[1] Bongaarts (1979) has, in some cases, used the terms *proximate determinants of fertility* and *intermediate variables* interchangeably. Restricting the analysis to the set of biological and behavioral factors determining fertility of married women, however, warrants the use of the term proximate to avoid any confusion with the broader set of variables traditionally identified with the work of Blake and Davis (see Bongaarts, 1978; Davis and Blake, 1956).

[2] A number of fertility studies have been conducted using one of two general types of simulation methods, microsimulation and macrosimulation, each with its own relative strengths and weaknesses. (For microsimulation techniques see MacCluer, 1973, pp. 241–504; Sheps and Menken, 1973; and Henry, 1973. For macrosimulation techniques, see Leridon, 1977, pp. 104–120; and Bongaarts, 1976.) Simulation methods have been utilized recently by

Trussell (1979), for example, to investigate the relative importance of various direct determinants of fertility, such as the impact of variations in fecundability and duration of lactation amenorrhea.

[3] If the death date was not available for either husband or wife, enabling us to determine whether the family was closed during the reproductive years of life of the wife, we eliminated that family from the file, thus excluding 7.7 percent of the cases. Excluding families in which the first child was premaritally conceived resulted in the elimination of an additional 8.0 percent of the cases, and a further 4.4 percent of the cases were eliminated because the wife died prior to age 49. In 4.5 percent of the cases, there were missing data on chronologically inconsistent data, resulting from either data entry or recording errors, and they were omitted. A very small number of cases, 0.4 percent, were also eliminated because the reported age of marriage of the woman was less than 10 years or greater than 49 years of life.

[4] While the rigid controls which we have introduced reduced our sample by 25 percent, the loss is far less than found in other studies. For example, the Tanguay, French-Canadian data on which the Bongaarts simulation is based covers roughly 1,226,230 events in 111 parishes over a 179-year interval. Henripin (1954), who originally analyzed these data, noted that there were 6,847 marriages between 1700 and 1730. Selecting first marriages recorded on every seventh page, he was able to consider for his analysis 1,131 marriages. Of this group, only 623 were found to have records complete enough to be utilized, resulting in a loss of nearly 45 percent of the selected marriages.

[5] The year of marriage is estimated by subtracting 1.30 years from the first child's birth date. This mean interval was determined by using families with no missing dates. The mean age at first birth has been compared for those with and without marriage information; for the 1840–1869 birth cohorts it was 21.74 and 22.35 respectively with 8.5 percent missing the data; for the 1870–1899 cohorts it was 22.91 and 22.17 with 2.0 percent missing the data.

[6] The estimate is the midpoint between the previous birth and the next birth. If it is the first child in a family of two or more children, the missing birth date is placed between the marriage date and the second child's birth as follows: ($\text{interval}_{m,\ n+1}$ * .37) + marriage date.

[7] The m and M values have been calculated for this population based upon marital age-specific fertility rates using ages 20, 21, 22, 23, . . . , 49 and regressing over ages 20 to 44. They are as follows:

Cohort	*m*	*M*	*Mean Square Error*
1840–44	−.093	.943	.0045
1845–49	−.051	.962	.0020
1850–54	−.059	.940	.0022
1855–59	−.027	.946	.0026
1860–64	.082	.958	.0020
1865–69	.081	.924	.0024
1870–74	.148	.929	.0020
1875–79	.229	.926	.0017
1880–84	.326	.927	.0018
1885–89	.457	.913	.0029
1890–94	.632	.920	.0025
1895–99	.855	.913	.0044

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