Fertility in the United States

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From the postwar high of 3.8 births per woman at the peak of the baby boom, the total fertility rate in the United States has fallen to 1.8, where it has remained unchanged for nearly a decade. This below-replacement level of fertility has, in recent decades, characterized most Western countries, some of which have shown declines to well below 1.5 births per woman. Were it not for the continued infusion of immigrants, the U.S. population, which already shows the aging characteristic of low fertility, would stop growing and begin to decline before the middle of the next century. The low fertility in the United States has been accomplished by a postponement of marriage and by the widespread use of contraception, with heavy reliance on surgical sterilization as a contraceptive method. Judging from the experience of other Western countries and from our own historical experience of two centuries of fertility decline interrupted only by the baby boom, as well as from the absence of social trends that would counteract those contributing to that decline, the prognosis is for a continued low level of fertility in the United States.

In 1972, the Commission on Population Growth and the American Future issued its final report (*1*) after 2 years of study and deliberation about the consequences of the rapid rate of population growth in the preceding 15 years, the period commonly known as the baby boom. The spirit of that report was essentially one of relief that the total fertility rate of the period, which had reached a high of 3.8 births per woman, had subsided. It extolled the social, economic, and environmental advantages of the hoped-for arrival of the two-child average and the eventual advent of zero population growth.

Since that time, the concerns initially ignited by the baby boom and fueled by anxieties about the environment of the late 1960's have abated somewhat and, to the extent that population is a subject of any public concern, it is now focused on illegal immigration, the aging of the population (soon to be exacerbated by the baby boom), teenage pregnancy, and the population problems of the Third World.

Demographic change moved much more rapidly than anyone on that commission ever expected. The period total fertility rate, at 2.5 in 1970, dropped well below replacement to a new historic low of 1.7 by 1976 and has varied little from an average of 1.8 since then. Abortion was legalized by the Supreme Court just months after the commission released its report; contraceptive services for the indigent have continued to be provided by the government; and illegal immigration continues in unknown volume. In other parts of the Western world, where fertility has declined to even lower levels and where sustained baby booms were not part of the demographic legacy, some governments are becoming nervous about impending, or already experienced, excesses of deaths over births. It is not beyond imagination that the next population commission will be pondering inducements to marriage and childbearing. But all of that is much farther down the road in the United States than in Europe.

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Population Projections

Population projections are the numerical results of assumptions about the future course of mortality, international migration, and fertility, applied to an initial population classified by age and sex, and extended for specified numbers of years. Improvements in mortality will have little effect on population growth in the United States because they will not contribute significantly to the reproductive potential of the population since increases in life expectancy will be achieved largely at ages beyond the reproductive span. Changes in the volume of net international migration are certainly possible and can have an effect on population growth. The main problem in this connection is that we have such inadequate information about either the net flows of undocumented aliens or the amount of perfectly legal emigration from the United States. In the case of illegal entry, the covert nature of the process makes estimation nearly impossible, whereas in the instance of emigration there is simply no record system to enumerate persons who leave the country more or less permanently. The prevailing estimates of the size of the undocumented alien population have varied from the recent 2 to 4 million figure of the National Academy of Sciences (*2*), to a 3.5 to 6 million estimate from the Census Bureau in 1980. Legal immigration amounts to around a half million annually, with an estimated 100,000 Americans leaving the country each year.

The major question of the demographic future is of course fertility. Whereas mortality rates are already low and of little potential significance for future growth rates (not to diminish the importance of the increasing longevity of the aged) and international migration is at least theoretically controllable by government, the future quantity and tempo of childbearing is the main key to the demographic future and is by far the most complex and least understood component. Integrating different assumptions about the future course of fertility into population projections is a trivial exercise compared with understanding and predicting the complex and imperfectly comprehended social and economic forces that determine its course. Despite their forecasting limitations, however, population projections illustrate the numerical implications of different assumptions, largely those about different fertility trajectories. In Table 1, I show the population totals projected with three different assumptions about fertility and net immigration, but all assuming a moderate increase in longevity (*3*). In 40 years, the range between combinations of extreme assumptions (a total fertility rate

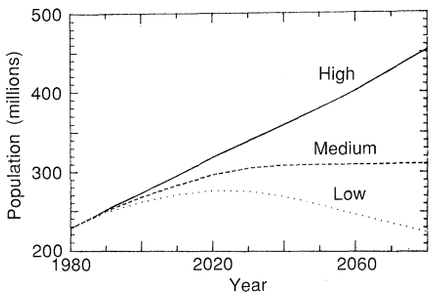

Fig. 1. Projections of the U.S. population to 2080.

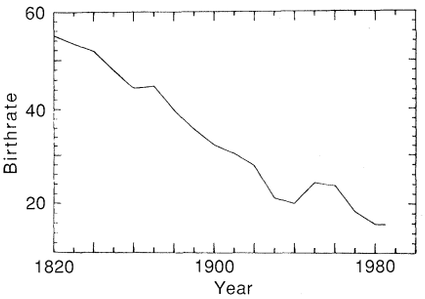

Fig. 2. U.S. births per 1000 population, 1820 to 1985.

at 1.6 births per woman and net immigration at 250,000 compared with total fertility at 2.3 and net immigration at 750,000) is between a population of 266 million and 349 million; by the year 2080 the range has widened to between 203 and 509 million persons. By this time the effect on population growth of the differences between a total fertility rate of 1.6 and 2.3 becomes quite dramatic, implying a difference in numbers on the order of two to one. The gap would continue to increase in part because with the low fertility assumption, the population is declining rapidly.

The trajectories of growth depicted in Fig. 1 make both the simplifying assumptions of moderate improvements in longevity and annual net immigration continued at the current volume of 450,000; only fertility is varied. With total fertility assumed at the low level of 1.6 births per woman, the population continues to grow for 50 years and begins declining thereafter, returning to its initial level after a century but with the decline gathering momentum. With the middle assumption of 1.9 births, the population essentially stabilizes at 310 million by the middle of the next century. This fertility rate, which is 10% below the level required to replace one generation with the next, would imply population decline were it not for the continued infusion of migrants from abroad. Under the highest assumed fertility of 2.3 births per woman (combined with the immigration) the population shows fairly rapid growth, doubling in size over the century.

One important consequence of sustained low fertility as well as of the aging of the baby boom is the significant growth implied for the aged population. Under the low fertility assumption, the percentage 65 and over would grow from 12 in 1985 to 27 in 2080. In contrast, the high fertility assumption would imply an aged population of 18.5%. Even the middle assumption, which is our current demographic situation, would mean an increase of the aged to 23.5% in a century. This impending change is now well known, as indicated by the frequent journalistic accounts of the "social security" crisis. At the opposite end of the age distribution, the proportion of youth diminishes in relative size and eventually in absolute numbers. In between, the proportion of the population of working force age increases, a demographic change with likely favorable economic consequences, although possibly offset by an aging labor force.

In thinking about low fertility, it is useful to keep in mind that the momentum of population growth—the implicit force in the age distribution that takes a couple of generations to unwind—operates in both ways. In populations with a recent history of high fertility, the large proportions of persons under age 15 constitute a high potential for reproduction; therefore, the large size of that young cohort will keep the population growing for some decades even when the fertility rate declines and reaches replacement. Exactly the opposite is true for populations with recent histories of low fertility. Since these populations are characterized by small proportions of young people, even if fertility moves back up to replacement, only this small cohort will be reproduced and the total population will continue its decline until this new higher level of fertility stabilizes the size of succeeding cohorts. We are more familiar with the demographic force of the baby boom generation, which has prevented the annual number of births from dropping to the low level commensurate with the intrinsic rate of reproduction, than we are with the demographic situation in Europe today where the longer history of declining birthrates will require much higher fertility to arrest the negative momentum, just in order to avoid more deaths than births.

The Historical Record

The birthrate estimated for the United States at its first census in 1790 was 55 per 1000 population, which implies a total fertility of just under eight births per woman. Nearly two centuries later, the birthrate is 15.5 (Fig. 2), with a total fertility rate around 1.8 births per woman. During these 200 intervening years, the United States has experienced a more or less continuous decline in fertility with the major exception of the baby boom between 1947 and 1964. The picture in other Western countries is similar except that the declines began only a little more than one rather than two centuries ago (except in France, where the decline started at approximately the same time as it did in the United States), and their postwar baby booms tended to be of much shorter duration. At present, there is a substantial convergence of fertility rates in the large majority of these countries to a level below that required to replace generations (Fig. 3). Were it not for the sustained baby boom in this country, it seems clear that our main uncertainty about the future would relate to how low the decline would fall and whether fertility rates would return to replacement. These are important considerations; if fertility remains below replacement, the prospect is for increasingly older populations, and eventually for a decline in numbers with the only solutions to be found in some combination of increasing immigration and providing economic incentives to raise fertility. Each of these solutions connotes major problems of one kind or another. Of

Table 1. Projections of the U.S. population (in millions) by 2025 and 2080 on the assumption of moderate improvement in longevity (life expectancy at birth is assumed to increase gradually from 77 to 81) with different assumptions about future fertility and net immigration (*3*, table 8).

Assumed fertility rate	Projections ($\times 10^6$) with assumed net annual immigration of		
	250,000	450,000	750,000
	Year 2025		
1.6	266	276	293
1.9	291	301	320
2.3	318	330	349
	Year 2080		
1.6	203	224	261
1.9	286	311	355
2.3	422	453	509

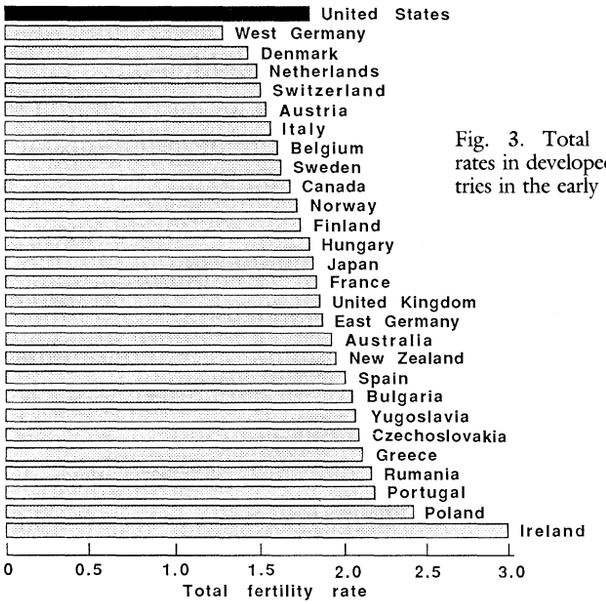

Fig. 3. Total fertility rates in developed countries in the early 1980's.

course, there are some who would welcome the advent of negative population growth and eventual smaller populations.

The baby boom, however, has given pause to demographers about the future course of fertility. Having failed to predict a reversal in the fertility rate that would last nearly two decades during which the fertility rate would climb as high as 3.8 by 1957 (Fig. 4), many demographers are understandably wary about offering new predictions. There are essentially two schools of thought. One is that another baby boom lurks on the demographic horizon for the 1990's when the small birth cohorts of the 1970's come of age, enjoy the economic opportunities of smaller numbers and diminished competition, and translate this good fortune into earlier marriage and higher fertility (*4*). The other view is that low fertility is more or less here to stay since it represents the unfolding of a historical trend in all developed countries reflecting, in part, changes in the status of women that do not seem reversible. This perspective is probably held by the majority of demographers. Whether birthrates can be stimulated for sustained periods of time by governments concerned about actual or impending population decline is not yet established. Outlawing abortion, as was done in Rumania in 1966, where few alternative forms of birth control were available, had at least a temporary, though substantial effect. East Germany temporarily raised the birthrate with substantial economic incentives (*5*). But despite the enormous population problems in some Third World countries today, it may be easier ultimately to bring down fertility in developing countries than to raise it in developed nations.

One uneasiness with the conclusion that fertility is destined to remain low is that similar views were held in the years before World War II. In fact, in most of the countries of the developed world, fertility has remained low, with postwar baby booms of only short duration, as expected. But in several countries, mainly the former British colonies of Canada, Australia, New Zealand, and the United States, the baby boom lasted far longer than anyone predicted, thereby at least suggesting the possibility that it could recur.

A good deal of research effort has been expended on understanding the baby boom in the United States. Although the demography is now clearly delineated, the sociological explanations remain elusive. The demographic explanations feature an early rush into marriage (the percentage of women aged 20 to 24 never married dropped from 49% in 1940 to 28% by 1960) and a large increase in the proportion of women having at least two births (*6*), but only a small increase in the rate of childbearing beyond two children. There seemed to be a new norm of early and near-universal marriage and rapid childbearing, but no return to large families. At the sociological level, we have only plausible hypotheses about what happened: the expansion of the economy after the country emerged from the Depression of the 1930's, the advantages of membership in the small cohorts coming of age 20 years after the low birthrates of the early 1930's, the enormous expansion of credit for home buying, the growth of the suburbs, and so on. All of these hypotheses probably have some merit but they cannot be conclusively tested.

The Contemporary Picture

One of the post–baby boom changes in American life of great significance for the birthrate has been the postponement of marriage (Fig. 5). The trend has been dramatic: in 1960, only 28% of women 20 to 24 years of age had never married; by 1985, it was 58.5% (*7*). At 25 to 29 years, the increase in single women has gone from 10 to 26% during the same period. This massive postponement of marriage is partly offset by a growth in informal cohabitation, but since such arrangements are not conducive to childbearing, the overall result has been an increase in the age of mothers at the time of the first birth. Whereas 70% of women born between 1935 and 1939 had a first birth by age 25, the comparable figure had declined to 60% for the birth cohort of 1945–1949, and down to 53% for the cohort of 1950–1954 (*8*). The mean age at first birth for women in the next cohort of 1955–1959 is projected to be 25.3, nearly 3 years older than that for women born two decades earlier (*9*). This postponement of childbearing inevitably means that increasing proportions of women who are delaying their first birth until their middle and late 30's will remain childless or have only one child.

It seems unlikely that the trend toward the postponement of marriage has yet run its course. No doubt part of it is propelled by the still growing economic independence of women, part by the costs of marriage, especially those associated with housing, and part by changing norms that now permit many couples to live together without a long-term commitment. Since these social changes are still unwinding, it seems likely that the average age at marriage will continue to increase for some time.

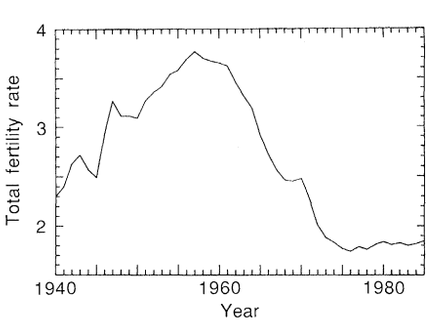

Fig. 4. U.S. total fertility rate, 1940 to 1985.

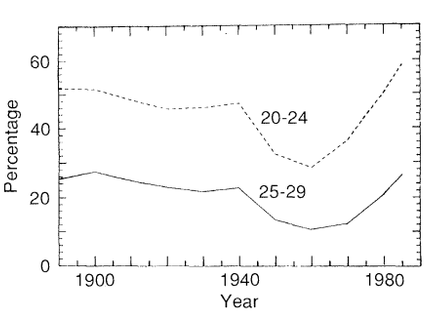

Fig. 5. Percentage of women never married in the United States, 1890 to 1985, in two age groups.

The modern peak in fertility was reached in the late 1950's; a decline followed that quickly dropped the rate back down to below the earliest historic low reached in the middle 1930's. It has now stabilized for the past decade at near the lowest level ever in American history. According to Ryder's (*10*) analysis of trends in cohort fertility during nearly a century in the United States, the cohort total fertility rate appears to have stabilized at its historic low of 1.9 births per woman for the women born between 1951 and 1955. This estimate at 1.9 of completed cohort fertility is somewhat higher than the observed period total fertility of 1.8 because of the postponement of childbearing; the shift upward in the age pattern of reproduction distorts the period rate downward.

Despite the low fertility rate, the actual annual number of births, however, is fairly high even by recent historical standards because of the demographic "echo boom": the number of young women reaching reproductive age reflects the swollen cohorts of the baby boom, so that despite the decline in the rate of reproduction, the sheer numbers of young women are sufficient to produce large numbers of births. Unless the fertility rate increases, however, the annual numbers of births will soon begin to decline as the smaller cohorts of the late 1960's and early 1970's reach the age of parenthood.

Fertility Regulation

The United States has experienced a contraceptive revolution in the past quarter century. First, the oral contraceptive appeared in the early 1960's and quickly became the most commonly used method. The "pill" revolutionized the contraceptive habits of American women (*11*) and has no doubt liberalized sexual attitudes and contributed to the postponement of marriage as well. Beset with medical concerns over the years (some real, others not), the pill survives and continues to be the method of choice for women up to age 30, but it is being used for shorter durations of time and is increasingly concentrated among young women who have not yet been pregnant.

At older ages, surgical sterilization for contraceptive purposes dominates the picture; it is now used by 41% of all married couples who use contraception (68% of all married couples currently practice contraception) and by 61% of couples who intend to have no more children (*12*). In earlier years, in the mid-1960's, the proportion sterilized among couples using any contraceptive method was only 12%, and as recently as 1973 the procedures were almost equally divided between the male (vasectomy) and the female (tubal ligation). Since then, probably because of improvements in surgical technology, use of the female procedure has increased more rapidly and now accounts for nearly two-thirds of the sterilizations among married couples. What explains this rapid growth in reliance on such a radical procedure? Although not known precisely, the reasons undoubtedly include: concern about possible health implications of prolonged use of the pill, the inadequacies of other methods, the attractiveness of not having to worry about contraception, and, of course, a fear of unwanted pregnancy. Although there may be some regret about being sterilized, perhaps because of the declining average age at the time of the operation, the method nevertheless remains the principal means of fertility control used by American married couples today.

Considering the widespread use of such effective contraception, it seems surprising that unintentional pregnancies occur at significant levels. Yet the 1982 National Survey of Family Growth, based on interviews with a national probability sample of women of reproductive age (*12*), reports a total of 30% of all births in the preceding 5 years as either unwanted (not wanted at the time of conception or at any future time, 7%) or mistimed (conceived sooner than the mother wanted, 23%). And these estimates, based on births only, do not include all of the unintentional pregnancies that are aborted. An estimated half of all pregnancies are unintended. How does this happen?

First, not all women use contraception. Nonuse and chance-taking, especially common among unmarried teenagers, also occur among married couples. Second, contraception, as used, is not foolproof. Between 2% and 3% of women using the pill conceive in the first year. The failure rate is twice as high for the IUD and higher still for other methods, reaching close to 20% for the least effective methods. Despite the widespread use of more effective methods, there remains a serious problem with the technology and with motivating those at risk of unintentional pregnancy to use some method.

The incidence of unintentional births has nevertheless declined since the early 1960's because of the increasing reliance on the pill and sterilization. Both the mistimed and the more serious component of unwanted births have declined (*12*). For example, the percentage of unwanted births has dropped from 20% in the early 1960's to 13% a decade later and to 7% in the early 1980's. Almost half of the decline in the overall fertility of American women in the decade before 1982 can be attributed to the decline in unwanted births, a result both of improved contraception and the availability of legal abortion (*12*).

Another indication of the failure of contraceptive methods and of the failure to use contraception is the high rate of abortion in the United States. In 1984, an estimated total of 1.5 million abortions occurred in this country, an estimated 25% of all pregnancies (*13*). At current rates of abortion, a woman could expect to have an average of one abortion during her lifetime. The abortion rate in this country is higher than in other Western nations (*14*), largely because of the high teenage pregnancy rate in the United States (most abortions are among young, unmarried women).

Since abortion was legalized by the Supreme Court in 1973, the trend in the rate of abortion had been steadily upward until 1979 when it leveled off. In 1983 there was the first evidence of a decline in the abortion rate, reflecting a decrease in the pregnancy rate (*13*).

Teenage Fertility

One major exception to the very low fertility of the Western world is the high birthrate of U.S. teenagers. This rate has declined in the last decade, but only because of increasing abortions; the teenage pregnancy rate in fact was rising. Some part of these high teenage pregnancy and abortion rates is a consequence of earlier ages of sexual activity and some part to increases in age at marriage, both of which have increased exposure to the risk of unintentional pregnancy. Only a few decades ago, pregnancies that did occur would be legitimized by marriage; today there is more of a tendency to seek abortion or to have an out-of-wedlock birth than in the past.

The rate of teenage births is especially high in the black population. An international comparison around 1980 (*15*) revealed that the black U.S. teenage fertility rate was 2.3 times the white and 3.2 times the average of 30 advanced countries. The contrast is even greater among the youngest teenagers: blacks under 18 years of age had a rate in 1980 that was more than three times that of whites. Nonetheless, even white teenage birthrates were 40% higher than the average for other advanced countries. An intensive study of several countries with cultures similar to the United States but with much lower teenage pregnancy rates has suggested that poverty, conflicting messages on sexuality, and the lack of contraceptive services play a major role in the explanation (*16*).

Infertility

There is a significant fraction of couples of reproductive age who, for one reason or another, are incapable of or have great difficulty in, having children. All told, one in three can be classified with some type of impaired fecundity, but half of this results from elective sterilization for contraceptive reasons. The involuntary subfecund consist of 8% surgically sterile (for medical reasons) and another 8% who are unable to conceive (*17*). The question of policy significance is what fraction of couples would like to have another child or at least one child and are unable to do so (including some contraceptively sterilized couples who regret the operation). On the basis of 1982 data, some 15% of women both want and appear unable to have a child or another child (*18*).

Differential Fertility

How much variation in reproductive behavior remains in the United States? Does the melting pot process extend to religious, race, ethnic, and class norms and behavior in connection with fertility?

Although the Roman Catholic tradition has long been associated with well-known disapproval of most forms of fertility regulation, Catholic couples in the United States no longer deviate significantly from the rest of the population in their contraceptive behavior (showing only a lower rate of sterilization and higher use of rhythm) according to the most recent (1982) National Survey of Family Growth (*12*). Consistent with this convergence of contraceptive practice, there is also no longer any distinctive "Catholic" fertility in this country. The convergence of Catholic and non-Catholic differences in fertility observed in the 1970's (*19*) continues in 1982 when married Catholic women (age 15 to 44) reported an average of 1.96 children born per woman compared with 1.92 for Protestant women. American Jewish women have had lower fertility in recent decades, an average of 1.79 in 1982 (estimated from a very small sample in the National Survey of Family Growth).

There are still significant differences in the fertility of racial and ethnic groups in the United States, although they follow the same time trends. The average number of children ever born to women aged 35 to 44 (a measure of completed fertility) as of 1985 is 2.15 for whites and 2.56 for blacks, a difference that has not changed in a quarter of a century (the corresponding averages in 1960 were 2.42 and 2.85, respectively). A measure of current fertility (the total fertility rate for the year 1984) shows the effects of the recent decline in fertility, with whites reproducing at a rate of 1.72 compared with 2.15 for blacks, a level 25% higher (*20*). A new analysis by Evans (*21*) indicates that the low fertility of both groups is achieved through different paths, with nonwhite fertility concentrated much more at the younger ages. Her projections up to the cohort of 1956 (now 30 years of age) suggests a trend toward convergence of completed fertility between whites and nonwhites.

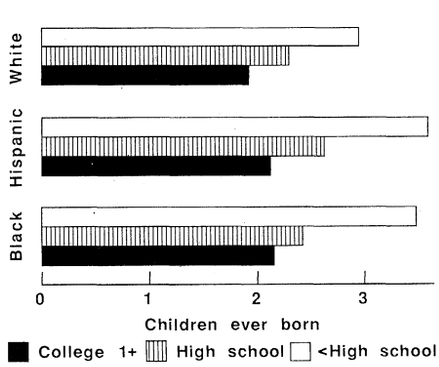

Fig. 6. Number of children ever born to women aged 35 to 44, by education, for whites, Hispanics, and blacks, 1984.

In contrast to black-white differences, the fertility of the Asian minority in this country is lower (by 14%) than that of the white majority, although there is a considerable range among Asian-American groups, with the fertility of Japanese-Americans about a third lower and the fertility of Vietnamese in this country about a third higher than that of whites (*22*).

The fertility of the population of Hispanic origin in the United States is high in comparison with other groups. In 1985, the mean number of children ever born to Hispanic women 35 to 44 years of age was 2.85, a level somewhat higher than blacks (*23*). As with Asian-Americans, there is considerable variation among the different Hispanic minorities, ranging from a high among Mexicans to a low among Cubans in the United States.

An important component of these race and ethnic differences lies in the group differences in educational achievement and the inverse relation between education and fertility. Women with less than 4 years of high school education have twice as many children as women with more than 4 years of college, a relationship that characterizes minority groups as well (Fig. 6). The impact on the differences in fertility is considerable; for example, if whites and blacks had the same educational achievement, the difference in fertility between the two groups would be reduced by at least a third and the difference between Hispanics and majority whites would be reduced by two-thirds. The differences in educational achievement of the three groups is considerable: among white women between 35 and 44 in 1985, 41% had some higher education, compared with 33% for blacks, and 16% for Hispanics. This does not mean that educational equality is a necessary prerequisite to the disappearance of fertility differences, since many other forces of homogenization are at work (*23*).

Income continues to differentiate fertility and is also responsible for some of the group differences in reproductive behavior. In 1985, the recent fertility of women with an annual family income under $10,000 was twice the level of those with an income of $35,000 and higher (*23*). The source of this income effect lies in the behavior of women under 25 years of age, where the ratio of the fertility of the lowest to the highest income category is five to one.

The Future of Fertility

There seems to be little basis for assuming that the low level of fertility in this country is a demographic aberration. The basic social forces that underlay the historical decline in fertility—the shift from an agrarian to an industrial (increasingly service) economy, the decline of a rural way of life, the shift in the economic status of children from producer to consumer, the spread of universal education, the substitution of an ethos of rationality for one of traditional values from more religious times, the declining functions of the traditional family, the changing status of women, the development of modern contraception, and so on—none of these seems ready to reverse direction. Some, in fact, have not yet run their course; for example, women still have a long way to go before they reach economic equality with men, a prospective change that will probably further weaken the institution of marriage. Perhaps legal abortion will be made more difficult to obtain, but this would probably only drive it back underground. There is little doubt that further technological advances in contraception will occur that will further reduce fertility. There are even signs that the high rate of teenage fertility in this country has begun to turn downward.

When we consider these trends and observe that fertility in the United States has been declining for two centuries (with the

exception of the baby boom, which may indeed have been the demographic aberration), and when we see similar and even more extreme declines in other Western countries in recent decades, the conclusion that fertility appears destined to remain low seems inescapable. The greater uncertainty appears to be how low it will fall. The large problems on the demographic horizon in Western countries will be those associated with aging, with population decline, and with questions of immigration.

It is worth remembering that similar prognostications were made in the late 1930's when concerns were expressed about impending population decline in parts of Europe. Events of the next two decades in retrospect made those prognostications look quaint. Quite clearly, there are serious limits to forecasting in the social sciences.

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Ablation of Polymers and Biological Tissue by Ultraviolet Lasers

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When pulsed, ultraviolet laser radiation falls on the surface of an organic polymer or biological tissue, the material at the surface is spontaneously etched away to a depth of 0.1 to several micrometers. In the process, the depth of etching is controlled by the width of the pulse and the fluence of the laser, and there is no detectable thermal damage to the substrate. The material that is removed by etching consists of products ranging from atoms to small fragments of the polymer. They are ejected at supersonic velocities. This dry photoetching technique is useful in patterning polymer films. It is also under serious investigation in several areas in surgery.

A SIMPLE AND CONVENIENT SOURCE OF LASER RADIATION in the ultraviolet (UV) region became available with the invention of the excimer laser in the 1970's. Studies on the interaction of UV laser pulses with solid organic matter such as synthetic polymers and biological tissue led to the discovery in 1982 (*1–4*) of the phenomenon of "ablative photodecomposition," which results in the breakup of the structure of the organic solid by the photons and the expulsion of the fragments at supersonic velocities. The result is an etch pattern in the solid with a geometry that is defined by the light beam. The principal advantages in using UV laser radiation rather than visible or infrared laser radiation for this purpose lie in the precision (±2000 Å) with which the depth of the cut can be controlled and the lack of thermal damage to the substrate to a microscopic level. The results obtained with a UV laser at 193 nm are compared in Fig. 1 to those with an Nd:YAG (yttrium-aluminum-garnet) laser at 532 nm for etching a sample of human arterial tissue (*5*).

Mechanism of Absorption of Light

Synthetic organic polymers are made up of molecules which consist of 10^3 to 10^5 atoms, principally carbon, hydrogen, oxygen, and nitrogen. A small molecular unit (monomer) of 6 to 40 atoms is repeated over and over along a chain to form a polymer. In Fig. 2, two typical polymers called poly(methyl methacrylate) (PMMA) and polyimide are shown along with the monomer units in each case. A polymer molecule may consist of 10^2 to 10^3 monomer units. The bonding between atoms within a polymer is covalent (shared electrons) in nature and strong (60 to 150 kcal/mol), but the forces between the molecules are weak (<10 kcal/mol). Absorption of photons of UV wavelength excites the bonding electrons in polymers, and specific absorptions correlate with specific groups of atoms (chromophores) in the molecules. An energy diagram (Fig. 3)

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