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Part I
Demographic Behavior of the Household

Contraception and Fertility: Household Production under Uncertainty *

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I. INTRODUCTION

OVER the past century, fertility behavior in the United States has undergone profound changes. Measured by cohort fertility, the average number of children per married woman has declined from about 5.5 children at the time of the Civil War to 2.4 children at the time of the Great Depression. It is seldom emphasized, however, that an even greater relative change took place in the dispersion of fertility among these women: the percentage of women with, say, seven or more children declined from 36 per cent to under 6 per cent.[1] While students of population have offered reasonably convincing explanations for the decline in fertility over time, they have not succeeded in explaining the fluctuations in the trend and have made surprisingly

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[1] These figures are taken from the report of the President's Commission on Population Growth and the American Future (see Taeuber 1972). They are indicated below in Table 1.

little effort to explain the large and systematic decline in the dispersion of fertility over time. In this paper, we attempt to study contraception behavior and its effects on fertility. One of the effects on which we focus considerable attention is the dispersion, or variance, in fertility. Our analysis is applied to cross-sectional data but it also provides an explanation for the decline in the variance of fertility over time.

The study of fertility behavior has received increasing attention by economists in the past few years. Much of this analysis has been conducted in the context of the new theory of consumer behavior pioneered by Becker (1965) and Lancaster (1966). The work on fertility behavior complements many other studies dealing with aspects of household production. One of the specific topics in the fertility literature has been the relationship between childbearing and several life-cycle production decisions, such as marriage, schooling, women's career choices, life-cycle time and money allocations, and so forth. A second and related topic of the economics of fertility behavior is the tradeoff in household production between the family's number of children and the expenditure of resources per child, particularly the expenditure of time devoted to children at the preschool age. A third focus of this research has been the fertility demand function—the form and stability over time and across groups of the household's demand function for children.[2]

Nearly all of these studies of household fertility behavior assume that the household can produce exactly the number of children it wants, costlessly and with certainty. We have previously pointed out that costly fertility control operates as a subsidy to childbearing, lowering the marginal cost of having additional children (see Willis 1971) and we have suggested a framework for analyzing the household's fertility control decisions (see Michael 1973). In this paper, we consider the household's fertility control behavior both in terms of the selection of specific fertility control strategies (the costs and benefits of specific contraceptive techniques) and in terms of the effects of different control strategies on household fertility.

One could introduce fertility control costs into a deterministic model of fertility behavior by treating these costs as transaction costs associated with acquiring any given level of fertility. In this framework,

[2] For a thorough model of fertility demand and the quantity-quality tradeoffs in the context of a static framework, see Willis (1973). For an extensive set of papers pertaining to topics in fertility behavior see the two NBER conference volumes, *New Economic Approaches to Fertility* and *Marriage, Family Human Capital and Fertility,* Schultz, ed., (1973) and (1974). These volumes indicate, we think, that much of observed fertility behavior is amenable to economic analysis.

TABLE 1

Mean Number of Children and Frequency Distribution by Number of Children for Selected Cohorts from 1835–1930 for Ever-Married Women

Cohort	Mean Number of Children	Percent Distribution				
		0 Children	1–2 Children	3–4 Children	5–6 Children	≥ 7 Children
1835–39	5.40	7.7	17.3	20.0	18.7	36.3
1845–49	5.27	8.2	18.5	20.3	18.3	34.8
1855–59	4.97	8.9	20.6	21.3	17.9	31.3
1865–69	3.90	12.3	26.6	26.1	16.0	18.9
1875–79	3.46	15.0	30.4	25.2	14.4	15.0
1885–89	3.15	16.6	33.1	25.1	13.1	12.2
1895–99	2.71	18.6	39.0	23.9	10.0	8.4
1905–09	2.36	20.8	43.2	22.4	7.8	5.9
1915–19	2.60	13.9	43.7	28.1	8.9	5.4
1926–30	3.08	8.0	36.5	36.2	12.3	7.0

SOURCE: Taeuber 1972 (with the exception of the most recent cohort, the women were at least age 45 at the time of the enumeration; for the 1926–30 cohort the women were 40–44 at the time of the survey.)

the household can select any number of children with certainty, provided it pays the requisite costs of fertility control. Assuming that total fertility control costs are larger the smaller the number of children chosen, the positive marginal cost of fertility control raises average fertility by acting as a subsidy to childbearing. In this paper, we have treated the costs of fertility control in a somewhat different framework. We have adopted a model in which the household can select with certainty any particular monthly probability of conception,[3] but in which the household's actual fertility N is a stochastic variable. By selecting and producing a particular monthly probability of conception, the household selects a distribution of fertility outcomes. The mean of that distribution is its expected fertility; its variance indicates the uncertainty that the household faces.

As Table 1 indicates, the decline in average fertility over the past century has been accompanied by a significant reduction in the dispersion of fertility. The stochastic model of fertility control which

[3] The probability is bounded by zero and by the probability implied by natural or intrinsic fecundability, say, a probability of about 0.2 per month.

we discuss in the following section emphasizes the relationship between the mean and variance of fertility, and offers an explanation for the observed decline in the dispersion in fertility over time.

Child rearing is an exceptionally costly activity, both in terms of direct dollar outlays and forgone time and human capital.[4] Few events in one's lifetime affect subsequent behavior more extensively than having a child. While other important life-cycle decisions, such as marriage and career choice, are subject to considerable uncertainty, the uncertainty generally pertains to the quality or the characteristics of the object of choice. Of course, uncertainty about the characteristics of the prospective child exists, but in addition there is another uncertainty, the one which we are emphasizing: uncertainty about the acquisition itself.

At the individual household level, this uncertainty about the number of children affects at least three aspects of behavior. First, it may affect decisions about the expenditures of resources on existing children—if ordinary substitution between quantity and quality is relevant to children, then not knowing the final number of children may affect the household's expenditure decisions on its early children. Second, there is the possibility of substitution between expenditures on children and on other household goods and services, and also between expenditures over time. Consequently, uncertainty about the number of children, and about the timing or spacing of children, can be expected to affect the composition and timing of consumer expenditure and savings behavior. Third, because of important interactions with other household production and with the relative value of family members' time, uncertainty about the number of children may have effects on the parents' occupation choices, schooling decisions, and general orientation toward market and household activities.

At the aggregate level, positive fertility control costs and the stochastic nature of fertility behavior affect the observed mean and variance of fertility. The size and growth rate of the population affect the age distribution of the population—and the rate of growth and the composition of the economy's output.[5] The variance in fertility, on

[4] For estimates of the direct costs of children, see Cain (1971) or Reed and McIntosh (1972). Lindert (1973) presents a useful discussion of existing evidence on various aspects of the costs of children. Michael and Lazear (1971) emphasize the potential cost of children in terms of forgone human capital, and Mincer and Polachek (1974) estimate the depreciation in the mother's human capital related to her nonmarket child-rearing activity.

[5] See Kelley (1972) for a recent discussion of population growth and economic

the other hand, influences the distribution of income and of wealth. If uncertainty about fertility outcomes affects household investment and savings decisions, it may have an important influence on the distribution of inherited wealth across generations.

These considerations are not the focus of our paper, but we think the points we emphasize here—the costs of fertility control, fertility as a stochastic process, and the relationship between the mean and variance of fertility—have important implications for the level and distribution of the economy's wealth. We do not explore these aggregate relationships, nor do we resolve many of the more esoteric problems which we encounter in our analysis. We do, however, attempt to integrate into an analysis of contraceptive choice and optimum fertility behavior the constraints imposed by biological limitations and resource (or economic) limitations. We indicate how the choice of contraceptive technique affects the observed mean and variance of fertility. We also analyze the choice of contraceptive technique, in particular the adoption of the new oral contraceptive in the United States in the first half of the 1960s.

II. THE ANALYTICAL FRAMEWORK

The theory of the choice of a fertility control strategy treats the fertility goals of the household as given, while the economic theory of fertility demand focuses on the factors which determine these goals. If fertility control is costly, however, these costs, as well as the resource costs of bearing and rearing children, influence the couple's choice of fertility goals. The link between the theory of the choice of birth control technique and the theory of fertility behavior is provided by assuming that the household maximizes its lifetime utility, subject to the constraint of a fertility control cost function, as well as to the conventional economic resource constraint. The fertility control cost function is simply the combination (the envelope) of least-cost birth control strategies for all possible fertility outcomes.

In this section, we describe a stochastic model of reproduction, emphasizing the relationship between the mean and variance of fertility outcomes. We then discuss the economic benefits and costs of fertility control and conclude with an exposition of the optimal fertility control strategy.

progress. See Kuznets (1960) and other essays in *Demographic and Economic Change in Developed Countries* for discussions of the effects of population on output employment and demand.

A. Birth Control and the Distribution of Fertility Outcomes

The number of children born to a couple and the pace at which these children are born is ultimately constrained by the fact that reproduction is a biological process. The observed reproductive behavior of an individual woman over her life cycle may be regarded as the outcome of this biological process, as modified by nonvolitional social and cultural factors and by the effects of deliberate attempts to control fertility. In the past two decades, the nature of the biological constraint on fertility choices has been greatly clarified and given rigorous expression in stochastic models of the reproductive process by Henry, Potter, Perrin and Sheps, and others. The basic reasoning underlying these models and their main implications for average fertility were recently summarized by Keyfitz (1971).

These models suggest that the number of children a woman bears during her lifetime is a random variable whose mean and variance depend on her (and her partner's) choice of a fertility control strategy. In this section, we draw heavily on this literature in order to present, under simplifying assumptions, analytical expressions for the mean and variance of live births as a function of two sets of parameters, one representing the couple's biological characteristics and the other its fertility control strategy.

The simple observation that it takes a random amount of time to produce a baby provides the point of departure for recent biological models of fertility. Suppose that a woman faces a probability p of conceiving in a given month. If that monthly probability of conception is constant over time, the probability that she will conceive in exactly the jth month ($j = 1, 2, \ldots$) is $p(1-p)^{j-1}$, where $(1-p)^{j-1}$ is the probability that she fails to conceive in the first $j-1$ months. Employing the demographer's term "conceptive delay," i.e., the number of months v it takes a fecund woman to conceive, the random variable v is distributed geometrically with mean $\mu_v = (1-p)/p$ and variance $\sigma_v^2 = (1-p)/p^2$.[6]

Once a woman conceives, she becomes sterile during her pregnancy and the anovulatory period following pregnancy. The length of the sterile period s is also a random variable whose value depends on the type of pregnancy termination (i.e., fetal loss or stillbirth or live birth) and on the physiological and social factors (e.g., age, parity, breast-feeding practices, time until resumption of sexual activity)

[6] See Sheps (1964) for a derivation of this result. It should be noted that conceptive delay is defined to be zero months if the woman conceives in the first month.

which determine the length of the anovulatory period following each type of pregnancy termination. For simplicity, we shall assume that all pregnancies terminate in a live birth and that the length of the sterile period s is of fixed, nonrandom length.[7] The length of one reproductive cycle—the number of months it takes a fecund woman to become pregnant, give birth, and revert to a fecund, nonpregnant status—can be expressed as $t = v + s$, a random variable with mean $\mu_t = \mu_v + s$ and variance $\sigma_t^2 = \sigma_v^2$.

The number of children the woman bears during a lifetime, say a reproductive span of T months, depends on the number of reproductive cycles completed during this period. Since each cycle is of random length, the woman's fertility will also be a random variable. The probability distribution of the number of births can be represented in a simple way if the model of reproduction is represented as a Markov renewal process. In order to qualify as a renewal process, the intervals between successive births must behave as independent, identically distributed random variables (Potter 1970). To meet these qualifications, it is necessary to assume that all of the parameters of the reproductive process (i.e., p and s) are constant over time and that the reproductive period, T, is sufficiently long (i.e., infinity). Assuming reproduction to be a renewal process, the distribution of the number of births N is asymptotically normal with mean[8]

$$\mu_N = T/\mu_t \tag{1}$$

and variance

$$\sigma_N^2 = T\,\frac{\sigma_t^2}{\mu_t^3} \tag{2}$$

[7] See Perrin and Sheps (1964) for a model in which pregnancy terminations other than live births are allowed and the sterile period associated with each type of pregnancy is of random length. Compared with the formulas we shall present, the Perrin and Sheps model implies a smaller mean and larger variance in the number of live births a woman has over her reproductive span.

[8] See Sheps and Perrin (1966), who warn that the asymptotic normal distribution above does not adequately approximate the exact probability of N for the relevant (finite) range of T. In another paper, Perrin and Sheps (1964) suggest more accurate approximate expressions for the first two moments of N. Since the qualitative implications of these approximations are quite similar to those of the more exact approximations, it does not seem necessary to encumber the discussion with more complicated expressions for mean and variance. A more serious problem is suggested by Jain (1968), who found that the actual mean of natural fertility tends to fall progressively below the theoretical mean given by the Perrin-Sheps model as T increases, while actual variance rises progressively above the theoretical variance.

Equations 1 and 2 provide a useful way of summarizing the insights into the determinants of a woman's fertility behavior provided by mathematical demography. Her mean fertility varies in direct proportion with the length of her reproductive span T and in inverse proportion with the expected length of her reproductive cycle. The variance of her fertility outcome depends upon these same two factors and also upon the variance in the length of her reproductive cycle. The three variables which determine both the mean fertility μ_N and the variance of fertility σ_N^2 in this framework are the length of the reproductive span T, the monthly probability of conception p, and the length of the sterile period s following conception. Given T, p, and s, the mean and variance are jointly determined. Treating T and s as parameters, the mean and variance of N are related, at all values of p, as

$$\sigma_N^2 = \mu_N - k_1\mu_N^2 + k_2\mu_N^3 \qquad (3)$$

with

$$k_1 = \frac{2s-1}{T}; \qquad k_2 = \frac{s(s-1)}{T^2}$$

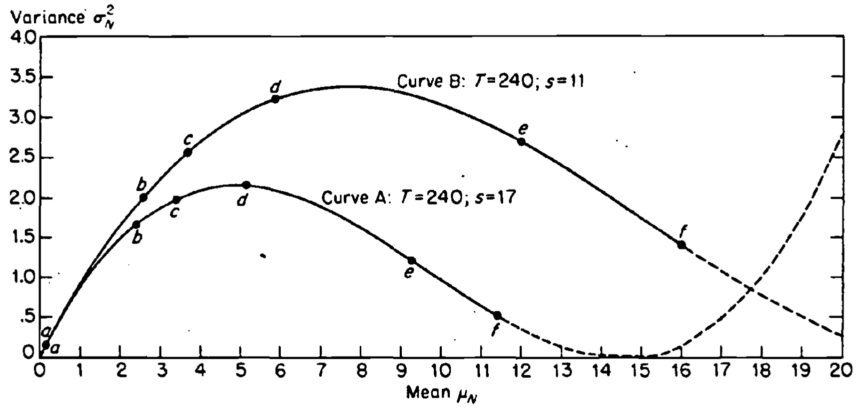
where k_1 and k_2 are positive constants.

Consider, next, the determinants of the monthly probability of conception p. A woman's biological capacity to reproduce may be represented by her intrinsic fecundability $\hat{p}$, which is defined as the probability of conception from a single unprotected act of coition at a random time during the menstrual cycle (which is assumed to be one month in length). In the absence of conception, the probability p that she will conceive during a given month is then equal to the product of $\hat{p}$ and her monthly frequency of coition c.[9] Demographers frequently discuss "natural fertility" defined, following Henry (1961), as the number of live births a woman expects to have in a reproductive lifespan of T months in the absence of any deliberate attempt to control fertility. If we suppose there is some "natural" level of coital frequency $\hat{c}$ for a given couple, then $\hat{c}\hat{p} = p^*$, the couple's monthly probability of conception in the absence of any fertility control. We will generally assume $\hat{c} = 7$ and $\hat{p} = 0.03$ (see Tietze 1960), hence we will assume that $p^* = 0.2$. Given p^* and given the reproductive time span T and the length of the period of infertility s, the mean and variance of natural fertility, $\mu_{\hat{N}}$ and $\sigma_{\hat{N}}^2$, are defined by equations 1 and 2.

[9] Intrinsic fecundability is discussed in the demographic literature, which contains an empirical justification for expressing p as approximately proportional to c over the relevant range of variation in monthly frequency of coition.

FIGURE 1

A Theoretical Relationship between Mean and Variance of Fertility (See Equation 3)



Variations across couples in the monthly probability of conception p may result from variations in fecundity—which affect $\hat{p}$—or from variations in coital frequency. Variations may also result from contraception. If the adoption of a particular contraceptive strategy i reduces the monthly probability of conception by e_i per cent, then

$$p_i = p * (1 - e_i) \qquad 0 \leqslant e_i \leqslant 1$$

So the couple's actual monthly probability of conception p_i is determined by its fecundity, coital frequency, and contraceptive practice.

As we emphasized above, to qualify as a Markov renewal process of reproduction the monthly probability p_i is assumed to be constant for all fertile months in the reproductive time span of T months. Under these circumstances Figure 1 indicates the relationship between the mean and variance of fertility as summarized in equation 3. Curve A assumes $T = 240$ months (a reproductive span of 20 years) and $s = 17$ months (a 17-month period of sterility following conception, see Keyfitz 1971). Each point on curve A corresponds to a different constant monthly probability of conception ranging from $p = 0.0$ (the origin) to $p = 0.2$ (point f on the curve).[10] Curve B in Figure 1 depicts the same

[10] For example, if $p = 0.0008$ then $\mu_N = 0.19$ births and $\sigma_N^2 = 0.18$, which is shown as point a on curve A. The values of p which correspond to points a, b, c, d, e, f in the figure are 0.0008, 0.0120, 0.0182, 0.0336, 0.1000, 0.2000 respectively. These values refer to specific forms of fertility control and are discussed below.

relationship under the assumption that T equals 240 months, and s equals only 11 months.

Suppose a couple, at the time of their marriage, were characterized by the parameter values $T = 240$ months, $s = 17$ months, and $p^* = 0.2$. They would then face an ex ante distribution of fertility outcomes with a mean of 11.4 births and a variance of 0.5 (point f on curve A in Figure 1). The couple could, however, alter this expected outcome by adopting a strategy of fertility control which lowered their constant monthly probability of conception below p^*. If, for example, the couple selected a contraceptive technique with efficiency $e_1 = 0.5$, then their monthly probability would be $p_i = p^*(1 - 0.5) = 0.1$ and their ex ante distribution of fertility outcomes would have a mean of 9.2 births and a variance of 1.2 (point e on curve A). Thus, the couple affects its expected fertility and its uncertainty about the number of its births by its selection of a contraceptive strategy.[11]

Both the contraceptive technique used and the care with which it is used can affect e_i, which in turn determines p_i. In general, the couple can also affect p_i by altering its frequency of coition c and can also affect the distribution of fertility outcomes for any given p_i by altering the length of the reproductive period at risk T through decisions about the age at marriage and the age at which either partner is sterilized.[12] So the full range of fertility control strategies includes considerations other than the choice of contraceptive method, but it is the contra-

[11] In reality, it is plausible to suppose that the frequency of coition and contraceptive efficiency will tend to vary over time to accommodate a couple's preferences for child spacing as well as for total number of births, or to accommodate any changes in their fertility goals.

It is also plausible to suppose that the choices of c and e_i will be conditioned on past pregnancy and birth outcomes. Thus, in general, the values of p in a given month will tend to be a function of time (i.e., age), past reproductive history (i.e., parity), and random fluctuations in variables that determine fertility goals.

Unfortunately, the analytical simplicity of considering the stochastic model of reproduction as a renewal process is lost under these conditions. While it is possible to write out probability statements in which a couple's contraceptive strategy (i.e., its choices of c and e_i) is defined conditional on all possible fertility outcomes at each period of time, it is not possible to derive the implications of the resulting stochastic process for completed fertility outcomes using analytic methods. Moreover, the dynamic optimization problem involved in selecting a contraceptive strategy that maximizes a couple's expected utility under conditions of uncertainty may itself be analytically intractable. At this stage, it appears wiser to minimize the formal difficulties, thus the contraceptive parameters c and e_i, as well as the biological parameters, $\hat{p}$ and s, are assumed to remain constant over time.

[12] Interruptions of exposure within the time span T caused by cessations of sexual relations due to divorce or separation are ruled out by the assumption that the parameters of the process remain constant over time.

ceptive choice on which we will focus. By selecting contraceptive strategy *i*, which yields a monthly probability of conception p_i, the couple has, in effect, selected a particular ex ante distribution of its fertility outcomes. The mean of that distribution is μ_{N_i} and its variance is $\sigma_{N_i}^2$. We will assume for now that the couple is constrained to a pure contraceptive strategy, defined as the adoption of some form of fertility control which sets p at some fixed level (during fertile periods) for the entire reproductive span.

From studies of the average contraceptive failure rates of various contraceptive techniques, the efficiency-in-use of each technique can be computed. Table 2 lists the contraceptive efficiency e_i and the implied monthly probability of conception p_i for several contraceptive techniques.[13] The table also computes for each technique the mean and variance of the length of the reproductive cycle and the mean and variance of the fertility outcomes in a 20-year reproductive span. Thus, given the biological constraint on its fertility (e.g., curve A in Figure 1) the couple can determine the expected distribution of its fertility (its μ_N and σ_N^2) by selecting a contraceptive strategy which achieves any particular p_i. The various points labeled on curve A indicate the mean and variance of births associated with various contraceptive techniques (point *a:* pill; *b:* diaphragm; *c:* suppository; *d:* rhythm; *e:* 50 per cent reduction in coital frequency and no other contraception; *f:* no fertility control).

In this framework, the number of children born to a couple is a random variable which results from a stochastic process. Ex post, the couple has only one number of children N. However, the couple cannot determine its number of children with absolute certainty. Rather, it can select any particular value of p, the monthly probability of conception, which yields a particular distribution of fertility outcomes summarized by the distribution's mean and variance.

So long as we assume that the couple selects one value for p and retains that particular monthly probability of conception for all the fertile months in the twenty-year span—an assumption we will characterize as a "pure" strategy model—the couple cannot alter its expected fertility μ_N without also altering the variance σ_N^2. In short, the pure

[13] The estimates of contraceptive efficiency were compiled by Michael (1973) from the demographic literature (see especially Tietze (1959) and (1962)). See Michael (1973) for a discussion of the difficulties in estimating and the hazards in using this comparative list of the efficiency of contraceptive methods. In particular, note that these values represent average observed use-effectiveness and will, in general, be affected by the intensity and care with which they are used.

TABLE 2

Contraceptive Technique	Observed Use-Effectiveness R	Contraceptive Efficiency e_i	Monthly Birth Probability p_i^*	Mean Length of Reproductive Cycle μ_t	Variance of Reproductive Cycle σ_t^2	Reproductive Lifetime of 240 Months: Expected Number of Children μ_N	Reproductive Lifetime of 240 Months: Variance of Number of Children σ_N^2
Pill	1.0	.9958	.0008	1,266	1,561,250	.19	.18
IUD	2.5	.9896	.0021	492	226,100	.48	.46
Condom	13.8	.9425	.0115	103	7,482	2.33	1.64
Diaphragm	14.4	.9400	.0120	100	6,723	2.40	1.61
Withdrawal	16.8	.9300	.0140	87	4,970	2.74	1.79
Jelly	18.8	.9217	.0157	80	4,032	3.00	1.89
Foam tablets	20.1	.9167	.0168	76	3,540	3.17	1.94
Suppositories	21.9	.9088	.0182	71	2,970	3.36	1.99
Rhythm	38.5	.8396	.0312	47	930	5.11	2.15
Douche	40.3	.8321	.0336	46	870	5.21	2.15
50% reduction in coital frequency		.5000	.1000	26	90	9.24	1.23
No method		.0000	.2000	21	20	11.42	.51

NOTE: R = (number of conceptions/number of months of exposure) × 1,200 = failure rate per 100 years of use (Source: Tietze, 1959, 1962, 1970).

$p_i = R_i \div 1{,}200$ = monthly probability of conception.

$e_i = (p^* - p_i) \div p^*$ = percentage reduction in p^* where p^* is a constant equal to 0.20.

$\mu_t = [(1 - p_i) \div p_i] + s$, where $s = 17$.

$\sigma_t^2 = (1 - p_i) \div (p_i)^2$

$\mu_N = T \div \mu_t$, $\sigma_N^2 = T\sigma_t^2 \div \mu_t^3$, where $T = 240$.

strategy model restricts the couple to the biological constraint (curve A in Figure 1 if $T = 240$, $s = 17$). Before we relax the assumption of the pure strategy, we discuss the determinants of the couple's choice of its most preferred position along the biological constraint. We consider in turn the benefits and the costs of fertility control.

B. Benefits of Fertility Control

Recent economic theories of household behavior postulate the existence of several constraints (e.g., a money income constraint, a time constraint, production function limitations) on the household's maximization of utility. The utility is derived from a broad set of desiderata which are produced by the household itself in the nonmarket sector, using purchased market goods and services and the household members' own time as the inputs in the production.[14] These production functions emphasize the distinction between the household's *wants* (the *output*) and the *means* used to satisfy these wants (the goods and time inputs).

Willis (1973) recently utilized the household production framework to formulate an economic model of human fertility behavior. We will generalize a simple version of Willis's model to deal with imperfect and costly fertility control. The formal analysis is conducted in a static lifetime framework, although we informally suggest how the implications of the model might be altered in a more dynamic or sequential decision-making framework.[15]

In Willis's model, it is assumed that the satisfaction parents receive from each of their N children is represented by $Q_1, Q_2, \ldots, Q_N$, and the satisfaction from other sources of enjoyment is represented by S. The Q_i, or "quality," of each child, and the other composite commodity S are produced within and by the household using the family members' time and purchased market goods as inputs. The household production functions characterize the relationship between inputs of time and goods and the outputs of Q_i and S. Assuming (among other things) that parents treat all their children alike, the total amount of child services C may be written as a product of quality per child Q and the number of children N: $C = NQ$. It is assumed that Q is positively related to the amount of time and market goods devoted to each child—

[14] See Becker (1965) and Lancaster (1966) for early statements of this model. Several monographs and articles in recent years, notably through NBER, have utilized this framework. For a recent brief survey see Michael and Becker (1973).

[15] For a model of sequential decision making regarding contraceptive behavior in a heterogeneous population see Heckman and Willis, this volume.

Q is perhaps best considered an index of the child's human capital. The household's preferences for number and quality of children and for all other forms of satisfaction are summarized by its lifetime utility function.

$$U = U(N, Q, S) \tag{4}$$

The household's capacity to produce C and S is limited by its lifetime real income and by the quantity of its nonmarket time. Willis (1973) discusses in detail the relationship between the relative prices of N and Q, and considers how various changes in the household's characteristics and circumstances would be expected to affect its demand for N, Q, and S.

One important implication of the economic model of fertility demand should be noted. From an assumption that children are relatively time intensive as regards the wife's time (i.e., C production requires more of the wife's time per dollar of goods input than does S production), the relative cost of C rises as the wife's wage rate rises. Hence the cost of both number of children N and quality of children Q also rises with the wife's wage rate. If the relative price of N rises with the wife's wage rate, then abstracting from the change in income, women with higher wages (or higher levels of education) are expected to have lower fertility. This is the basis of the "cost of time" hypothesis (Ben-Porath 1973), which has, since Mincer's pioneering paper (1963), received much attention as an explanation for the observed negative relationship between the wife's wage and her fertility.

The household's lifetime money income constraint, its time constraint, and its production function constraints can be treated as a single constraint on the household's lifetime full real income I. Defining the marginal costs of child services π_c and the composite other commodity π_s, the formal optimization problem characterizing the household's choice is the maximization of the utility function (equation 4) subject to the full real income constraint.

$$\max \{U(N, Q, S) - \lambda[I - \phi(\pi_c, \pi_s)]\} \tag{5}$$

where λ is the Lagrange multiplier. This optimization problem assumes that the household can costlessly and with certainty select any number of children (N) it wishes and can achieve any given level of the child's human capital (Q) it chooses.

To relax this assumption, we consider the benefits to the household of achieving any given number of children. Suppose the household had the utility function and the full real income constraint indicated in equation 5, but that the household was endowed with some arbitrary number of children N', where $N' = 0, 1, \ldots$. (To simplify the mathematics, N' will be treated as a continuous variable.) Given its arbitrary N', the household's only remaining choices would be the optimal values of child quality, Q, and other satisfaction, S, which must be chosen subject to the lifetime full real income constraint. If N and Q as well as N and S are substitutes in terms of the parents' preferences, the levels of both Q and S will tend to fall as N' is increased. This analysis implies that suboptimal values of Q and S would be chosen if fertility were arbitrarily constrained. Q and S would tend to be larger than (or smaller than) the optimal values, Q^* and S^*, as the arbitrarily constrained level of fertility N' is smaller (or larger) than the freely chosen desired level of fertility N^*.[16]

This hypothetical experiment of assigning some arbitrary N to the household is equivalent to maximizing equation 5 while treating N as a parameter, for all possible values of N. Such an exercise yields the household's net utility level as a function of its assigned level of fertility N' and the economic variables. Written as an implicit function the net utility V is

$$V = V(N; I, \pi_c, \pi_s) \tag{6}$$

For each arbitrarily assigned value of N', there is a maximum achievable level of utility, obtained by the appropriate mix of Q and S. By definition, the maximum value of V, indicated as V^*, will be achieved at the desired level of $N(N^* = N')$, as depicted on curve A in Figure 2.

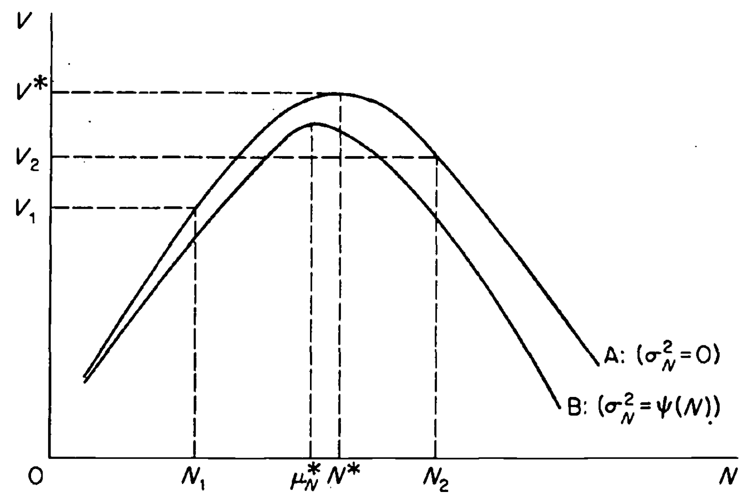
Deviations of fertility from N^* in either direction, such as N_1 or N_2, result in reduced utility levels, such as V_1 or V_2, in curve A of Figure 2. Given the emphasis in discussions of family planning on the problem of excess fertility and unwanted births (i.e., $N > N^*$), it is worth stressing that deficit fertility (i.e., $N < N^*$) may reduce welfare by at least as much as excess fertility.[17]

[16] It should be noted that we are implicitly assuming that the couple knows in advance what number of children it will have and can plan accordingly for its level of child quality and S.

[17] As indicated above, in the case of deficit fertility, quality per child, Q, would be higher than it would be in the case of optimal fertility or a fortiori for excess fertility. If from some ethical point of view, parents are judged to place too little weight on their children's welfare, and if we measure child welfare by the level of Q, it could be argued that the effect on Q of deficit fertility reduces or outweighs the parents' welfare loss $V^* - V_1$.

FIGURE 2

A Hypothetical Relationship between Utility and Number of Children



The opportunity cost of deficit or excess fertility ($V^* - V_1$ or $V^* - V_2$) is a measure of the benefits from improved fertility control. If in the absence of fertility control the household's fertility would have been N_i (yielding V_i), but with a given level of fertility control the household achieved N_j (yielding V_j such at $V_j > V_i$) then $(V^* - V_i) - (V^* - V_j) = V_j - V_i$ is a measure of the benefit from that level of fertility control. The utility benefits, then, are the gains in utility which accrue from moving nearer the optimal allocation of resources which would exist if fertility control were perfect and costless (i.e., N^*, Q^* and S^*).

We suggest above that the choice of particular values of fertility control parameters such as e_i yield particular ex ante distributions of fertility summarized by μ_N and σ_N^2. We can, therefore, formulate the discussion of the benefits of fertility control in terms of μ_N and σ_N^2. For purposes of illustration, suppose the functional form of equation 6 is quadratic in N:

$$V = a + bN + \frac{c}{2} N^2; \quad b > 0, c < 0 \tag{7}$$

where I, π_c and π_s are held constant. Since the unconstrained maximum of V gives the desired value of fertility, N^*, it follows from equation 7 that

$$N^* = \frac{-b}{c} \tag{8}$$

We may now treat N as a random variable and take the expected value of equation 7 to obtain:

$$E(V) = a + b\mu_N + \frac{c}{2}\mu_N^2 + \frac{c}{2}\sigma_N^2 \tag{9}$$

Recall that equation 3 indicates the relationship between σ_N^2 and μ_N^2, $\sigma_{N_i}^2 = \psi(\mu_{N_i})$, where ψ is a cubic function. If $E(V_0)$ is the value of equation 9 in the absence of any fertility control, and $E(V_i)$ is its value when fertility control of e_i (yielding μ_{N_i}, $\sigma_{N_i}^2$) is employed, then the benefit from fertility control strategy i is $E(V_i) - E(V_0)$.

If we maximize the expected V (equation 9) with respect to μ_N,

$$\frac{d}{d\mu_N}(E(V)) = 0 = b + c\mu_N + \frac{c}{2}\psi' \tag{10}$$

where ψ' is a quadratic equation derived from equation 3. Noting that ψ' may be roughly approximated by a positive constant K, ($\psi' = K$) for values of $\mu_N < 5$ (see Figure 1), the optimal value of μ_N, from equation 10 is

$$\mu_N^* = \frac{-b}{c} - \frac{K}{2} = N^* - \frac{K}{2} \tag{11}$$

The optimal expected fertility μ_N^* is somewhat lower than the desired fertility N^*. Equation 9 implies that the lower the variance σ_N^2 the higher the net benefit V, ceteris paribus. Since the mean and variance are positively related at low values of N (i.e., $K = \psi' > 0$ if $N < 5$), the induced reduction in mean fertility represents the adjustment to the variance associated with N^*. This is indicated by curve B in Figure 2.[18] By subtracting an amount proportional to N from curve A, curve B peaks at a level of N below N^*.

So far, we have shown that imperfect fertility control implies that a couple's actual fertility N is a stochastic variable. The couple, by its choice of a contraceptive strategy, acquires some distribution of expected fertility outcomes, and by the nature of the biological process

[18] As N increases along curve A, σ_N^2 rises by K per unit of N (up to $N = 5$), thus an amount of V proportional to N, $\left(\frac{cK}{2}\right) N$, is subtracted from curve A yielding curve B.

involved, the higher the mean of the distribution the greater its variance (up to at least $N = 5$). Thus, the greater the expected fertility, the greater the uncertainty about the actual fertility, or the greater the expected deviation between the mean and the actual fertility. Since deviations from desired fertility reduce net utility V, and since higher levels of expected fertility μ_N are associated with greater uncertainty, the household is induced to reduce its optimal expected fertility μ_N^* below its desired fertility N^* in order to reduce the uncertainty or variance σ_N^2.

C. Costs of Fertility Control

The costs of fertility control are the amounts of other desirables forgone in achieving the control. These costs include money costs but also include forgone time, sexual pleasure, religious principles, health, and so forth. It is, at best, difficult to measure these costs empirically. We will, instead, discuss some of the determinants of these costs and seek to derive testable hypotheses about the relationship between observed fertility and contraceptive behavior.

By definition, couples which avoid all the costs of fertility control have an expected level of fertility $\mu_{\hat{N}}$, which is frequently referred to as "natural" fertility.[19] We will assume that costly fertility control strategies are limited to two dimensions: (1) the choice of contraceptive technique (including regulation of coital frequency) and (2) the care or intensity with which a given technique is used (i.e., we assume that the contraceptive efficiency, e_i, of the ith technique is a variable which may be increased at increased cost to the couple).[20] In this section, we also restrict the choice of contraception strategies to "pure" strategies. Thus, each strategy yields a different monthly probability of conception and hence a different point on the mean-variance curve (say, curve A) in Figure 1.

Associated with each contraceptive strategy is an opportunity cost measured by the utility loss associated with the change in behavior

[19] See the discussion of natural fertility in an earlier section. Throughout Section II of this paper we continue to assume that the couple's fertility control strategy is determined at the outset of the period-at-risk of conception and remains constant throughout the reproductive span. "Natural" fertility results when the age at marriage (which affects T) and the rate of coition c are determined without regard to effects on fertility.

[20] Thus, we rule out, for now, abortion and sterilization, and we assume age at marriage to be exogenous. To emphasize this restriction we will use the term "contraception" in place of "fertility control" in discussing costs, strategies, and so on. For a study of abortion as a means of fertility control see Potter (1972) or Keyfitz (1971) or for an economic analysis see a study in progress by Kramer (1973).

required to implement that strategy. Some strategies cost money, some cost sexual satisfaction, some cost real or imagined decreases in physical health. The assumption of utility maximizing behavior implies that couples will choose the least costly strategy they are aware of in order to achieve any given level of p which yields μ_N and its associated σ_N^2. Suppose the couple's cost schedule for achieving any given p_i or its fertility outcome μ_N is

$$F = F(\mu_N) \tag{12}$$

where F is the total cost of achieving μ_N, using the least costly contraceptive strategy. More specifically, let the cost of the ith contraceptive strategy be the simple linear function

$$F_i = \alpha_i + \beta_i B = \alpha_i + \beta_i\,(\mu_{\hat{N}} - \mu_N) \tag{13}$$

where B is the difference between $\mu_{\hat{N}}$, the couple's natural fertility, and μ_N, the mean of the distribution of its expected fertility while using strategy i. Thus, B is the expected number of births averted.

Equation 13 implies that the total cost of contraception using the ith technique may be divided into two components: (1) a fixed cost α_i, ($\alpha_i \geqslant 0$), which must be incurred if the ith technique is to be used at all, and (2) a variable cost $\beta_i B$, which is proportional to the number of births averted by the use of technique i.[21] The term β_i, ($\beta_i \geqslant 0$), is the marginal cost per birth averted.[22]

It is important to stress that the classification of the contraception costs F_i of a given technique as fixed (α_i) or variable ($\beta_i B$) is distinct from the classification of costs by their source. An economic (e.g., money or time), sociological (e.g., teachings of the Catholic church, deviation from class norms), psychological (e.g., interference with sexual pleasure, fear of adverse effects on health) or physiological (e.g., health) cost may be either fixed or variable.

Some factors, however, are more likely to affect α_i than β_i or vice versa. Lack of contraceptive knowledge, for instance, is often cited as a reason for imperfect control. To the extent that this is true, it is sensible to suppose that the acquisition of information about fertility

[21] Each contraceptive strategy involves both the adoption of a contraceptive technique and the care and precision in its use. The adoption of technique i and its careless use results in less efficient contraception, a lower e_i, higher p_i and fewer births averted. Nearly all contraceptive techniques are capable of achieving a low e_i with careless use or a high e_i with proficient use.

[22] The linearity of the cost functions in equation 13 is not a particularly crucial assumption in the sense that the implications to be derived could be obtained under less restrictive assumptions.

control methods is costly. A characteristic of the cost of information is that it does not depend on the amount of use to which the information is put. It follows that the costs of information tend to influence the fixed costs of contraception (the α_i's), but not the marginal costs (the β_i's).[23] The cost to a Catholic of violating the church's precepts with respect to the use of a contraceptive, for example, might be a once-and-for-all cost, in which case α_i is higher for Catholics than non-Catholics for all forbidden contraceptive techniques. Alternatively (or additionally), a Catholic may experience greater guilt the more intensively the technique is used, in which case β_i is higher to Catholics than to non-Catholics.[24]

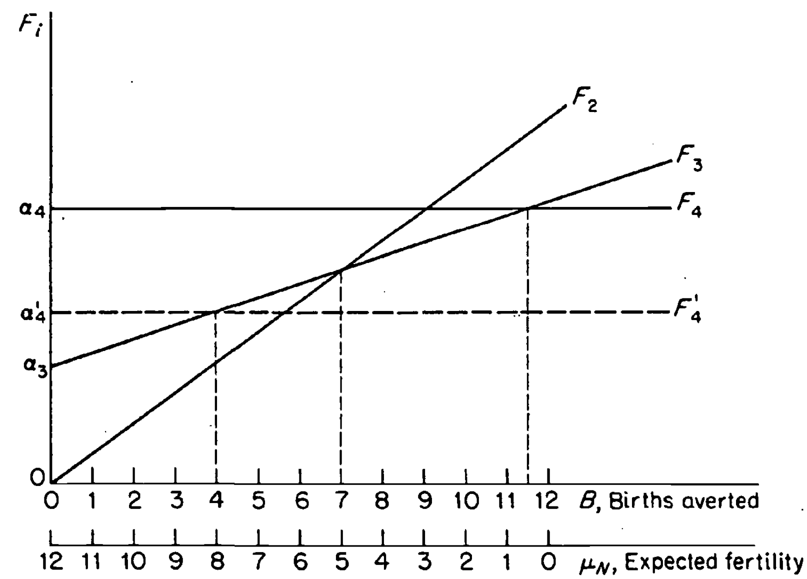
The loss of sexual pleasure occasioned by contraception almost surely affects only the marginal costs of contraception and not the fixed costs. Thus, the number of births averted by condoms depends on how frequently and with what care condoms are used. The most ancient contraceptive techniques—abstinence or reduced coital frequency, and withdrawal—probably have zero fixed cost and rather high (psychological) marginal costs. By way of example, consider the choice between reduced coital frequency or withdrawal as alternative contraceptive techniques. If a husband and wife use neither technique at all, they will expect to have $\mu_{\hat{N}}$ births and they will avert no births (i.e., $B = 0$). The more persistently either technique is used, the smaller will be the expected fertility, the larger the expected number of births averted, and the larger the total contraception costs. Which technique is least costly depends solely on which technique has the lower marginal cost. If the marginal cost of reduced coital frequency exceeds the marginal cost of withdrawal, for example, the couple would not use the former technique whatever its desired number of averted births (note that we are limiting the choice at this point to pure strategies).

[23] This argument should be qualified to the extent that information is acquired by a process of "learning by doing" or that information deteriorates with disuse by a process of forgetting. In this case, the marginal cost of the ith technique (β_i) would tend to shift downward as the volume of use increases. Analytically, the learning hypothesis and the once-and-for-all hypothesis have the same implication, namely, that the average contraception cost per birth averted decreases as B increases.

[24] The cost to an individual Catholic of violating the church's precepts may also be a function of the behavior of other Catholics or of other members of the society at large. Thus, the dynamics of diffusion of the pill use among Catholics might be interpreted, in part, as the progressive lowering in the cost of contraception to each individual Catholic as he or she sees others using the pill. Of course, the equivocation within the church itself also presumably lowers the costs of using forbidden techniques (see Ryder and Westoff 1971, Chapter 8, for evidence on the effect of the Papal Encyclical on the contraceptive behavior of Catholics).

FIGURE 3

Hypothetical Fertility Control Cost Functions for Various Contraceptive Techniques



It is not always the case that one technique dominates all others for all possible fertility goals. Suppose, for example, that a third technique, condoms ($i = 3$), has a lower marginal cost than does withdrawal ($i = 2$) (i.e., $\beta_3 < \beta_2$), but that it has a positive fixed cost (i.e., $\alpha_3 > \alpha_2 = 0$). This situation is depicted in Figure 3, where line $0F_2$ indicates the total contraception cost incurred if withdrawal is used to achieve each possible value of expected births averted (reading the upper horizontal scale from left to right) or, equivalently, at each possible level of expected fertility (reading the lower horizontal scale from right to left). Similarly, line α_3F_3 shows the cost of using condoms to achieve each possible outcome.

To avert fewer than seven births (i.e., to have five or more children), the least cost strategy in Figure 3 is withdrawal. However, to avert more than seven births, condoms are a less costly contraceptive method. The point of equal costs (where lines $0F_2$ and α_3F_3 intersect) is called the "switching point": as the number of births to be averted rises, at some point (e.g., seven in the example illustrated in the figure) it becomes cheaper to incur the fixed costs or make the investment in an alternative technique—to switch to the technique with the lower marginal cost.

Additional contraceptive techniques with still higher fixed costs and lower marginal costs may have lower average cost at higher numbers of averted births. The total cost function F (equation 12) is defined as the collection of line segments which represent the least-cost method of achieving each number of averted births. It is the envelope of segments of the F_i curves in Figure 3. The limiting case would be a contraceptive with zero marginal cost (i.e., method $i = 4$ in the figure). A relatively low marginal cost appears to be a major advantage of modern contraceptive methods such as the pill and IUD. If line $\alpha_4 F_4$ represents such a technique in Figure 3, note that it represents the optimal contraceptive choice only if the couple wishes to have fewer than one child (as the figure happens to be drawn). That is, only couples wishing to avert nearly all potential births would select that high fixed cost, zero marginal cost technique.

D. Optimal Fertility Control Strategy

The preceding sections have discussed the separate elements in the determination of an optimal fertility control strategy. Using the simplifying assumption that a household must follow a pure strategy (i.e., must choose a constant value of p for the entire reproductive span), we derived a biological constraint on fertility choices illustrated by the mean-variance curve in Figure 1.

Next, we derived the expected utility of the household as a function of the mean and variance of fertility outcomes. This relationship is depicted in Figure 2. The fertility level with the highest net value N^* under conditions of certainty (i.e., $\sigma_N^2 = 0$) and costless contraception is defined as the couple's "desired fertility." If, however, the couple is constrained to choose points on the mean-variance curve in Figure 1 (but may choose any point without incurring any fertility control cost), the decrease in uncertainty associated with decreases in expected fertility makes it optimal to choose a level of expected fertility μ_N^* that is somewhat lower than its desired fertility, N^*.

Finally, we introduced the (utility) costs of controlling fertility by means of specific contraceptive techniques. We derived a fertility control cost function as the envelope of least-cost segments of the cost curves of the individual techniques, which is shown in Figure 3. Holding the couple's expected natural fertility, $\mu_{\hat{N}}$, constant, its total cost of fertility control F is larger, the smaller the level of its expected fertility μ_N.

The selection of the couple's optimal fertility control strategy involves two steps. First, for any given choice of μ_N and, jointly, σ_N^2, the couple selects the least costly contraception technique—say the *i*th technique—with total cost $F_i = \alpha_i + \beta_i(\mu_{\hat{N}} - \mu_N)$. Second, it selects a level of μ_N (and σ_N^2) such that total expected utility (i.e., the expected net utility from children $E(V)$, minus the total cost F_i) is maximized. That is, using the specific functional forms in equations 9 and 13

$$\max \{E(V) - F_i\} = \max \{a + b\mu_N + \frac{c}{2}\mu_N^2 + \frac{c}{2}\sigma_N^2 - \alpha_i - \beta_i(\mu_{\hat{N}} - \mu_N)\} \quad (14)$$

The necessary condition for maximization with respect to μ_N is

$$0 = b + c\mu_N + \frac{c}{2}\psi' + \beta_i \quad (15)$$

Solving for μ_N and again approximating ψ' (see equation 10) by the constant $K > 0$

$$\mu_N = -\left(\frac{b}{c} + \frac{K}{2} + \frac{\beta_i}{c}\right) = N^* - \frac{K}{2} + \beta_i k = \mu_N^* + \beta_i k \quad (16)$$

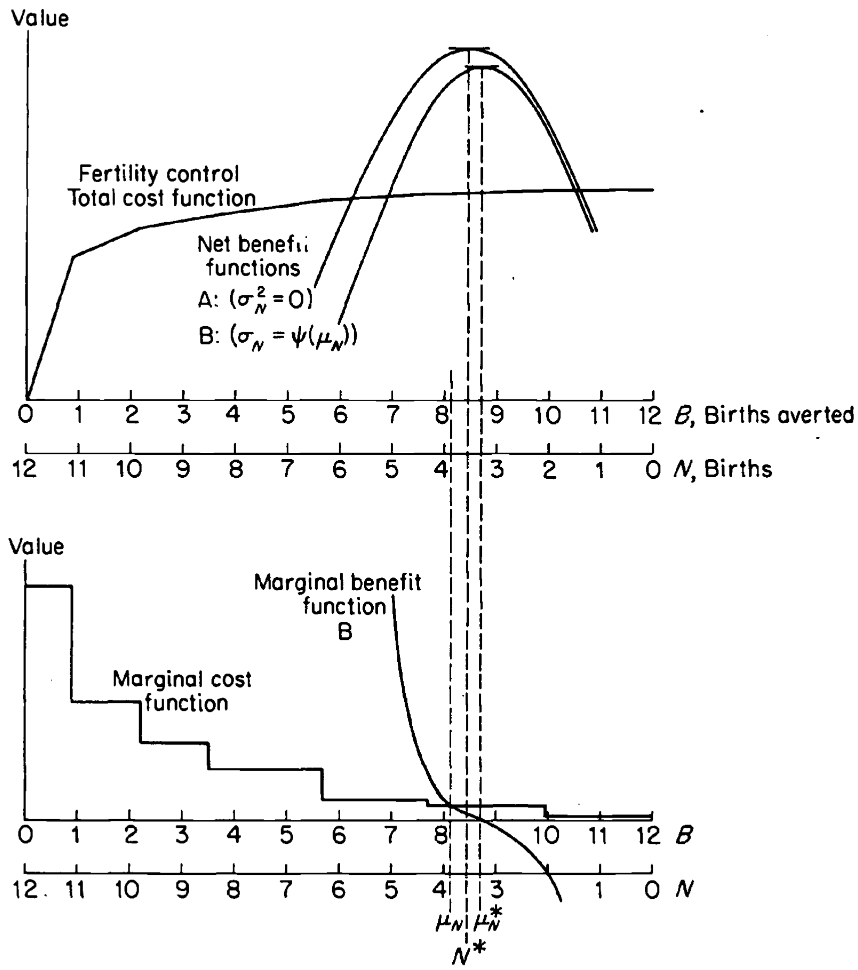
where $k = \frac{-1}{c} > 0$.

Equation 16 summarizes the influence on fertility outcomes of imperfect and costly fertility control. If the couple could select any level of fertility costlessly and with certainty, it would select N^*, its "desired fertility" determined by its tastes, economic circumstances, and so forth. Since fertility outcomes involve an element of uncertainty (i.e., result from a stochastic process), there is a variance associated with each level of fertility, and since this uncertainty lowers the expected benefits or utility from each level of N, this uncertainty induces the couple to prefer an expected level of fertility μ_N^* lower than N^* ($\mu_N^* = N^* - K/2$). Furthermore, since it is costly to avert births, the costs of fertility control further modify the optimal fertility outcome, raising the optimal above the level μ_N^* ($\mu_N = \mu_N^* + \beta k$). In effect, β_i is a per unit subsidy to childbearing, because a couple may reduce its contraceptive cost by β_i with every additional birth it has.

The relationship between these various levels of fertility can be indicated by combining Figures 2 and 3 (see Figure 4). Utility would be maximized at a level of $N = N^*$ if the costs of fertility control were zero and the uncertainty about fertility outcomes were ignored

FIGURE 4

Hypothetical Fertility Control Cost and Benefit Functions
Indicating the Optimal Level of Fertility Control



(e.g., the maximum of the net benefit function A is at a level of $N = N^*$). The presence of uncertainty modifies the optimum by raising the peak of the net benefit function (function B) to the level $N = \mu_N^*$. The presence of fertility control costs further modifies the optimum by lowering the preferred N to μ_N, the intersection of the marginal cost of fertility control and the marginal benefit from fertility control.

III. PURE AND MIXED CONTRACEPTIVE STRATEGIES

In the previous section, we restricted the discussion of contraceptive strategies to a "pure" strategy, defined as one in which the couple selects some specific contraceptive technique and uses it with some specific amount of care throughout the reproductive span of T months. The pure strategy model, in which the couple uses one technique continuously, implies a constant monthly probability of conception p over the fertile months in the reproductive span. This implication is essential for the Markov renewal process on which are based the equations for the mean and variance of fertility outcomes (equations 1 and 2) and the mean-variance curves depicted in Figure 1. So the pure strategy model lends itself to a simple analytical structure and represents a boundary on the relationship between mean and variance of fertility. As we have noted, this Markov renewal model also underlies much of the important analytical work done in the past decade in mathematical demography.

However, it is evident that, in reality, a couple is not restricted from altering its contraceptive technique over the reproductive span. Even in the context of a lifetime strategy which could be mapped out initially and carried out over time, a couple might choose to use different contraceptive techniques (including no contraception) in various segments of that span of time. Furthermore, since the discussion of the benefits of fertility control emphasized that under fairly general conditions couples prefer to reduce the variance in their expected fertility, it is economically sensible as well as technically feasible for couples to select a mixed contraceptive strategy which may result in a lower σ_N^2 for any level of expected fertility μ_N.[25]

For example, if a couple used the oral contraceptive at its average observed use-effectiveness throughout its twenty-year reproductive span, Table 2 indicates that the distribution of its expected fertility

[25] The economic rationale, offered in Section II, for preferring a reduced variance in fertility was that any deviation in actual fertility from the desired level of fertility implies a reduction in utility. The greater the variance σ_N^2 the greater the likelihood that the discrepancy between actual and desired fertility will be relatively large.

There is an additional economic reason for generally preferring a lower variance in the distribution of expected outcomes, risk preference aside. The more certain the couple is about the number of children it will eventually have, the more efficiently it can optimize the allocation of its resources. The couple which is more certain about the timing and number of its children can more efficiently plan its savings pattern, select an optimal size home, automobile, et cetera, plan the labor force behavior of the wife, and so forth. The same principles apply here as in the case of a firm which can achieve lower average cost of production if its rate of output is constant over the long run than if its rate of output varies significantly from season to season or from year to year.

has a mean of 0.19 births and a variance of 0.18 (point *a* on the mean-variance curve in Figure 1). If this couple wished to have about three children, it could use a less effective technique or use the pill somewhat carelessly, thereby achieving a monthly probability of conception of 0.0182 which over a twenty-year span would yield an expected fertility of 3.4 and a variance of 1.99 (point *c* on the mean-variance curve in Figure 1). The couple could also achieve a mean fertility of 3.4, however, by combining periods of pill use with periods of time in which no contraception was used. The result would be a mean of 3.4 children and a variance considerably below that indicated by point *c* on the mean-variance curve. Indeed the variance would be no greater than that indicated by point *f*, the variance associated with the use of no contraception over the entire twenty-year time span.[26]

Furthermore, the pure strategy implies that the births will arrive at random intervals over the twenty-year span, while the mixed strategy permits the couple to achieve the same number of children with considerable control over their spacing.[27] By combining the use of a highly effective technique with periods of no contraception, a couple can achieve its desired number of children with a relatively low variance σ_N^2 and relatively little uncertainty about the spacing of its children.

The mean-variance curve in Figure 1 represents the biological constraint on the distribution of expected fertility when a particular monthly birth probability persists for the entire span of T months. By using a mixed strategy, combining contraception with periods of no contraception, the biological constraint is no longer an effective constraint—the couple can move off the mean-variance curve toward the horizontal axis representing a distribution of fertility outcomes of mean μ_N and zero variance. The more efficient the contraceptive tech-

[26] The logical extreme would be a mixed strategy in which natural fertility (no contraception) is pursued in those segments of the reproductive span in which a birth is desired and perfect contraception (i.e., $e_i = 0$) at all other times. This strategy would enable a normally fecund couple to achieve any given number of children fewer than, say, five with virtual certainty and would also enable them to approximate many plausible desired spacing patterns fairly closely (see Potter and Sakoda 1967).

Such a strategy is not only a logical possibility, but it is also technically feasible, since the monthly probability may be set to zero at any time by reducing coital frequency to zero. The fact that couples do not appear to follow this "perfect contraception" strategy suggests that the problem of fertility control is not a matter of technical feasibility. The biological constraint on fertility choices must be considered simultaneously with other constraints on behavior, with fertility goals viewed as competing with other family goals.

[27] In the pure strategy case the variance of the interval of time between successive births, σ_t^2, is inversely related to p and hence μ_N. Thus, reduction in expected fertility along the mean-variance curve is accompanied by an *increase* in variance σ_t^2.

nique chosen during periods of contraception, the smaller is the achievable variance σ_N^2 for any given mean μ_N. Thus the more efficient the contraceptive technique chosen, the weaker is the relationship between μ_N and σ_N^2,[28] and the smaller is the incentive to lower the mean fertility as a mechanism for reducing uncertainty or variance.

The mixed strategy (defined in terms of using one specific technique while contracepting and no contraception otherwise) is feasible only when the expected number of births from the continuous use of the technique is less than the number of children the couple desires. So this form of mixed strategy is more likely to be used the greater is the efficiency of the contraceptive technique chosen.

In this discussion of mixed strategies of contraception, we have focused upon one particular type of mixed strategy—that of adopting and abandoning at intervals one contraceptive technique. Although shifting from contraceptive technique to technique is another possibility, the theoretical discussion of the costs of contraception suggested that this would not be the case. The fixed costs associated with the adoption of modern techniques would inhibit technique switching. Consistent with the model's implication, evidence from the 1965 National Fertility Survey (NFS) suggests that technique switching has not been a prevalent practice in the United States in the past two decades. Ranking contraceptive methods by their mean monthly probability of conception (as indicated in Table 2) and limiting the subsample to women who had used some contraception in each of their first three birth intervals, Michael (1973) found that the correlation among techniques used across the three pregnancy intervals was quite high (ranging from 0.57 to 0.97) for non-Catholic women partitioned by color and age cohort.[29] Ryder and Westoff (1971) study the relationship between use and nonuse of contraception across intervals and the relationship between contraceptive failures in successive intervals. They find considerable continuity of contraceptive status

[28] Some evidence that the correlation between mean and variance of fertility is positive is found in the 1960 U.S. Census of the Population. Grouping white women married once and husband present into cells defined by husband's occupation (8 categories), husband's education (5 categories) and wife's education (3 categories), the unweighted simple correlation between μ_N and σ_N^2 across cells is 0.89 for women aged 45–54 and 0.77 for women aged 35–44. If the younger cohort used better contraceptive methods on the average, then the reduction in this correlation across cohorts is consistent with the implication of a weaker correlation among users of better contraception.

[29] See Michael (1973), Table 4. One note of caution. The NFS data are oriented by the woman's pregnancy intervals, so Michael had information on only the best technique used by the woman in each interval. He could therefore identify switches in contraceptive techniques from pregnancy interval to interval, but not from technique to technique within a given pregnancy interval.

across intervals both in terms of whether a woman does or does not use contraception in successive intervals and in terms of the degree of success of use across intervals.[30]

IV. CONTRACEPTION AND FERTILITY OUTCOMES

In the model described in Section II, the household's number of children N is a random variable. The household adopts a contraceptive strategy which yields a particular value of p, the monthly probability of conception. Given p as a known and fixed parameter, the household has an ex ante distribution of fertility characterized by a mean μ_N and variance σ_N^2.

The discussion has focused on the ex ante distribution of fertility outcomes for a single household, but in our empirical analysis we focus on the corresponding distribution for relatively homogeneous groups of households. It is assumed that the observed mean and variance in births among households with relatively homogeneous demographic-economic characteristics reflect the mean and variance of the distribution of fertility outcomes faced by each of the households in that group. Recall that the equation for the variance in number of children (equation 2) assumed that the unprotected monthly probability of conception and the length of the period of infertility were constant over the couple's reproductive lifetime. To apply the model across households implies not only constancy of these parameters over time for a given household, but also constancy across households. Heckman and Willis deal explicitly with the problem of estimating the

[30] For example, 90 per cent of women who used some contraceptive technique in the first pregnancy interval (from marriage to first pregnancy) used a contraceptive in the second interval, while only 36 per cent of nonusers in the first interval used a contraceptive in the second interval. Similar percentages are found for each successive pair of intervals (i.e., from the fourth to the fifth interval the comparable percentages are 95 per cent and 18 per cent). See Ryder and Westoff (1971), Table IX-19, p. 255. Or, 95 per cent of the women who had used contraception in each of the first three pregnancy intervals used contraception in the fourth interval, while only 13 per cent of women who had not used contraception in any of the first three intervals used contraception in the fourth (see Ryder and Westoff (1971), Table IX-23, p. 260).

Evidence of consistency of use across intervals is indicated by the following rather remarkable statistic: of women who used a contraceptive "successfully" in the first three pregnancy intervals, 20 per cent experienced a contraceptive "failure" in the fourth pregnancy interval, while of those who had experienced a contraceptive "failure" in each of the first three intervals, 77 per cent experienced a "failure" again in their fourth interval (see Ryder and Westoff for definitions of success and failure).

This statistic and others support quite strongly, we think, the contention that couples act as if they adopt a lifetime strategy toward contraception and that that strategy involves considerable continuity in the use of a technique throughout a lifetime. (The Princeton Study begun in 1957 also suggested that across-interval changes in fertility control are "clearly not a matter of couples shifting from ineffective to effective methods" of contraception. See Westoff, Potter, and Sagi 1963 (pp. 232–235).)

average monthly probability p in heterogeneous groups of households. For our purposes, we will not pursue this issue.[31]

The model in Section II was set out in a lifetime context and considered fertility control in terms of a lifetime strategy. Accordingly, in our empirical work we frequently use information about contraceptive behavior at one point in the couple's marriage as an indication, or index, of the lifetime contraceptive strategy. As we indicated in Section III, there is considerable evidence that contraceptive behavior is not characterized by switching from contraceptive technique to technique over the life span. Consequently, in this section we will distinguish couples either by the best contraceptive technique used in the time interval from marriage to their first pregnancy or by the best technique used at any time in their marriage.[32]

[31] Consider two populations of fecund, nonpregnant women with identical mean monthly probabilities of conception, $\bar{p}$. One population is homogeneous in the sense that p is identical for all members of the population, and the other is heterogeneous in the sense that p varies across women according to some distribution with positive variance. It is known that the mean waiting time to conception in the heterogeneous population will be longer and the average birthrate lower than in the homogeneous population, and that this difference is a function of the distribution of p in the heterogeneous population (see, for example, Sheps, 1964).

[32] In addition to the evidence cited above regarding consistency of technique use between pregnancy intervals, the following table indicates the percentage of users of a specific contraceptive technique in the first interval who also used that technique in the second interval. The second column indicates the percentage who used either that same technique or no contraception in the second interval. These figures pertain to white non-Catholic women aged 40–44 from the 1965 NFS.

First Interval	Second Interval	
Technique Used	% Using Same Technique	% Using Same Technique or No Contraception
Diaphragm	77%	89%
Condom	72	82
Withdrawal	78	85
Jelly, foam, suppository	61	67
Rhythm	65	85
Douche	62	73

The table indicates, for example, that of those couples which used the diaphragm in the first pregnancy interval, 77 per cent also used the diaphragm in the second pregnancy interval. Furthermore, of that same group another 12 per cent used no contraception in the second pregnancy interval; thus, a total of 89 per cent used either that same contraceptive method or no method in the second interval. (The second interval here is defined as either the period of time from the first to the second pregnancy or from the first pregnancy to the time of the survey if no second pregnancy occurred.)

Since these data were collected by interview at the time these women were 40–44 years of age and pertain to periods of time shortly after marriage, there may be a tendency to give the same response for successive intervals. If so, these percentages overstate the consistency of technique selection across intervals.

In this and the following section, we use the 1965 National Fertility Survey, which was conducted by the Office of Population Research at Princeton University.[33] This cross-section survey of some 5,600 women aged 55 and under, currently married and living with their spouse, contains information on the specific contraceptive technique used in each pregnancy interval, as well as information on the couple's actual fertility outcome. In this section, we use this data set to document the relationship between contraception use and fertility outcomes. Since we are interested in studying the variance in fertility, we group the data into cells and study between-cell differences in observed behavior.

In this section we explore *how* contraception behavior is related to the observed distribution of fertility across groups of households; we do not attempt to explain *why* couples differ in their desired fertility or in the dispersion of their fertility. Although we indicated in Section II that the model is capable of treating contraception choice and fertility control choice in a simultaneous system of equations, we do not attempt to estimate the parameters of those structural equations. In the tables below, we partition the data set by household characteristics including color and religion, and we use either the wife's education or expected fertility and either age of wife or marriage duration to isolate relatively homogeneous groups of households. In the context of these homogeneous groups, we study contraception strategies as the mechanism for affecting fertility outcomes.

Figure 5 indicates the frequency distribution of live births for women aged 35–55 for groups defined by wife's level of schooling, color, and religion. Among the white non-Catholics (Figure 5(A)) the distributions appear to be less positively skewed and less dispersed (or more peaked) among women with higher levels of schooling.[34] By contrast,

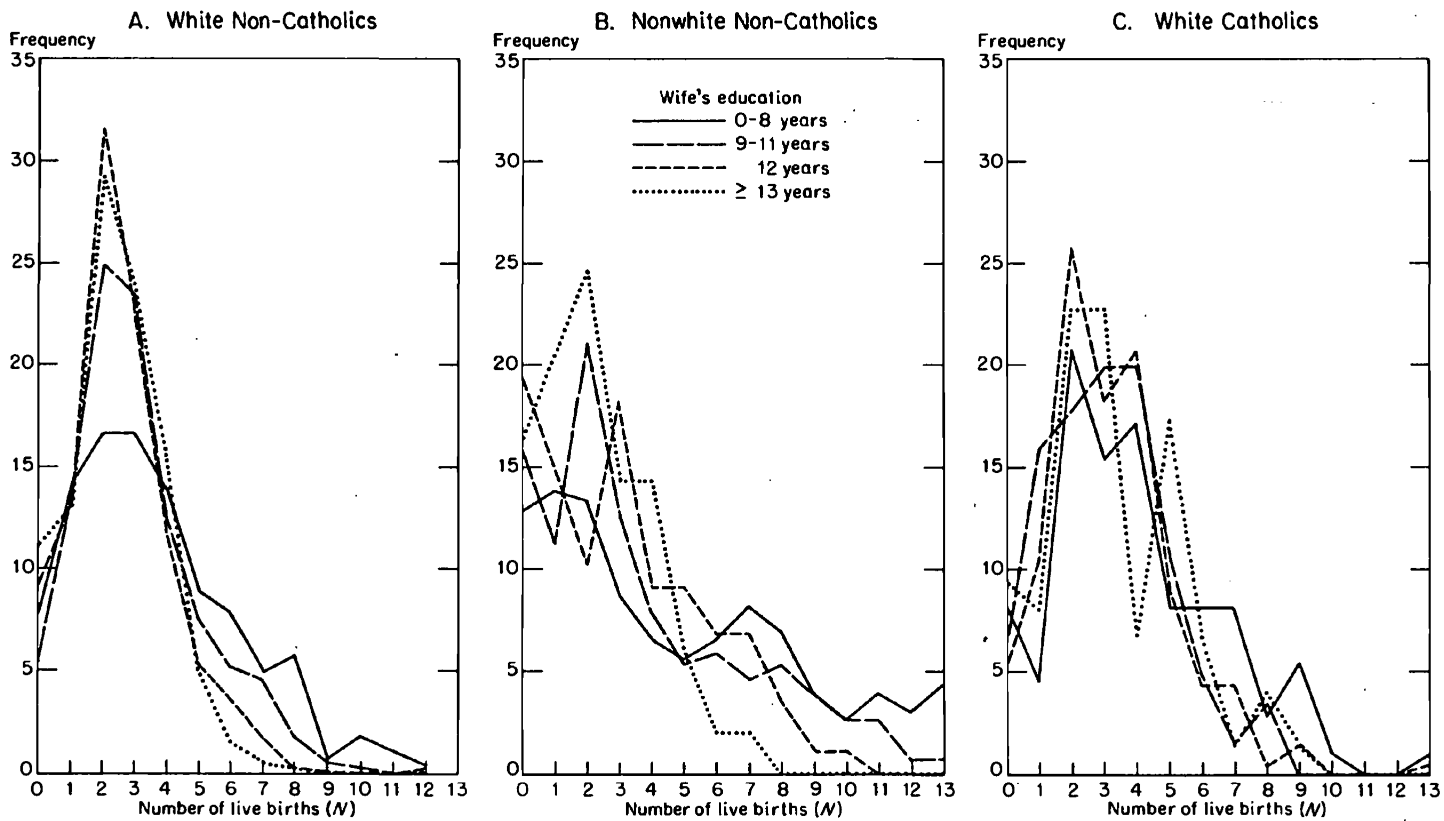
[33] We wish to thank Charles F. Westoff and Norman B. Ryder for their help in obtaining these data. Our previously published research from this data set (Michael 1973) used a small data file obtained from Professor Westoff. Our current research uses the publicly available data tape from the 1965 NFS, which was acquired through Larry Bumpass. The data set is fully described in Ryder and Westoff, *Reproduction in the United States 1965* (Princeton: Princeton University Press, 1971).

[34] A few chi-squared tests have been performed on pairs of distributions of live births for groups of white non-Catholics with different education levels from specific 5-year cohorts. These tests imply rejection (at $\alpha = .05$) of the hypothesis that the grade-school women's distribution of live births and the college women's distribution of live births might have been drawn from the same population.

For example, $\chi^2 = 36.8$ with 12 degrees of freedom for a comparison of ≤ 8 years versus ≥ 13 years of schooling for women aged 40–44. The critical value for χ^2 with 12 degrees of freedom at $\alpha = .01$ is 26.2.

FIGURE 5

Frequency Distribution of Live Births by Wife's Education, by Color and Religion for Women Aged 35–55



the distributions for nonwhite non-Catholics (Figure 5(B)) are considerably less peaked and more skewed. Among this latter group, the level of schooling does not distinguish the frequency distributions so clearly, although the percentage of households with, say, seven or more births appears to decline as the level of schooling rises. Among Catholics (Figure 5(C)) the distributions are somewhat less dispersed than among the nonwhite non-Catholics, and the level of schooling does not appear to influence the distributions systematically.

Among white non-Catholics, there appear to be distinctly different distributions of live births by wife's education. These differences are further emphasized by the following table derived from Appendix Table A.1. Also, the groups of nonwhites and Catholics appear from

Percentage of Women with Six or More Live Births:
White Non-Catholic Women
(calculated from Appendix Table A.1)

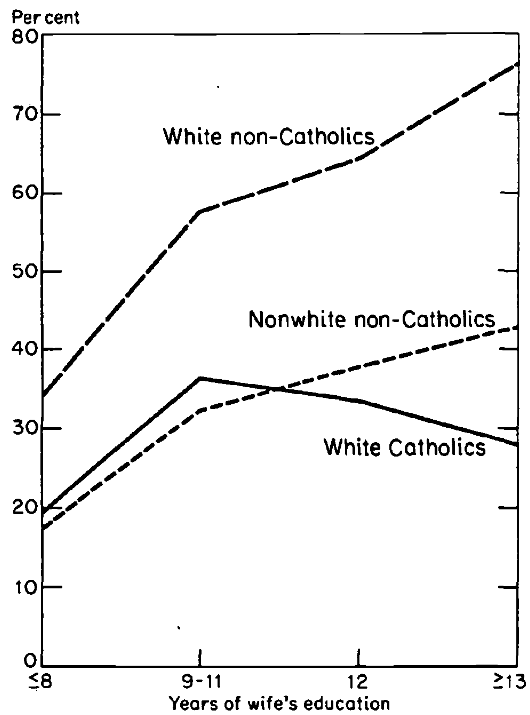
Wife's Education	Wife's Age			
	35–39	40–44	45–49	50–54
≤ 8	22.7	22.4	23.4	19.6
9–11	11.5	15.6	5.7	13.1
12	6.8	6.7	4.8	1.3
≥ 13	2.7	1.6	1.6	2.2
Total	8.8	10.1	7.9	8.7

Figure 5 to have considerably different frequency distributions than the most highly schooled white non-Catholic groups. The discussion above has suggested that different contraceptive strategies yield different distributions of fertility, so we expect to find that groups which differ in the distribution of their actual fertility also differ in their contraception behavior. The NFS data contain information on the particular contraceptive method used by each woman in each pregnancy interval. The data do not indicate how extensively, regularly, or carefully a contraceptive method was used; we know only that the woman indicated that between the time she married and the time she first became pregnant, for example, she used contraceptive method *i* (including no method at all).

Figure 6 indicates the percentage of women in each education, color,

FIGURE 6

Percentage Ever Using "Good" Contraception by Wife's Education for Groups by Color and Religion, Women Aged 35–55



and religion group which ever used a "good"[35] contraceptive technique. The relationship between these percentages and the distributions of births indicated in Figure 5 is striking. Among white non-Catholics, the percentage of users of "good" contraceptive techniques rises significantly with the wife's level of schooling, and this is also the group for which schooling most clearly distinguishes the dis-

[35] Throughout this section, "good" contraception is defined to include pill, IUD, condom, and diaphragm. For older cohorts, the best available contraceptive methods were the condom and diaphragm, while for the younger cohorts the more reliable pill and IUD were also available. Since we are attempting at this time to distinguish use of highly reliable from less reliable techniques, the distinction was arbitrarily made as indicated. All contraceptive methods other than the pill, IUD, condom and diaphragm are categorized as "poor" methods. The use of no contraception is called "none" and is distinguished from the "poor" methods.

tributions of births. The percentages rise less rapidly by education among the nonwhites, and for these groups the frequency distributions of births are less clearly delineated by education. Among Catholics, neither the percentage of users of good contraceptive techniques nor the frequency distribution of births seems to be closely related to wife's education. Thus, in comparisons among and within color and religion groups, there appears to be a quite consistent relationship: groups characterized by a relatively high percentage of users of good contraception are also characterized by relatively low dispersion in fertility.

Table 3 summarizes this same relationship. The table indicates, for each education, color, and religion group, the percentage of couples ever using "good" contraception and the actual mean and standard deviation of live births. Groups characterized by a high percentage of users of good contraception are characterized by relatively lower variance and somewhat lower mean fertility. Simple correlations across these groups between the percentage of couples which ever used good contraception (at any time since marriage), "% good," and the mean fertility μ_N, and between "% good" and the standard deviation σ_N are consistently negative. As emphasized in the theoretical discussion of the mean-variance curve, the observed correlation between the mean and variance (or standard deviation) in fertility is positive in all cases:

Simple Correlation Coefficients between % Good (the Percentage of Couples Which Ever Used Good Contraception), μ_N (the Group's Mean Number of Live Births), and σ_N (the Standard Deviation in the Group's Number of Live Births)

	Simple Correlation			
	% Good, μ_N	% Good, σ_N	μ_N, σ_N	(n)[a]
White non-Catholics	−.647	−.896	.884	(8)
Nonwhite non-Catholics	−.508	−.675	.952	(8)
White Catholics	−.334	−.700	.879	(8)
All combined	−.475	−.601	.864	(24)

[a] Number of cells.

The relationship between contraception behavior and fertility outcomes indicated by Table 3 is somewhat circumstantial—groups of

TABLE 3

Percentage of Couples Using "Good" Contraception, Mean and Standard Deviation of Live Births; by Wife's Education, Age, Color, and Religion

		Education of Wife				
		≤8	9–11	12	≥13	Total
		White Non–Catholics				
Age 35–44	% good [a]	37.4	62.9	67.4	79.9	64.9
	μ_N	3.658	3.284	2.738	2.583	2.946
	σ_N	2.635	1.942	1.567	1.472	1.849
	(*n*) [b]	(155)	(232)	(503)	(230)	(1,120)
Age 45–54	% good	29.9	45.4	57.2	67.8	50.9
	μ_N	3.645	2.616	2.136	2.189	2.579
	σ_N	2.459	2.004	1.593	1.415	1.962
	(*n*)	(121)	(99)	(206)	(106)	(532)
		Nonwhite Non-Catholics				
Age 35–44	% good	21.7	35.3	41.8	46.9	32.7
	μ_N	4.968	3.613	3.493	2.531	3.980
	σ_N	3.855	3.231	2.636	1.796	3.355
	(*n*)	(124)	(119)	(67)	(32)	(342)
Age 45–54	% good	11.3	21.2	25.0	35.3	17.4
	μ_N	4.474	3.848	1.800	1.765	3.754
	σ_N	4.309	3.173	1.765	1.480	3.797
	(*n*)	(97)	(33)	(20)	(17)	(167)
		White Catholics				
Age 35–44	% good	18.0	41.6	31.7	28.3	31.6
	μ_N	4.213	3.217	3.353	3.567	3.461
	σ_N	2.659	1.831	2.027	2.126	2.111
	(*n*)	(61)	(106)	(218)	(60)	(445)
Age 45–54	% good	20.9	23.0	39.3	26.7	28.8
	μ_N	3.646	2.564	2.705	2.133	2.896
	σ_N	2.497	1.832	1.395	1.598	1.949
	(*n*)	(48)	(39)	(61)	(15)	(163)

[a] Percentage of couples in the cell which ever used "good" contraception (i.e., pill, IUD, condom, or diaphragm).
[b] *n* indicates cell size. These figures are in parentheses.

households which had relatively high rates of use of good contraception also had relatively low mean and low variance in fertility. To relate contraception use to fertility outcomes more directly we partition the age, education groups of white non-Catholics by their contraceptive strategies. Table 4, for example, indicates the separate frequency distribution of live births for users of good contraception and users of poor contraception in the first pregnancy interval by wife's age for women with 12 years of schooling. That is, in Table 4 two of the cells in Table 3 (defined by wife's education equal to 12 years for women aged 35–44 and aged 45–54) are partitioned by the contraceptive technique used in the first birth interval.

For each of the two age groups the distribution of live births is considerably less dispersed among the users of good contraception than among users of poor contraception (e.g., the percentage of households with five or more live births was 10.3 and 3.0 among users of good contraception, while the percentages were 14.9 and 15.4 among users

TABLE 4

Frequency Distribution of Live Births for White Non-Catholic Women with 12 Years of Education by Contraceptive Method Used in the First Pregnancy Interval and by Wife's Age

Contraceptive Method	Number of Live Births					Cell Size
	0	1	2–4	5–6	≥7	
			Age 35–44			
Good [a]	1.4	7.0	81.2	8.9	1.4	(213)
Poor	2.0	13.9	69.3	11.9	3.0	(101)
None	15.3	14.8	55.6	11.1	3.2	(189)
Total	6.8	11.3	69.2	10.3	2.4	(503)
			Age 45–54			
Good [a]	0.0	16.7	80.3	3.0	0.0	(66)
Poor	0.0	12.8	71.8	7.7	7.7	(39)
None	31.7	20.8	41.6	5.0	1.0	(101)
Total	15.5	18.0	59.7	4.9	1.9	(206)

[a] "Good" methods are defined to be pill, IUD, condom, and diaphragm; "poor" methods include all other contraceptive methods excluding abstinence.

of poor contraception). Notice, too, the large percentage of nonusers in the first interval which had zero live births. Presumably a relatively large fraction of the users of no contraception knew themselves to be sterile or subfecund. In the terminology of the model developed in Section II, couples with a relatively low natural fecundity and a low expected fertility need avert fewer births to achieve any given level of desired fertility. Consequently, these couples have less incentive to use any contraception, in general, and less incentive to adopt high-fixed-cost techniques, in particular.

Table 5 also indicates the relationship between contraception use and fertility outcomes. While Table 4 shows a frequency distribution of live births by contraception use for two of the cells of white non-Catholic women from Table 3, Table 5 indicates the mean and standard deviation of the live births by contraception use for each of the 5 cells of white non-Catholic women aged 35–44 from Table 3.

Compare the fertility behavior of the "good" and "poor" contraceptors for some given level of schooling in Table 5. In terms of mean fertility, couples which used a "good" contraceptive method (pill, IUD, condom, or diaphragm) in the first birth interval had somewhat lower mean fertility than couples which used relatively "poor" contraceptive methods. As panel B indicates, however, very few of the differences in means are statistically significant. By contrast, the comparison of differences in the standard deviation of the fertility outcomes does exhibit statistical significance: the users of poor contraception have appreciably higher variation in their fertility outcomes than do users of good contraception.[36]

The lack of a stronger association between contraception use and mean fertility in Table 5 is somewhat surprising. However, recall that equation 16 emphasized two opposing forces influencing optimal mean fertility. The marginal costs of fertility control raised optimal mean fertility ($\beta_i k$), although the positive relationship between the mean and variance lowered optimal fertility ($-K/2$) as a mechanism for reducing the uncertainty about the number of births. We showed that couples wishing to avert more births would be induced to adopt better (higher-fixed-cost, lower-marginal-cost) contraceptive techniques. We also suggested that users of better techniques are more likely to use a mixed strategy of contraception, which implies a weaker relationship between the mean and variance of fertility. So users of

[36] Note that in the tests of significance of the variances, the few pair-wise comparisons which were not significant involved the relatively small cells containing 40 or fewer observations.

TABLE 5

Mean Number of Live Births μ_N and Standard Deviation of Number of Live Births σ_N for White Non-Catholic Women by Wife's Education and by the Contraceptive Method (Good, Poor, None) Used in the First Birth Interval, for Women Aged 35–44

A.

Contraceptive Method Used in First Birth Interval		Education of Wife				
		≤8	9–11	12	≥13	Total
Good	μ_N	3.769	3.069	2.784	2.887	2.920
	σ_N	2.065	1.476	1.274	1.076	1.334
	(*n*) [a]	(26)	(72)	(213)	(124)	(435)
Poor	μ_N	3.840	3.800	2.941	2.706	3.185
	σ_N	2.444	2.028	1.515	1.488	1.802
	(*n*)	(25)	(40)	(101)	(34)	(200)
None	μ_N	3.587	3.242	2.577	2.000	2.872
	σ_N	2.817	2.134	1.860	1.854	2.224
	(*n*)	(104)	(120)	(189)	(72)	(485)
Total	μ_N	3.658	3.284	2.738	2.583	2.946
	σ_N	2.635	1.942	1.567	1.472	1.849
	(*n*)	(155)	(232)	(503)	(230)	(1,120)

B.

Tests of Statistical Significance of Differences in Means and Variances in Number of Live Births, for Specific Pairs of Cells

Difference by Contraceptive Method	Education of Wife			
	≤8	9–11	12	≥13
Test of Difference in Means (Student's *t* Test)				
Good vs. poor	0.11	2.03 [c]	0.91	0.67
Poor vs. none	0.45	1.47	1.82 [b]	2.08 [c]
Good vs. none	0.37	0.64	1.20	3.70 [d]
Tests of Difference in Variance (F Test)				
Good vs. poor	1.40	1.88 [c]	1.42 [c]	1.91 [d]
Poor vs. none	1.33	1.11	1.50 [c]	1.56
Good vs. none	1.86 [c]	2.09 [d]	2.14 [d]	2.97 [d]

TABLE 5 (concluded)

Test of Differences in Mean and Variance of Number of Live Births by Wife's Education for Users of Good Contraception Only

	Difference in	
Difference by Wife's Education	Means (t Test)	Variance (F Test)
≤8 vs. 9–11	1.59	1.95 [c]
≤8 vs. 12	2.35 [c]	2.63 [d]
≤8 vs. ≥13	2.12 [c]	3.67 [d]
9–11 vs.12	1.46	1.34 [c]
9–11 vs. ≥13	0.92	1.88 [d]
12 vs. ≥13	0.78	1.40 [c]

[a] n indicates cell size. These figures are in parentheses.
[b] Implies statistical difference at $\alpha = .10$ (two-tailed t test).
[c] Implies statistical difference at $\alpha = .05$ (two-tailed t test).
[d] Implies statistical difference at $\alpha = .01$ (two-tailed t test).

good contraception are expected to have lower marginal costs of fertility control (a lower β_i) and also a weaker relationship between mean and variance (a lower K). Consequently, if wife's education sorts couples by their desired fertility in Table 5, the further partitioning by good or poor contraception may not have a systematic effect on mean fertility. The users of good contraception have lower marginal cost of averting births, but less incentive to reduce mean fertility as a mechanism for lowering the uncertainty or variance of fertility. As the relationships in Tables 3 through 5 indicate, *across* relatively homogeneous groups there is a negative relationship between the use of good contraception and mean fertility, but *within* the homogeneous groups, the use of good contraception systematically affects only the variance of fertility outcomes. Couples wishing to avert relatively more births have greater incentives to use good contraception, and within a group homogeneous with respect to their desired fertility, those who use good contraception achieve a lower variance of fertility.

Table 5 also indicates that there is a tendency for the more educated women to have lower mean fertility and smaller variance of fertility for each contraception category. The differences in the means do not often exhibit statistical significance (see panel B), but the differences in the variances among users of good contraception are statistically significant, often at $\alpha = .01$. The observed relationships between μ_N and σ_N across education groups for good and for poor contraception users separately, mirror the observed relationship between μ_N and σ_N across good and poor contraception users, holding education constant. This observation is quite consistent with more educated couples being more proficient users of each given contraceptive method – the partitioning of the sample of women aged 35–44 by "good" and "poor" (holding education constant) yields the same qualitative differences as the partitioning by more and less education (holding contraception quality constant).

To obtain another measure of the relationships among contraception choice, the wife's education, and fertility outcomes as indicated in Table 5 a multiple regression was run using the twelve education-contraception method cells. Let $\bar{N}_j$ and $\bar{V}_j$ be the mean and standard deviation of live births in cell j, G_j and P_j be dummy variables reflecting the use of good contraception (compared to poor) and poor contraception (compared to none), and E_j be the wife's education level (assigned the values 7, 10, 12, and 14 for the respective columns). The regressions, weighted by the square root of the cell sizes, yielded:

$$\underset{(8.51)}{\bar{N}_j = 5.23} - \underset{(-3.63)}{0.18(E_j)} + \underset{(1.13)}{0.34(G_j)} + \underset{(1.43)}{0.42(P_j)}$$

and

$$\underset{(15.45)}{\bar{V}_j = 3.38} - \underset{(-8.27)}{0.15(E_j)} - \underset{(-3.25)}{0.34(G_j)} - \underset{(-3.03)}{0.31(P_j)}$$ [37]

(Figures in parentheses are t ratios.)

The wife's education has a significant negative effect on both the mean and the standard deviation of the number of live births. Contraception use had no significant effect on the mean number of live births, but users of poor contraception had a significantly lower standard deviation in live births than users of no contraception, and users of good contraception had a significantly lower standard deviation in live births than users of poor contraception.

Table 6 partitions this set of households, the white non-Catholics, by duration of marriage and the expected number of children, for women married only once and aged 35 and above. Since age at marriage differs systematically by several socioeconomic characteristics,

[37] The standard deviations of N_j and V_j were 0.559 and 0.517 and the standard errors of the estimates were 0.359 and 0.127 respectively.

TABLE 6

Mean Number of Live Births μ_N and Variance in Number of Live Births σ_N^2 for White Non-Catholic Women Aged 35 or Above and Married Once; by Marriage Duration, Expected Number of Children and Contraceptive Method (Good, Poor, None) Used in the First Pregnancy Interval

		Estimated Number of Births [a]										
		2	3	Total	2	3	4	Total	2	3	4	Total
		Marriage Duration 15–19 Years			Marriage Duration 20–24 Years				Marriage Duration 25 Years			
Good	μ_N	2.815	3.125	2.907	2.724	2.803	3.455	2.809	2.277	2.842	4.000	2.746
	σ_N^2	1.162	2.042	1.573	1.349	1.661	4.873	1.745	1.596	1.528	4.286	2.138
	(n) [b]	(108)	(88)	(204)	(76)	(61)	(11)	(157)	(47)	(57)	(8)	(114)
Poor	μ_N	3.300	3.095	3.301	2.952	3.000	3.200	2.946	2.864	3.333	4.636	3.383
	σ_N^2	2.537	2.283	2.713	1.948	2.455	3.700	2.326	1.933	3.121	6.655	3.464
	(n) [b]	(20)	(42)	(73)	(21)	(45)	(5)	(74)	(22)	(48)	(11)	(81)
None	μ_N	2.286	3.050	2.640	2.225	3.109	4.333	3.012	1.836	3.106	4.182	3.184
	σ_N^2	2.790	4.368	4.006	3.512	3.087	5.884	4.182	2.991	5.860	7.466	7.001
	(n) [b]	(56)	(101)	(178)	(40)	(92)	(24)	(166)	(55)	(94)	(33)	(201)
Total	μ_N	2.707	3.087	2.866	2.613	2.990	3.950	2.919	2.185	3.085	4.250	3.098
	σ_N^2	1.881	3.079	2.746	2.107	2.497	5.331	2.867	2.380	3.957	6.623	4.914
	(n) [b]	(184)	(231)	(455)	(137)	(198)	(40)	(397)	(124)	(199)	(52)	(396)

[a] Estimated from a fertility demand equation (see text footnote number 38). The cells are defined on intervals: 2 is 1.5 to 2.5; 3 is 2.5 to 3.5; 4 is 3.5 to 4.5. Total includes observations with estimated number of births < 1.5 and > 4.5 as well.
[b] n indicates cell size. These figures are in parentheses.

the partitioning by marriage duration should more adequately standardize for the length of the period of time at risk of conception. To standardize further for the incentives to avert births, we have used a definition of expected number of children derived by regressing the actual number of live births on a set of economic and demographic characteristics.[38] We used this fertility demand function to estimate $\hat{N}$ for each household, then grouped households into cells defined by intervals of $\hat{N}$.[39]

One observes in Table 6 that when the marriage duration and the household's expected fertility $\hat{N}$ are held constant, users of good contraception had smaller variation in their actual fertility than did users of poor or no contraception. Also, standardized for marriage duration and contraception choice, households characterized by $\hat{N}$ equal to three tended to experience a larger variation in actual fertility than households characterized by $\hat{N}$ equal to two. That is, there appears to be a positive association between mean fertility and the standard deviation of fertility. Furthermore, as Figure 7 indicates, the positive relationship between $\hat{N}$ and σ_N appears to be strongest among users of no contraception.[40]

Since more educated women tend to marry at later ages, the total length of time at risk of conception probably differs by education for women of a given age. Table 5 partitions the sample by wife's age and education; for comparison Table 7 partitions the sample by wife's education and marriage duration for women married once and aged 35 and above. Although the cell sizes in Table 7 are smaller and the results somewhat more erratic, one again observes a tendency for users of good contraception to have somewhat lower mean fertility and, more systematically, lower variation in their fertility.

[38] The regression was estimated from the 1965 NFS for white non-Catholic women aged 35 or above. The estimation yielded: $N = 10.09616 - 0.35473\ (MAR1) - 0.00042\ (I) - 0.34462\ (ED) + 0.00003\ (EDXI) + 0.30078\ (URB) + 0.09881\ (MARD) - 0.12119\ (AGE)$, where $MAR1$ equals 1 if married more than once or equals zero otherwise; I is an estimate of the husband's income at age 40 based on an estimated earnings function using husband's education and market experience; ED is the wife's education level; $EDXI$ is a multiplicative interaction term using ED and I; URB equals 1 if the household lives in a rural area or equals zero otherwise; $MARD$ is the duration of the current marriage in years; and AGE is the wife's age.

[39] This procedure partitions the group of households into cells on the basis of the economic and demographic characteristics which, on average, are associated with one, two, three, or four children. For our purposes this procedure suffices, but it does not resolve the problem of partitioning the household's actual fertility into the "desired" and the "unwanted" components.

[40] The figure plots only cells based on 20 or more observations. Unfortunately the cell sizes for the users of poor contraception are quite small, making generalizations difficult.

FIGURE 7

Variance in Live Births by Expected Number of Births by Contraception Method and by Marriage Duration

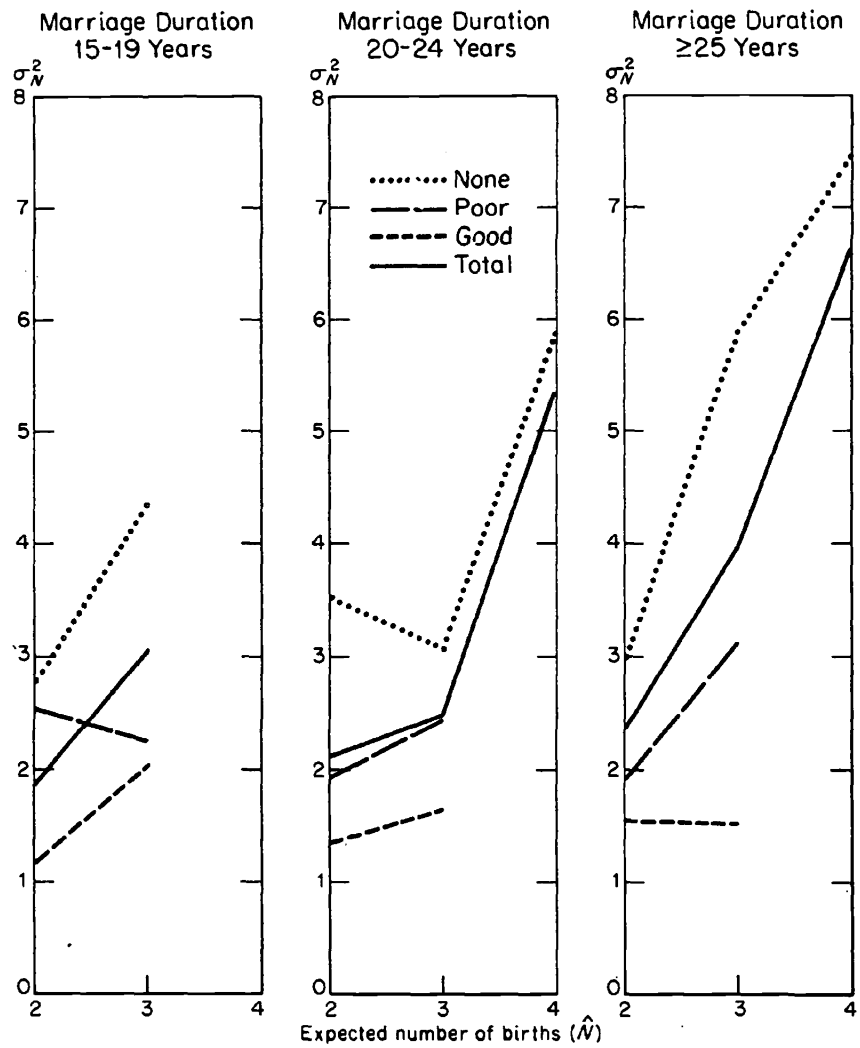


TABLE 7

Mean and Standard Deviation of Live Births and Unwanted Births for White Non-Catholic Women Aged 35 or Above and Married Once, by Marriage Duration, Wife's Education, and Contraceptive Method (Good, Poor, None) Used in the First Pregnancy Interval

A. Marriage Duration 15–19 Years

Contraceptive Method		Education of Wife ≤8	9–11	12	≥13	Total
		Live Births				
Good	μ_N	3.167	3.192	2.766	3.000	2.907
	σ_N	1.722	1.833	1.202	0.984	1.254
	(n) [a]	(6)	(26)	(107)	(65)	(204)
Poor	μ_N	4.182	2.857	3.098	3.429	3.301
	σ_N	1.991	2.410	1.428	1.453	1.647
	(n)	(11)	(7)	(41)	(14)	(73)
None	μ_N	2.708	3.146	2.600	2.061	2.640
	σ_N	2.458	2.056	1.946	1.580	2.001
	(n)	(24)	(41)	(80)	(33)	(178)
Total	μ_N	3.171	3.135	2.768	2.777	2.866
	σ_N	2.290	1.988	1.543	1.327	1.657
	(n)	(41)	(74)	(228)	(112)	(455)
		Unwanted Births [b]				
Good	μ_U	0.167	0.962	0.523	0.431	0.539
	σ_U	0.408	1.587	1.049	0.770	1.052
	(n)	(6)	(26)	(107)	(65)	(204)
Poor	μ_U	2.091	1.714	0.512	0.714	0.904
	σ_U	1.921	2.563	0.952	1.139	1.474
	(n)	(11)	(7)	(41)	(14)	(73)
None	μ_U	0.667	1.268	0.837	0.455	0.843
	σ_U	1.341	2.013	1.354	0.905	1.480
	(n)	(24)	(41)	(80)	(33)	(178)
Total	μ_U	0.976	1.203	0.632	0.473	0.716
	σ_U	1.573	1.916	1.155	0.859	1.311
	(n)	(41)	(74)	(228)	(112)	(455)

TABLE 7 (continued)

B. Marriage Duration 20–24 Years

Contraceptive Method		Education of Wife ≤8	9–11	12	≥13	Total
		Live Births				
Good	μ_N	4.000	2.571	2.784	2.610	2.809
	σ_N	1.961	1.513	1.219	1.115	1.321
	(n) [a]	(14)	(28)	(74)	(41)	(157)
Poor	μ_N	2.000	3.842	2.686	2.917	2.946
	σ_N	0.926	1.642	1.430	1.379	1.525
	(n)	(8)	(19)	(35)	(12)	(74)
None	μ_N	4.114	3.366	2.701	1.609	3.012
	σ_N	2.285	2.009	1.715	1.616	2.045
	(n)	(35)	(41)	(67)	(23)	(166)
Total	μ_N	3.789	3.216	2.733	2.355	2.919
	σ_N	2.169	1.765	1.459	1.402	1.693
	(n)	(57)	(88)	(176)	(76)	(397)
		Unwanted Births [b]				
Good	μ_U	1.571	0.571	0.311	0.171	0.433
	σ_U	1.910	0.920	0.720	0.442	0.942
	(n)	(14)	(28)	(74)	(41)	(157)
Poor	μ_U	0.0	1.211	0.400	0.167	0.527
	σ_U	0.0	1.273	0.604	0.389	0.879
	(n)	(8)	(19)	(35)	(12)	(74)
None	μ_U	1.971	1.561	0.881	0.391	1.211
	σ_N	2.419	1.988	1.332	1.076	1.822
	(n)	(35)	(41)	(67)	(23)	(166)
Total	μ_U	1.596	1.170	0.545	0.237	0.776
	σ_U	2.203	1.613	1.013	0.690	1.419
	(n)	(57)	(88)	(176)	(76)	(397)

(continued)

TABLE 7 (concluded)

C. Marriage Duration ≥ 25 Years

Contraceptive Method		Education of Wife ≤8	9–11	12	≥13	Total
		Live Births				
Good	μ_N	3.688	2.739	2.471	2.708	2.746
	σ_N	1.957	1.789	1.065	1.301	1.462
	(n) [a]	(16)	(23)	(51)	(24)	(114)
Poor	μ_N	4.105	3.400	3.152	2.667	3.383
	σ_N	2.105	2.113	1.523	1.658	1.861
	(n)	(19)	(20)	(33)	(9)	(81)
None	μ_N	4.240	3.580	1.932	1.706	3.184
	σ_N	3.004	2.548	1.680	1.359	2.646
	(n)	(75)	(50)	(59)	(17)	(201)
Total	μ_N	4.136	3.333	2.406	2.360	3.098
	σ_N	2.724	2.295	1.516	1.439	2.217
	(n)	(110)	(93)	(143)	(50)	(396)
		Unwanted Births [b]				
Good	μ_U	1.063	0.435	0.392	0.208	0.456
	σ_U	1.843	0.896	0.666	0.509	0.961
	(n)	(16)	(23)	(51)	(24)	(114)
Poor	μ_U	1.000	0.700	0.879	0.111	0.778
	σ_U	1.291	0.979	1.453	0.333	1.235
	(n)	(19)	(20)	(33)	(9)	(81)
None	μ_U	1.733	1.400	0.644	0.353	1.214
	σ_U	2.658	2.356	1.283	0.702	2.182
	(n)	(75)	(50)	(59)	(17)	(201)
Total	μ_U	1.509	1.011	0.608	0.240	0.907
	σ_U	2.376	1.879	1.157	0.555	1.759
	(n)	(110)	(93)	(143)	(50)	(396)

[a] n indicates cell size. These figures are in parentheses.
[b] For definition see text.

The demographic literature has emphasized a distinction between "wanted" and "unwanted" fertility, and it is tempting to try to partition actual fertility into these two components for separate analysis.[41] The difficulty, of course, is in obtaining an estimate of wanted births distinct from the household's actual fertility. The problem is not simply one of estimation. Viewed in the context of the stochastic model described above, it is not possible, even in principle, to designate each pregnancy as "desired" or "undesired." Also, we have emphasized that the household's optimal number of children is affected by fertility control costs (i.e., $\beta_i k$ in equation 16) and the relation between mean and variance of fertility (i.e., $-K/2$). So the definition of "desired" fertility depends critically upon what is assumed about fertility control costs, the variance in actual fertility, and so on.[42]

Recognizing these limitations, we nevertheless attempted to consider "unwanted" fertility since the NFS data set contains retrospective information on the couple's fertility goals prior to each pregnancy. By summing up the number of pregnancies "wanted"[43] and subtracting this number from the total number of live births, we obtained an estimate of the number of births "unwanted" in each household. Table 7 indicates the mean number of "unwanted" births by marriage dura-

[41] In addition to Ryder and Westoff (1971), see Bumpass and Westoff (1970), Ryder (1973) and Part IV "Unwanted Fertility" of Volume 1 of the Commission on Population Growth (1972), particularly the essay by Ryder and Westoff (1972).

[42] That is, in the terminology of equation 16 one might define unwanted fertility as $\mu_N - N^*$ or $\mu_N - \mu_N^*$. However, since $\sigma_N > 0$, actual fertility N differs in general from μ_N, so "unwanted" fertility presumably includes not only the discrepancy between some fixed target fertility and optimal mean fertility μ_N but also the variation in actual fertility around μ_N.

[43] The NFS data contain retrospective information about the contraceptive behavior and the husband's and wife's attitudes about another pregnancy prior to each of the wife's pregnancies. Following Ryder and Westoff (1971) we considered each live birth as "wanted" or "unwanted" on the basis of the behavioral and attitudinal circumstances prior to that pregnancy. The birth was considered "wanted" if any of the following three conditions was met: (1) The birth was "wanted" if the couple had used no contraception in the interval prior to that pregnancy and responded "yes" to the question "Was the only reason you did not use any method then because you wanted to have a baby as soon as possible?" (2) The birth was "wanted" if the couple had used a contraceptive method in the interval prior to that pregnancy and had "stopped using a method in order to have a child." (3) If the couple was not using contraception but responded "no" to the question quoted above, or if the couple had conceived while using a method or while having stopped using a method but "did not want to become pregnant at that time," then the couple was asked two additional questions. If the response was "yes" to either of these additional questions the birth was considered wanted. The two questions were "Before you became pregnant this time did you want to have a (another) child sometime?" and "Did your husband want to have a (another) child sometime?" Our definition of "wanted" differs slightly from the definition used by Ryder and Westoff.

tion, wife's education, and contraceptive method used in the first pregnancy interval. There appears to be a relatively strong negative relation between the number of "unwanted" births and the wife's education level,[44] and a somewhat systematic relationship between the number of "unwanted" births and the use of good contraception.

We want to stress that the results pertaining to unwanted births are subject to many qualifications and are included here primarily as some evidence that this one measure of the intuitively appealing notion of an unwanted pregnancy seems to be related to contraception use as one would expect. The arbitrariness of the precise definition of an unwanted pregnancy helps convince us that it is more useful in studying the uncertainty related to fertility behavior to focus on the distribution of actual births than to concentrate on partitioning observed fertility into "desired" and "unwanted" fertility. We have shown in this section that across broadly defined groups of households there appears to be a systematic relationship between contraception strategies and the mean and variance of observed fertility. Couples characterized by the use of more effective contraception appear to have somewhat lower mean fertility, lower variance of fertility, a weaker relationship between their mean and variance of fertility, and perhaps a lower level of "unwanted" fertility.

V. DIFFUSION OF THE PILL

The 1965 National Fertility Study and its sequel, the 1970 National Fertility Study, provide a unique opportunity to follow, at the household level, the diffusion of a major technical innovation—the oral contraceptive—from its introduction for sale in the United States in 1960. In addition to the intrinsic interest of studying the diffusion of new technology, the observed pattern of adoption of the pill provides an important test of hypotheses derived from our theory of contraceptive choice (see Section II).

There are two main reasons why the study of pill adoption provides a more powerful test of our model of contraceptive choice than would be afforded by studying differential choices among techniques existing

[44] This finding is consistent with Ryder and Westoff's conclusion that "there is a strong negative association of education and unwanted fertility" (see Ryder and Westoff 1972, p. 483). Their conclusion is also based on the 1965 NFS data and its sequel, the 1970 NFS, which is not yet available to us. It must be stressed however that Ryder and Westoff's definition of "unwanted" pregnancies and their criteria for selection of the subsample studied differ from ours, and one should not make inferences about fertility behavior from comparisons between their tables and ours.

before 1960. First, the introduction of the pill was an exogenous event from the standpoint of potential adopters. Second, the pill is a truly new kind of contraception in comparison with alternative methods available prior to 1960: it is significantly more effective and less coitus-related than alternative methods. This second consideration suggests that the pill has a significantly lower marginal cost of fertility control than other methods, at least in terms of the psychic costs associated with forgone sexual pleasure. Thus, couples were confronted, after 1960, with a significantly different set of potential contraceptive methods to choose from, and we investigate in this section the differential rates of adoption of the pill among women with different initial conditions in 1960 (e.g., marital status, age, parity, and prior contraceptive practices).

We first present a few hypotheses about the expected pattern of diffusion, assuming that contraceptive choice is governed by factors considered in our theoretical model. Next, we utilize data from the 1965 NFS to test these hypotheses and to estimate the probability of pill use as a logistic function of the household's economic characteristics, parity in 1960, and prior use of contraception.

The main behavioral hypothesis underlying our theory of choice of contraceptive technique is that couples choose the least costly technique to achieve a given fertility goal (e.g., a given value of the mean and variance of fertility outcomes). It was shown in Section II (C) that the same technique will not be least costly for all possible goals unless the technique with the smallest marginal cost is also the technique with the lowest fixed cost. This proposition led to the derivation of the contraception cost curve for a "typical" couple in Figure 3 as the envelope of least costly segments of the curve associated with particular contraceptive techniques. According to this analysis, the more births a couple expects to avert, the more likely it is to choose a technique with relatively low marginal cost and high fixed cost.[45]

To derive hypotheses about the adoption of the pill from this theory, we shall assume that for most couples the pill has a lower marginal cost than other contraceptive techniques available in 1960–65. Since it is easy to provide examples of components of marginal cost which are higher for the pill than for alternative techniques (e.g., money cost, side effects on health, and so on), the plausibility of this assumption depends on the further assumption that the major component of

[45] For the time being, we shall ignore risk considerations and argue in terms of variations in expected fertility within an essentially deterministic framework.

the marginal cost of contraception for most people stems from the conflict between effective use of a method and sexual pleasure.[46] The fixed cost of the pill includes the cost of acquiring information about its existence, characteristics, and method of distribution in addition to the money cost of visiting a doctor to obtain a prescription and various psychic costs (e.g., religious principles) which are not related to information acquisition.

We can use Figure 3 (page 47) to illustrate the hypothetical fertility control costs faced by a typical couple. Recall that the line $0F_2$ represents a zero-fixed-cost, high-marginal-cost technique such as withdrawal, and line $\alpha_3 F_3$ represents another technique such as the condom. Suppose that the high-fixed-cost, lower-marginal-cost technique depicted by $\alpha_4 F_4$ represents the costs of the pill at the time of its introduction on the market in 1960.[47]

If Figure 3 depicts the cost conditions faced by a typical couple newly married in 1960, the couple will adopt the pill only if it wishes to avert all of its potential births (i.e., if it wishes to have zero children). If the couple wishes to avert between seven and eleven births (i.e., if it wishes to have one to five children) it will use the condom as its contraceptive method. As the figure is drawn, if the couple wishes to avert fewer than seven births (i.e., if it wishes to have more than five children) withdrawal will be used as its contraceptive method.

The probability P that a couple will adopt the pill is equal to the probability that the total contraception cost of using the pill is less than the total cost of using the least costly alternative technique. This statement may be expressed as:

$$
\begin{aligned}
P &= Pr[F_p < \min (F_i)] \\
&= Pr\{[\alpha_p + \beta_p(\mu_{\hat{N}} - \mu_N)] < \min [\alpha_i + \beta_i(\mu_{\hat{N}} - \mu_N)]\}
\end{aligned}
\qquad (17)
$$

where $F_p = \alpha_p + \beta_p(\mu_{\hat{N}} - \mu_N)$ is the total cost of the pill and $F_i = \alpha_i + \beta_i(\mu_{\hat{N}} - \mu_N)$ is the total cost of the ith alternative method ($i = 1, 2, \ldots$). If all the α's, β's, $\mu_{\hat{N}}$, and μ_N were identical constants for all

[46] The IUD, a close rival of the pill in terms of effectiveness and coitus-related costs, was not widely available until after 1965.

[47] While the line $\alpha_4 F_4$ in the figure has a slope, or marginal cost β_4, of approximately zero, the cost curve for the pill could have been drawn with a positive although relatively low marginal cost.

Also, for simplicity of exposition, we will assume here that these three techniques, withdrawal, condom, and pill, represent the entire envelope cost curve. In our empirical analysis all available techniques are included.

members of the population, P would be either zero or one for everyone, and the pill would be used either universally or not at all.

In fact, of course, these variables will be distributed according to some joint probability distribution across the population so that we should expect to find some fraction, $0 \leq P \leq 1$, for whom the pill is least costly. Moreover, our theory suggests that each of these variables is a function of exogenous variables as well as purely random factors. For example, μ_N is a function of husband's lifetime income and wife's price of time, two variables which help determine the couple's demand for children. Likewise, $\mu_{\hat{N}}$ is a function of the couple's natural fecundability and the wife's age at marriage, and the α's and β's are functions of variables such as religion and education which determine the fixed and variable costs of each contraceptive technique.

These considerations suggest that we may express the aggregate proportion of households using the pill as

$$P = \int_{-\infty}^{\infty} \ldots \int_{-\infty}^{\infty} Pr\,[(F_p - \min (F_i)\,|x_1, \ldots, x_n) < u] \; h(x_1, \ldots, x_n, u)\, dx_1, \ldots, dx_n du \quad (18)$$

where $Pr(\cdot)$ is the probability of using the pill conditional on the values of the exogenous variables $x_1, \ldots, x_n$, which determine natural fertility, the demand for children, and the costs of contraception, and where u is a random variable and $h(x_1, \ldots, x_n, u)$ is a joint density function of the x's and u.

If we assume that u is distributed logistically and is independent of the x's, the conditional probability of using the pill may be expressed as a logistic function of the form

$$P = \{1 + \exp\,[-(a + b_1x_1 + \cdots + b_nx_n + u)]\}^{-1} \quad (19)$$

or, alternatively, the natural log of the odds of using the pill becomes a linear function of the form

$$\ln\left(\frac{P}{1-P}\right) = a + b_1x_1 + \cdots + b_nx_n + u \quad (20)$$

which can be estimated using standard maximum likelihood procedures. After discussing several hypotheses about the set of variables $x_1, x_2, \ldots, x_n$, we estimate the parameters of logistic functions of the form suggested in equation 20.

We shall first consider the pattern of pill use in a static setting in which the distributions of natural fertility $\mu_{\hat{N}}$, the demand for children, μ_N, and the costs of contraception, the α's and β's, are stable in the population. Subsequently, we consider the question of diffusion of the pill over time. For convenience, assume for the moment that all couples in the population face identical cost functions for the three techniques depicted in Figure 3, but differ in their natural fertility or in their demand for children. If couples are then distributed by the number of births they wish to avert, Figure 3 implies that the proportion of couples in the population which adopts the pill will be equal to the proportion wishing to avert 11.5 or more births; the proportion which uses the condom will be equal to the proportion wishing to avert between 7 and 11.5 births, and the proportion using withdrawal will equal the proportion wishing to avert fewer than 7 births. In short, given a distribution of couples by the births they wish to avert, the switching points on the envelope total cost curve determine the proportion of couples using the various available techniques.

We have suggested three sets of factors determining the proportion of couples which might be expected to adopt the pill. We will consider each in turn. Holding constant factors affecting the fertility control total cost curve (the α's and β's) and the demand for children (the μ_N), any factor which increases natural fertility $\mu_{\hat{N}}$ will increase expected births averted ($B = \mu_{\hat{N}} - \mu_N$). Thus for a group of households, an increase in $\mu_{\hat{N}}$ will, ceteris paribus, increase the proportion of households using the pill (and decrease the proportion using withdrawal).[48] The major observable variable related to $\mu_{\hat{N}}$ is the wife's age when the pill became available. So our hypothesis is that, ceteris paribus, the older the wife was in 1960 the less likely she is to adopt the pill.[49]

[48] In the simple three-technique case the effect on condom usage is uncertain, since some who previously used the condom are expected to switch to the pill, while some who previously used withdrawal are expected to switch to the condom. In the more general case of several techniques, an increase in B is expected to increase the proportion using the high-fixed-cost, low-marginal-cost technique, ceteris paribus.

[49] That is, the older she is, the shorter the remaining reproductive time span, so the smaller her remaining natural fertility and thus the smaller her remaining expected averted births. Since she wishes to avert fewer births, ceteris paribus, her incentive to adopt the high-fixed-cost pill is relatively slight.

This hypothesis should be qualified in two respects. First, there may be an advantage to postponing the investment in the fixed cost associated with pill adoption until the benefits of the reduced variable costs associated with pill use are close at hand. If these benefits are greatest when the couple wishes to contracept with high efficiency in order to prevent any additional pregnancy, the adoption of the pill might be postponed until desired fertility is reached. Second, age at marriage is likely to be inversely correlated with the couple's demand for children. So the younger the woman is at a given parity, the more likely she wants to have a large family, which would tend to offset the effect of age on expected births averted, unless desired fertility is explicitly held constant. Thus our inability to hold desired fertility precisely fixed may introduce biases on the other variables.

Alternatively, if we hold constant natural fertility $\mu_{\hat{N}}$ and the fertility control total cost curve, factors which increase the demand for children μ_N reduce the expected averted births B and, therefore reduce the probability of adopting the pill. In studies of completed fertility, the husband's lifetime income, H, and the wife's education, W (as a proxy for her potential lifetime wage or price of time), have been found to be the most important economic variables. Sanderson and Willis (1971) and Willis (1973) argued on theoretical grounds for a positive interaction effect between H and W.[50] Estimating an equation of the form

$$\mu_N = \gamma_0 + \gamma_1 H + \gamma_2 W + \gamma_3 HW \tag{21}$$

in a number of samples of United States women, they found that γ_1 and γ_2 are negative and γ_3 is positive, as expected. If we include these three variables in the equation for P, since we hypothesize a negative relationship between μ_N and P, we expect to observe positive coefficients on H and W and a negative coefficient for HW.[51]

Estimating the effects on pill use of variation in the fixed and marginal costs of the pill and alternative methods of contraception presents a number of difficult problems. These costs are likely to be dominated by psychic or nonmarket components which may vary widely across households but which cannot be measured directly. Certain variables such as Catholicism are known to influence the costs of certain forms of contraception, and it is frequently argued that education reduces the cost of acquiring birth control information (see Michael 1973). Unfortunately, both of these variables also help determine the demand for children and it is not easy to see how this influence can be disentangled from their influence on the cost of contraception.

[50] Briefly, the argument is this. When the wife is not supplying labor to the market, the shadow price of her time is higher than her potential market wage and is an increasing function of her husband's income. When she supplies labor to the market, her price of time is equal to her market wage and is independent of her husband's income. Since children are assumed to be time intensive, the positive income effect of H on the demand for children is offset by a substitution effect against children in families with nonworking wives, while there is no offset in families with working wives. Since the wife's labor force participation is negatively related to H and positively related to W, Willis (1973) shows that the effects of H and W on number of children will be nonlinear with a positive coefficient on the interaction variable, HW. See, however, Ben-Porath (1973) for alternative interpretations of nonlinearity in the demand function for children.

[51] The husband's lifetime income and the wife's education are not, of course, the only variables relevant for the demand curve for children. The demand curve used in the previous section, for example, included several additional variables (see footnote 38) and also pertained to white non-Catholics only. For the analysis of pill adoption in this section, we again restrict ourselves to white non-Catholics.

One advantage of studying the adoption of the pill is the fact that we may study the response to the introduction of the pill by women whose initial conditions differed in 1960. This procedure enables us to study the effect of prior use of other forms of contraception before 1960 on the probability of adopting the pill after 1960. The theory suggests that couples which have incurred the fixed costs associated with some other technique will, ceteris paribus, be less likely to adopt the pill. Hence, we expect prior use of the diaphragm and condom, for example, to be negatively associated with pill adoption.[52] A second aspect of prior use which may influence the probability of adopting the pill is the success the couple has with the previous method. If the couple's previous method has had high marginal costs, our theory suggests that it would be used relatively inefficiently. The couple would have, therefore, a higher risk of an "accidental" pregnancy while using that method. Since the pill has a relatively low marginal cost, the higher the marginal cost of the alternative method, the more likely that the pill will be adopted. Consequently, we expect prior "contraceptive failure" to be positively related to the probability of adopting the pill. This expectation is strengthened by the likelihood that couples which have experienced contraceptive failure confront the prospect of larger losses of expected utility from additional "unwanted" births than do couples who have successfully contracepted in the past.

While we have discussed three separate sets of factors influencing the probability of pill adoption in a static framework, we have not as yet considered the diffusion of the pill over time. A major driving force in any process of diffusion of new technology is the reduction over time of the cost of acquiring information about the new innovation. By the simple act of adopting and using the new technique, early adopters convey information to later adopters about the existence of the technique, how it is distributed, and so on. Since the pill is a prescription

[52] That is, after the fixed costs are borne, the fertility control costs fall from $\alpha_i + \beta_i B$ to simply $\beta_i B$. There are difficulties in this test of the "sunk-cost" hypothesis, however. A woman's prior contraception history is not independent of residual variance caused by variation in the couple's demand for children, fecundability, or costs of contraception which we are unable to hold constant with the other variables in the model. Several potential biases tend to work against the "sunk-cost" hypothesis. For example, subfecundity or sterility, which may be one of the reasons that a woman has not contracepted in the past, would also tend to reduce her probability of adopting the pill. If this bias dominated, we might find that prior users of contraception have a higher rather than a lower probability of using the pill compared with prior nonusers.

drug, its adoption is affected by the diffusion of information among doctors as well as among potential adopters. The dynamics surrounding the cost of information about the pill and the speed and pattern of its diffusion will also be related to socioeconomic differentials in rates of adoption, since this information is spread by word of mouth.[53]

To consider the effect of decreasing information costs of pill adoption, we again make use of Figure 3 (page 47). With the passage of time the fixed cost (which includes the information cost) of the pill for the average household may fall from $0\alpha_4$ to $0\alpha_4'$. Thus the switching point —the number of averted births at which pill adoption is warranted— falls from about 11.5 births averted to about 6 births averted, as the figure is drawn. Obviously, in the aggregate, the reduction in the fixed cost increases the proportion of couples using the pill. Notice that the model implies that the users of the next-best technique will be those who most readily adopt the new technique as its costs of information fall over time. The new low-marginal-cost technique first displaces the existing technique with the lowest marginal cost.[54]

To test the hypotheses advanced above, from the 1965 National Fertility Study we have selected three samples of white non-Catholic women who began their first, second, or third pregnancy interval in the period 1960–64 (see Table 8 for a description of these samples). In each sample we estimate the probability that a woman uses the pill in the specified interval as a function of three sets of variables that determine, respectively, (1) the woman's potential (i.e., natural) fertility from the beginning of the interval until menopause; (2) the couple's demand for children; and (3) the couple's costs of contraception.

[53] Although they are not information costs, a similar mechanism may operate to reduce the costs associated with deviation from group norms as individuals in the group witness increased nonconformity with these norms. In the case of the pill, the interaction between the teachings of the Catholic church and the behavior of individual Catholics might be interpreted along these lines (see Ryder and Westoff 1971, Chapter 8).

[54] Hence, should a new contraceptive technique be introduced which further lowers the marginal cost of contraception, our theory implies that the pill could be the first technique to be displaced. Ryder (1972) shows that by 1970 pill use differentials by education, race, and religion had converged. Much of the convergence, however, was caused by an absolute decline in the use of the pill after 1967 by highly educated white non-Catholics, the group which has the highest rate of pill use. It is interesting to speculate whether new techniques such as the IUD and the increased popularity of the vasectomy and tubal ligation had begun to displace the pill in this group. Ryder emphasizes the effects of fears about long-term adverse health effects of the pill, but these alleged effects were not widely publicized until the U.S. Senate Hearings in 1969, well after the 1967 peak in pill usage in the high-use group.

TABLE 8

Means and Variances of Variables Used in Logistic Estimates of Probability of Pill Use [a]

Variable	First Interval ($N = 495$) [b]		Second Interval ($N = 502$) [b]		Third Interval ($N = 472$) [b]	
	Mean	Variance	Mean	Variance	Mean	Variance
% contracepted in interval	.471	.249	.775	.174	.828	.142
% used pill in interval	.083	.076	.183	.148	.242	.183
% used diaphragm in previous interval	–	–	.080	.073	.153	.129
% used condom in previous interval	–	–	.267	.196	.324	.219
% used pill in previous interval	–	–	.046	.044	.028	.027
% used other method in previous interval	–	–	.173	.143	.269	.197
% had contraceptive failure in previous interval	–	–	.129	.112	.229	.176
Date of beginning of interval (century months)	748.2	297.2	750.1	272.5	750.8	320.8
Wife's age at marriage	20.4	15.5	20.1	9.8	19.9	9.6
Wife's age in 1965	23.6	17.3	25.1	19.4	27.0	23.6
Education of wife	12.1	4.1	12.1	4.3	11.9	4.2
Husband's predicted income at age 40 ($000's)	8.58	2.2	8.56	2.6	8.44	2.7
Interaction (husband's predicted income × wife's education ($000's)	105.9	1,041	106.2	1,196	102.7	1,186

[a] The samples consist of white non-Catholic women married once whose pregnancy interval began in 1960–64. The beginning of the interval is defined as the date of marriage for the first interval, the date of birth of the first child for the second interval, and the date of birth of the second child for the third interval. These dates are stated in "century months." To find the year in which the interval began divide by 12 and add 1900 (e.g., 750 century months equals 1962.5).

[b] N indicates sample size.

These variables, which are listed in Table 8, may be grouped as follows:

Variable	(Expected Effect on *P*)
I. Potential fertility	
Wife's age in 1965	(–)
II. Demand for children	
Wife's education	(+)
Husband's income at age 40	(+)
Income-education interaction	(–)
III. Cost of contraception	
(A) Date interval began	(+)
(B) Used diaphragm in previous interval	(–)
Used condom in previous interval	(–)
Used pill in previous interval	(+)
Used other method in previous interval	(–)
(C) Contraceptive failure in previous interval	(+)
IV. Age at marriage	(+)

The sign accompanying each variable indicates the hypothesized direction of effect of that variable on the probability of using the pill in a particular pregnancy interval. These hypotheses stem from the discussion on the preceding few pages, and most seem to require no further discussion. Note that the "date the interval began" operates as a time trend in this analysis, so it is assumed to be negatively related to the information cost of pill adoption. The prior use of other specific contraceptive techniques is compared with prior nonuse of contraception, hence the fixed costs associated with each technique are expected to deter adoption of the pill.[55]

We have estimated the probability of adopting the pill *P* as a logistic function of the form in equation 20 by a maximum likelihood method.[56]

[55] One might in fact offer hypotheses about the relative magnitudes of these negative effects based on the assumed ranking of the fixed cost components (the α_i) of each. But there may be persistent or serially correlated error terms across intervals, so we have refrained from emphasizing this hypothesis. For example, couples which chose the condom in the previous interval presumably did so for reasons only some of which we have accounted for. Also, each technique has its own set of characteristics which may be related to pill adoption (e.g., the diaphragm is a prescription method, so some of its fixed costs which are related to a medical examination may in fact lower the fixed cost of pill adoption).

[56] The computer program was written by Kenneth Maurer of the Rand Corporation. The advantage of the maximum likelihood estimation procedure is that the data need

The results are indicated in Tables 9 and 10. Two different versions of the pill adoption model are investigated. First, we considered the choice of pill versus all other techniques including no contraception. These results are labeled as pertaining to the "total sample." Second, we considered the conditional choice of pill versus all other techniques, given that some contraceptive technique was used. These results pertain to the sample of "contraceptors." This latter dichotomy is the appropriate one if pill adoption is characterized by the two-stage decision: (1) contracept or not contracept and (2) select a contraceptive technique.

Table 9 indicates the estimates on the total sample for each of the first three pregnancy intervals, excluding the variables which indicate prior contraception use.[57] The time trend (the date interval began) is positive and statistically significant. This conforms with our hypothesis regarding the effects of a decline in information costs over time. The age of the wife has the expected negative sign in only the second interval, while the age at marriage has an unexpected negative effect on the probability of pill adoption.[58]

The effects of the variables related to the demand for children were computed both with and without the income-education interaction term. In all cases, the variables exhibited the expected signs. The relatively stronger effect of husband's income than wife's education, however, is quite surprising. In several studies estimating the effects of these variables on fertility demand, the wife's education has the stronger effect. The introduction of the interaction effect does strengthen the effect of the wife's education in the first and third intervals.[59] In general, the signs and magnitudes of the effects of these three variables tend to support the hypothesis that these variables affect fertility demand and have an effect of opposite sign on the probability of using

not be grouped. Thus, the effects of a relatively large number of independent variables may be estimated from relatively small samples.

[57] The estimates were computed on both the total sample (for the unconditional P) and the sample of contraceptors (for the conditional P). The results were quite similar in the two cases, so only the former are reported here.

[58] We have no explanation for the consistently negative effect of age at marriage. Holding wife's age and current parity constant, a higher age at marriage implies a shorter duration of time from marriage to current parity. Thus, we think age at marriage in these estimates may be positively related to relatively high fecundity, relatively high rates of coital frequency, or relatively low demand for children, but each of these factors implies a positive effect of age at marriage on the probability of pill adoption, ceteris paribus.

[59] The effect of the wife's education W on the probability of pill adoption in, say, the third interval, is $\partial P/\delta W = .084 - .013H$, which is positive at lower values of husband's income and negative at high values of husband's income.

TABLE 9

Estimates of Probability of Pill Use by White Non-Catholic Women in Pregnancy Intervals Beginning in 1960–1964 [a] (total sample; asymptotic t ratio in parentheses)

	First Interval		Second Interval		Third Interval	
	($\bar{p} = .08$)		($\bar{p} = .15$)		($\bar{p} = .24$)	
	(1)	(2)	(1)	(2)	(1)	(2)
Age at marriage	−0.003	−0.005	−0.004	−0.004	−0.028	−0.028
	(−0.77)	(−0.99)	(−0.29)	(−0.29)	(−2.30)	(−2.29)
Age of wife	-	-	−0.023	−0.023	0.001	0.001
			(−2.05)	(−2.04)	(0.13)	(0.21)
Education of wife	0.008	0.090	0.019	0.022	0.015	0.084
	(1.01)	(1.64)	(1.36)	(0.36)	(0.98)	(2.17)
Husband's predicted income ($000's)	0.03	0.14	0.06	0.06	0.03	0.19
	(2.30)	(1.85)	(3.05)	(0.76)	(1.71)	(2.32)
Income-education interaction ($000's)	-	−0.009	-	−0.000	-	−0.013
		(−1.52)		(−0.05)		(−2.01)
Date interval began	0.002	0.002	0.009	0.009	0.007	0.007
	(3.22)	(2.86)	(5.63)	(5.62)	(4.72)	(4.77)

[a] The coefficients reported above the t ratios are analogous to coefficients that would be estimated in a linear probability model of the form $p = a + b_1x_1 + \ldots + b_nx_n$. These are obtained from the β's estimated by maximum likelihood in the logistic function $p = 1/[1 + \exp(\alpha + \beta_1x_1 + \ldots + \beta_nx_n)]$ by the relation $b_j = \frac{\partial p}{\partial x_j} = \bar{p}(1 - \bar{p})\beta_j$ where $\bar{p}$ is the mean proportion using the pill. The asymptotic t ratios, of course, pertain to the β's.

TABLE 10

Estimates of Probability of Pill Use by White Non-Catholic Women in Pregnancy Intervals Beginning in 1960–1964 for Total Sample and for Subsample of Women Who Contracepted during the Interval[a]
(asymptotic t ratios in parentheses)

	Second Interval		Third Interval	
	Total Sample (1)[b]	Contra-ceptors (2)	Total Sample (3)	Contra-ceptors (4)
Age of marriage	−.014	−.017	−.024	−.029
	(−0.95)	(−0.86)	(−1.92)	(−2.00)
Age of wife	−.015	−.014	.004	.004
	(−1.27)	(−0.89)	(0.55)	(0.49)
Education of wife	.017	.027	.137	.154
	(1.15)	(1.29)	(2.07)	(2.07)
Predicted income of husband ($000's)	.050	.041	.190	.206
	(2.6)	(1.66)	(2.23)	(2.14)
Income-education interaction ($000's)	–	–	−.013	−.015
			(−1.94)	(−1.90)
Date interval began	.009	.011	.006	.007
	(5.33)	(5.19)	(4.51)	(4.25)
Used diaphragm in previous interval	−.024	−.077	.076	−.117
	(−0.29)	(−0.75)	(0.94)	(−1.17)
Used condom in previous interval	−.089	−.195	.118	−.082
	(−1.56)	(−2.71)	(1.74)	(−0.96)
Used pill in previous interval	.286	.419	.370	.228
	(3.24)	(2.80)	(2.84)	(1.41)
Used other method in previous interval	−.119	−.223	.102	−.095
	(1.85)	(−2.70)	(1.39)	(−1.04)
Contraceptive failure in previous interval	.142	.198	.138	.153
	(2.27)	(2.54)	(2.69)	(2.62)
$\bar{p}$	.15	.23	.24	.29

[a] See note at bottom of Table 9.
[b] Minimization technique did not coverge after 11 interations.

the pill, given the wife's age, parity, and the time sequence of the pregnancy interval.

Turning to Table 10 the effect of prior use of contraception is added to the estimating equations. The table includes the results for the total sample and for the subsample of contraceptors. The effects of the fertility demand variables, the information cost variable, and the age of the wife and age at marriage variables are only slightly affected by the introduction of the set of prior-use variables, so they will not be discussed again here. The effect of failure in the preceding interval is positive as hypothesized. The effects of prior use of the diaphragm, condom, or other contraception are negative as hypothesized in the subsample of contraceptors, but are seldom statistically significant; the signs are not as hypothesized in the third interval for the total sample. The expected positive effect of prior pill use is quite strong in most cases.

While it is tempting to discuss in detail several of these estimated coefficients, we will not do so here. We think the qualitative results of our study of pill use offer rather strong support for the hypotheses we developed earlier in this section. In addition, the model can help us interpret the observed trend and differential use of the pill since 1960. In the preceding section we showed that the implications about the relationship between distributions of fertility outcomes and contraception behavior are also supported by the observed behavior from the 1965 National Fertility Survey.

APPENDIX

[Appendix tables appear on following pages.]

TABLE A.1
Frequency Distribution of Number of Live Births by Wife's Age, Wife's Education, for White Non-Catholic Women
(per cent)

Wife's Age and Education	Cell Size	Number of Live Births 0	1	2	3	4	5	6	7	8	9	10	11	12
Age 35–39:														
≤ 8	66	10.6	9.1	16.7	18.2	16.7	6.1	7.6	4.5	6.1	1.5	0.0	3.0	0.0
9–11	104	2.9	8.7	25.0	21.2	17.3	13.5	6.7	2.9	1.9	0.0	0.0	0.0	0.0
12	249	8.4	11.2	28.9	25.7	14.1	4.8	4.0	2.4	0.4	0.0	0.0	0.0	0.0
≥13	112	8.0	10.7	28.6	22.3	18.8	8.9	0.9	0.9	0.9	0.0	0.0	0.0	0.0
Total	531	7.5	10.4	26.6	23.2	16.0	7.5	4.3	2.4	1.5	0.2	0.0	0.4	0.0
Age 40–44:														
≤ 8	89	2.2	16.9	25.8	18.0	5.6	9.0	6.7	3.4	6.7	1.1	3.4	0.0	1.1
9–11	128	5.5	13.3	21.1	27.3	12.5	4.7	3.1	7.8	3.1	1.6	0.0	0.0	0.0
12	254	5.1	11.8	31.9	25.6	11.8	7.1	5.1	1.6	0.0	0.0	0.0	0.0	0.0
≥13	118	11.9	8.5	31.4	28.8	13.6	4.2	0.8	0.8	0.0	0.0	0.0	0.0	0.0
Total	589	6.1	12.2	28.5	25.5	11.4	6.3	4.1	3.1	1.7	0.5	0.5	0.0	0.2
Age 45–49:														
≤8	60	8.3	13.3	10.0	15.0	21.7	8.3	11.7	3.3	5.0	0.0	1.7	1.7	0.0
9–11	53	9.4	22.6	28.3	20.8	7.5	5.7	3.8	1.9	0.0	0.0	0.0	0.0	0.0
12	126	7.9	19.8	34.9	16.7	13.5	2.4	1.6	1.6	0.8	0.8	0.0	0.0	0.0
≥13	61	8.2	11.5	29.5	31.1	18.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Total	300	8.3	17.3	27.7	20.0	15.0	3.7	4.0	1.7	1.3	0.3	0.3	0.3	0.0
Age 50–54:														
≤8	61	11.5	14.8	8.2	16.4	16.4	13.1	4.9	8.2	4.9	0.0	1.6	0.0	0.0
9–11	46	6.5	17.4	30.4	21.7	6.5	4.3	8.7	0.0	0.0	0.0	2.2	0.0	2.2
12	80	27.5	15.0	32.5	15.0	3.8	5.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
≥13	45	20.0	31.1	22.2	8.9	11.1	4.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Total	232	17.7	18.5	23.7	15.5	9.1	6.9	3.9	2.2	1.3	0.0	0.9	0.0	0.4

TABLE A.2

Frequency Distribution of Best Contraceptive Method Ever Used by Education for White Non-Catholic Women (per cent)

Method	Education of Wife				
	≤8	9–11	12	≥13	Total
			Wife Aged 35–44		
Pill	3.2	12.1	10.9	13.0	10.5
IUD	0.6	0.4	0.8	1.7	0.9
Condom	31.0	35.8	37.4	37.4	36.2
Diaphragm	2.6	14.6	18.3	27.8	17.3
Withdrawal	8.4	4.7	4.4	1.7	4.5
Jelly	3.2	0.9	1.8	2.2	1.9
Foam	0.0	0.9	0.4	0.9	0.5
Suppository	1.3	0.4	2.0	0.4	1.2
Rhythm	3.9	3.9	5.6	2.6	4.4
Douche	3.9	7.3	4.0	1.3	4.1
Other	0.0	0.0	0.0	0.0	0.0
None	41.9	19.0	14.5	10.9	18.5
(*n*)[a]	(155)	(232)	(503)	(230)	(1,120)
			Wife Aged 45–54		
Pill	0.0	0.0	2.4	6.6	2.2
IUD	0.0	0.0	0.5	0.9	0.4
Condom	24.0	32.3	32.0	35.8	31.0
Diaphragm	5.9	13.1	22.3	24.5	17.3
Withdrawal	9.9	9.1	5.3	5.7	7.1
Jelly	0.8	2.0	4.8	1.9	2.8
Foam	0.0	0.0	0.0	0.0	0.0
Suppository	2.5	2.0	0.5	0.0	1.1
Rhythm	3.3	3.0	3.4	2.8	3.2
Douche	8.3	11.1	1.9	4.7	5.6
Other	0.8	0.0	0.0	0.0	0.2
None	44.6	27.3	26.7	17.0	28.9
(*n*)[a]	(121)	(99)	(206)	(106)	(532)

[a] *n* indicates cell size. These figures are in parentheses.

TABLE A.3

Frequency Distribution of Best Contraceptive Method Ever Used by Education for Nonwhite, Non-Catholic Women (per cent)

Method	Education of Wife ≤8	9–11	12	≥13	Total
Wife Aged 35–44					
Pill	2.4	10.9	3.0	9.4	6.1
IUD	0.0	0.0	0.0	0.0	0.0
Condom	18.5	18.5	25.4	21.9	20.2
Diaphragm	0.8	5.9	13.4	15.6	6.4
Withdrawal	4.0	3.4	6.0	3.1	4.1
Jelly	4.0	4.2	7.5	6.3	5.0
Foam	0.0	1.7	1.5	3.1	1.2
Suppository	1.6	3.4	4.5	0.0	2.6
Rhythm	0.8	0.8	1.5	6.3	1.5
Douche	12.1	8.4	9.0	12.5	10.2
Other	0.0	0.0	0.0	0.0	0.0
None	39.9	42.9	28.4	21.9	42.7
(*n*)[a]	(124)	(119)	(67)	(32)	(342)
Wife Aged 45–54					
Pill	0.0	3.0	0.0	0.0	0.6
IUD	1.0	0.0	0.0	0.0	0.6
Condom	8.2	15.2	10.0	35.3	12.6
Diaphragm	2.1	3.0	15.0	0.0	3.6
Withdrawal	1.0	0.0	0.0	0.0	0.6
Jelly	3.1	3.0	10.0	0.0	3.6
Foam	0.0	3.0	0.0	0.0	0.6
Suppository	0.0	0.0	5.0	0.0	0.6
Rhythm	0.0	3.0	0.0	0.0	0.6
Douche	19.6	21.2	5.0	11.8	17.4
Other	0.0	0.0	0.0	0.0	0.0
None	64.9	48.5	55.0	52.9	59.3
(*n*)[a]	(97)	(33)	(20)	(17)	(167)

[a] *n* indicates cell size. These figures are in parentheses.

TABLE A.4

Frequency Distribution of Best Contraceptive Method Ever Used by Education for White Catholic Women

Method	Education of Wife				
	≤8	9–11	12	≥13	Total
Wife Aged 35–44					
Pill	6.6	10.4	5.5	5.0	6.7
IUD	0.0	0.0	0.5	1.7	0.4
Condom	9.8	25.5	17.4	18.3	18.4
Diaphragm	1.6	5.7	8.3	3.3	6.1
Withdrawal	21.3	11.3	6.9	5.0	9.7
Jelly	3.3	1.9	0.0	3.3	1.3
Foam	0.0	0.9	0.0	1.7	0.4
Suppository	0.0	1.9	1.4	0.0	1.1
Rhythm	13.1	16.0	35.8	38.3	28.3
Douche	6.6	0.9	2.3	1.7	2.5
Other	0.0	0.0	0.0	0.0	0.0
None	37.7	25.5	22.0	21.7	24.9
(*n*)[a]	(61)	(106)	(218)	(60)	(445)
Wife Aged 45–54					
Pill	0.0	0.0	1.6	0.0	0.6
IUD	0.0	0.0	0.0	0.0	0.0
Condom	14.6	17.9	27.9	26.7	21.5
Diaphragm	6.3	5.1	9.8	0.0	6.7
Withdrawal	6.3	15.4	6.6	13.3	9.2
Jelly	2.1	0.0	0.0	6.7	1.2
Foam	0.0	0.0	0.0	0.0	0.0
Suppository	0.0	0.0	0.0	0.0	0.0
Rhythm	10.4	15.4	19.7	13.3	15.3
Douche	10.4	5.1	3.3	0.0	5.5
Other	0.0	0.0	1.6	0.0	0.6
None	50.0	41.0	29.5	40.0	39.3
(*n*)[a]	(48)	(39)	(61)	(15)	(163)

[a] *n* indicates cell size. These figures are in parentheses.

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Comments on "Contraception and Fertility: Household Production under Uncertainty"

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MICHAEL and Willis have written a careful, and sometimes ingenious, paper developing the economic theory of behavior regarding the choice of contraceptive technique, deriving implications from the theory, and putting these implications to the test of consistency with observed experience.

The paper examines intensively one decision among the array of decisions made in households, which are perceived to be engaged in production activity. It is written in a context which has now come to be conventional, and which involves an extension of the theory of the firm to household behavior. According to this convention, households are viewed as being engaged in the production of utility, and this utility is postulated to be maximized subject to some cost constraint. In the abstract form most commonly employed, households produce a basket of two commodities: some quantity of the consumption services of children (which is, itself, a combination of some number of children and some distribution of what has come to be called "quality" embedded in them) and some quantity of the services of goods (which is also a combination of numbers of units of goods and embedded quality). Again, in the commonly employed abstract form, households produce this basket of commodities by employing two inputs in combination: time and goods. From here, familiar principles of equality at the margin and least-costing are applied to define optimizing rules.

Of course, no actual household is presumed to have explicitly run through the optimizing calculus. It is merely that when it is postulated that households do apply those rules, predictive statements can be made about the behavior of aggregates of individuals. Empirical work has revealed that these statements are fruitful in the sense that they are frequently upheld by experience.

Since the application of the theory of the household permits the derivation of implications about the number of children desired, Michael and Willis begin there and develop a theory of fertility control which defines optimizing rules for choosing among alternative contraceptive strategies.

Before explicitly discussing various aspects of their work, I should like to suggest two variants on the conventional literature of the theory of the household which are antecedent to their work.

In the conventional literature, households are assumed to solve the output-combination problem (some quantity of children's services and some quantity of the services of other goods) as though children's services can be produced only by own children. This is, of course, not true. If utility is derived from the presence of children, or from observing them, or from their being the object of one's tenderness, or love, or care, or from forming them physically or morally, then utility can be procured from the children of others as well as from one's own. The instruments for achieving this are myriad. Adoption and foster parenthood are obvious substitutes for own children. But one might also be a schoolteacher, a playground supervisor, a Little League coach, a worker in a day-care center, a pediatrician, a Cub Scout den mother or a scoutmaster, and so on. There are numerous forms of association with children, both in markets and nonmarkets, and, therefore, numerous forms of consumption of children's services. All of these forms of consumption appear, in principle, in the "other goods" category in the conventional "children's services–other goods" dichotomy. However, since these forms of consumption are more perfect substitutes for the children's services of own children than for other kinds of "other goods," it might pay to consider them explicitly in this context.

This is especially true, because, in some respects, the consumption of children's services through the medium of others' children is to be preferred to the consumption of children's services through own children.

Own children are usually kept by their parents, whatever their quality. Criteria for admission can be applied to the children of others. If the child is autistic or hyperactive, too quiet or too noisy, too smart or too dumb, he can be turned away. The preference set of the consumer can govern. It may also govern for the consumer of children's services from own children, but the differences in cost are enormous. Parents will work for years to fashion the child into the form that will give them most pleasure; a scout den mother, shopping among dens, will know in hours whether she has what is, for her, the right set of boys.

In addition, the consumer of the children's services of the children of others has many more degrees of freedom in the allocation of time to this consumption activity than has the consumer of the children's services of own children. To illustrate, consumption may take place during the day but not at night; in winter but not summer; during later years of life but not earlier.

This introduces the second of the two variants previously mentioned. By and large, the conventional literature has treated time—an input in household production—as though it is a homogeneous commodity. Gronau's paper (*Journal of Political Economy,* March/April 1973) discusses the different prices of time for different subsets of the population. What I suggest is that time is nonhomogeneous in another respect: that, for a given population subset (indeed for given individuals and households), different units of time in the daily, yearly, and lifetime cycles have different prices, which are determined by the values of alternative activities in which units of time may be employed.

If different time units do have different values, desired spacing of desired births will be affected.

Thus, the explicit introduction of the two variants will affect desired number of births and the desired time-distribution of births over the whole span of life; it will, therefore, affect the definition of the maximand which strategic fertility control behavior will seek to achieve.

All of this is logically antecedent to the Michael-Willis paper, because while explaining the calculus of optimization which finally yields some desired number of children in an ancillary way, the authors take that number as a datum and proceed from there.

They have written a sensible paper of quite considerable power. Households are confronted by a set of contraceptive strategies among which they may choose. Strategies and households employing them are more or less contraceptively efficient. No strategy and no household is contraceptively certain (except where complete abstention occurs). Each strategy has associated with it a distribution of failures; each has associated with it, therefore, a mean expected number of conceptions and a variance around the mean. Households employing a contraceptive strategy choose among different probability sets of outcomes. Every strategy is costly. Costs have fixed and variable components. The magnitudes of components of cost vary among population subsets. Households choose least-cost strategies for given probable outcomes.

The theory generates behavioral implications which are spelled out, the implications are tested and, generally, the tests do not discredit the implications.

Since, in treating their topic, Michael and Willis have done what I think only a fraction of all economists would do—but what I think any good, bright, well-trained economist should do—my comments may appear to be quibbling.

1. There is some ambiguity in the notion of a "pure strategy." It is formally defined as "the adoption of some form of fertility control which sets [the monthly probability of conception] at some fixed level (during fertile periods) for the entire reproductive span," but it is sometimes used to mean an inflexibly unchanged contraceptive strategy for the entire reproductive span. These are not necessarily the same thing and will not be the same, if, for example, the fecundity of the woman changes over time.

2. People do not talk very much about what they do in bed, so information is defective. Nonetheless, if inferences can properly be drawn from a small sample, the use of a pure strategy in either of these two meanings is not common. This is not to say, given the power of abstraction and the fruitfulness of unreal postulates, that pure strategies should not be assumed to characterize behavior. Indeed, the authors say, where they assume pure strategies, that they do so for analytical convenience. Unfortunately, implications derived from pure strategy models might not be applicable in mixed strategy worlds. Or indeed they might be applicable. Only empirical tests will tell, and thus, the apologia appearing in the text may be superfluous.

3. The notion that the length of the reproductive period at risk is altered by decisions about the age at marriage clouds one's perception of the behavior of the unwed.

4. The paper assumes that the quality of a child is positively related to the quantity of time and market goods devoted to him. Beyond some point, at least, the relationship may be inverse.

5. The existence of fixed costs in adopting a fertility control strategy turns out to have considerable influence upon strategic choice outcomes. Since, at least for some strategies, the fixed cost consists of reading the label on the box, it may be that this cost component is overweighted in the paper.

6. The pill is said to have a low marginal cost associated with its use. This would not be true if women perceive (whether correctly

or not) that adverse side effects will be generated by its ingestion, and that the magnitudes of those effects will be a function of the quantity of pills ingested. Nor is it clear, on the face of it, why the pill is said to be a high-fixed-cost control strategy.

7. Some evidence that the authors believe supports the statement that technique switching does not commonly occur in the United States really seems to suggest something else. They say (p. 54): "90 per cent of women who used some contraceptive technique in the first pregnancy interval (from marriage to first pregnancy) used a contraceptive in the second interval, while only 36 per cent of nonusers in the first interval used a contraceptive in the second interval." This seems only to say that the first set of women, having applied optimizing rules the first time around, having sought to avoid conception and having failed, now, in the second interval, applying the same rules and coming to the same strategic outcome, still seek to avoid conception. The second set of women, applying the same optimizing rules and given the parameters of their experience, seek to conceive in the first interval and, having succeeded, seek to conceive in the second interval as well. The evidence does not seem to support a conclusion of no switching.

8. It is not clear whether a household will choose the pill as its contraceptive strategy if it is very important to it that its uncertainty be diminished, or whether it will do so if it is very important to it that the number of conceptions be diminished.

9. The authors explain differences in adoption rates of the pill by women of different age classes at the time the pill first became available (lower rates by older women and higher rates by younger women) by differences among them in payoff periods for investment in the fixed costs of adopting the technique. It would be useful here to take account of different strengths of preferences for avoiding conception among women of different ages.