Measuring the effect of family planning programs on fertility, edited by C. Chandrasekaran and Albert I. Hermalin. Organization for Economic Development Center, and International Union for the Scientific Study of Population. Ordina Edition, Dolhain, 1975.

Chapter 6
BIRTHS AVERTED

by
David Wolfers

I. INTRODUCTION

The term "births averted" has been employed by different authors to describe several different approaches to the measurement of the demographic impact of contraceptive programs. This chapter is confined to the relatively narrow field of estimation of the births averted from cohorts of acceptors of birth control by a single "segment" of use, defined as follows:

> "The estimation of births averted is a measure of the quantitative change in the expectations, assessed in terms of probabilities, of future births to a cohort of women resulting from the adoption or modification of birth control practice by them or their husbands."

It is important to distinguish these estimates from others which compare the future fertility of acceptors with that of non-acceptors. In these the contraceptive strategy of acceptors *after* termination of a segment of use is incorporated into the calculations. While estimates of births averted as defined may play a part in predicting or accounting for changes in fertility indices over time (period approach) or in establishing the temporal fluctuations caused by isolated bursts of contraceptive activity, they are not specifically addressed to these problems.

This method of quantifying the demographic significance of contraceptive use has proved useful in exercises to determine cost/benefit of family planning programs which employ the economic cost (or benefit) of marginal births as a measure of the value of demographic change. Estimates of births averted also provide convenient indices for the comparison of different program strategies, different birth control methods and different age-mixes of acceptors. In addition, they have a place in the process of "target-setting" (See Chapter 2 and Chandrasekaran *et al.*, 1971) and in providing a necessary demonstration of the way in which program performance leads to demographic changes.

While brief reference is made to the calculation of births averted by abortion and sterilization, the problem chiefly considered is births averted by the use of contraceptive methods for which continuation is suited to analysis by life-table methods: mainly the IUD, but also oral contraceptives. As pointed out by Chandrasekaran and Karkal (1972), there are serious difficulties in handling the use of conventional contraceptives in this way.

The principal published approaches to calculating births averted (as defined) are described and discussed in detail in section IV and an attempt to reconcile them is made in section V. Earlier sections (II and III) examine the materials used in constructing these model solutions, first from the theoretical point of view of their justification and the considerations which dictate the ways in which they must be handled; second, in relation to the types and sources of data required and to the analytic or synthetic procedures applied to the data.

Among the important and to some extent controversial factors which must be brought together to construct a realistic model is the potential fertility of acceptors against which their reduced fertility after acceptance must be weighed. Its estimation requires the introduction of a considerable number of parameters, including the age-specific fertility performance of the population at the time of measurement, ways in which acceptors may be expected to differ in their fertility potential from otherwise similar groups of women, the extent to which acceptance is merely the substitution of a program for a non-program method, the incidence and prevalence of sterility amongst acceptors and, where possible, expected spontaneous change in fertility levels not attributable to programs. Pregnancy rates during contraceptive use, live-birth ratios, overlapping between contraceptive use and post-partum anovularity, duration of use of contraceptives, mortality, widowhood and divorce are other factors to be considered.

Where simulation models are used for estimating births averted, the substitution of fecundability estimates for potential fertility simplifies many of the problems involved, but the derivation of these estimates raises its own problems.

II. CONCEPTS

THE UNIT OF CONTRACEPTIVE USE

The unit of contraceptive use is one month's contraception by one couple.

A SEGMENT OF CONTRACEPTIVE USE

A segment of contraceptive use is an uninterrupted sequence of months of use of the same method by the same couple. Segments commence at adoption and terminate at abandonment, expulsion (for IUDs), exhaustion of supplies, pregnancy or death, whichever is soonest.

THE DEMOGRAPHIC EFFECT OF A UNIT OF CONTRACEPTIVE USE

The demographic effect of a unit of contraceptive use is to reduce, usually substantially, the probability of conception occurring

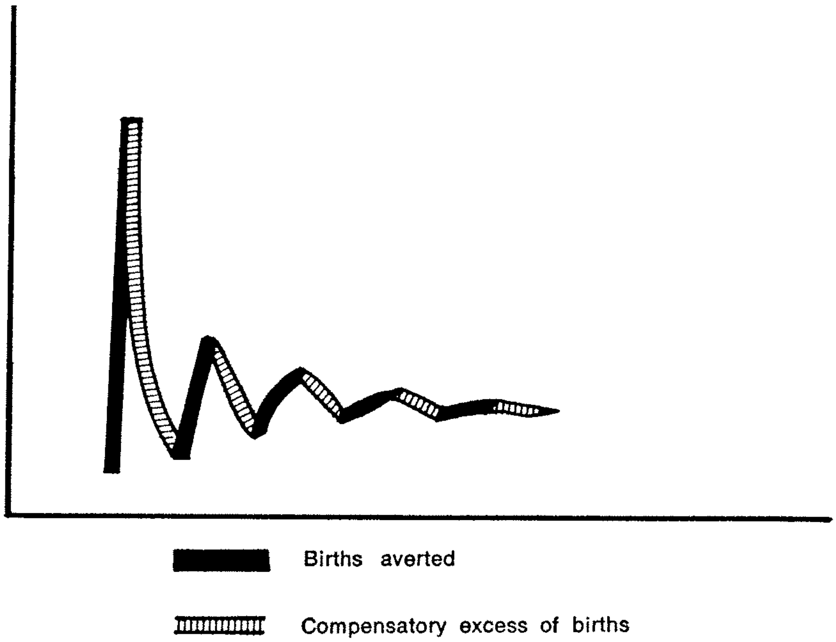

Fig. 6.1. *Timing of births averted by one unit (month) of contraceptive use.*

during that month and hence of a birth taking place seven to ten (usually nine) months later and to alter, in progressively diminishing degree, the probabilities of conception in all subsequent months of reproductive life. The birth-averting (or birth-preventing) value of a unit of contraceptive use is the arithmetic sum of all these changes in probability. Some of the changes are positive, representing an increased probability of conception in that month, others are negative. The sum, except in the case of a less efficient contraceptive being substituted for a more efficient one, will always be either zero or negative, confirming that contraceptive use operates to reduce the total probability of births, i.e., it averts births. Figure 6.1 shows these changes in monthly probabilities for a unit of contraceptive use of a one hundred per cent effective contraceptive by a woman in the fecundable state during the month of use.

BIRTHS AVERTED BY A SEGMENT OF USE

The birth-averting effect of a segment of use is the arithmetic sum of the effects of each month of use comprising the segment.

A "REPRODUCTIVE UNIT" OF TIME

A reproductive unit of time is the average interval between successive recurrences of the same stage of a woman's reproductive cycle, i.e., the interval between conception and conception, delivery and delivery or resumption of post-partum fecundity between one birth and the next. The reproductive unit is applicable only to women who retain the capacity to reproduce (i.e. are non-sterile) throughout its duration. It corresponds to the expected prospective birth interval and is strongly age-specific. The length of the reproductive unit may be simulated for groups of women by the use of the monthly probability of conception (fecundability), post-partum anovularity, pregnancy duration, foetal wastage and monthly probabilities of conversion from a non-sterile to a sterile state.

THE "DURATION PER BIRTH"

The duration per birth is only subtly distinguishable from the reproductive unit of time. This period includes in its calculation the contribution of women who, while non-sterile at the beginning of an interval, nevertheless do not conceive again before becoming sterile. It is equivalent therefore to the average contribution from their total reproductive lives which is required from women for each pregnancy.

The period is always longer than the reproductive unit of time and the prospective birth interval, and towards the end of the reproductive life it is very much longer.

RELATION BETWEEN DURATION PER BIRTH, SEGMENT OF USE AND BIRTHS AVERTED

It can be shown that the use of effective contraception commencing in the fecundable state for a segment of use equal to a woman's duration per birth averts exactly one birth from the total expected by her, and its use for a given proportion of the duration per birth has that proportionate probability of averting a birth. The computation of births averted from a cohort of women by a number of segments of contraceptive use therefore consists of the expression of this use in terms of corresponding durations of births which it comprises, with appropriate corrections for inadequacy of the contraceptive and periods of use by women not in the fecundable state. The most important theoretical problem in the estimation of births averted is the accurate computation of appropriate durations per birth for cohorts of acceptors.

CHARACTERISTICS OF METHOD AND USERS

The quantitative value of the probability changes induced by contraceptive use is importantly influenced by a number of characteristics of the method and the client.

1. *THE EFFECTIVENESS OF THE METHOD*, as measured by proportionate reduction in probability of pregnancy in one month of use by a woman exposed to the risk of pregnancy, is usually a function of:

a) the method itself;
b) the length of time it has been used by the individual client;
c) age and parity of the client (Zatuchni, 1970: 297 and 329);
d) physical and social characteristics of the client.

Certain methods (abortion and sterilization), however, are virtually immune to the influence of *b*), *c*) and *d*).

2. *THE PHYSIOLOGICAL STATE OF THE WOMAN DURING THE MONTH OF USE.* A woman of reproductive age may at any time be in any one of the following states:

(i) Fecundable - Having a greater than zero probability of conception, dependent on frequency of intercourse, quality of mate's sperm, timing of intercourse, chance factors, etc.

(ii) Temporarily infecundable - With no probability of conception for reasons which are spontaneously reversible, for example, anovulatory cycle, absence of spouse.

(iii) In a state of post-pregnancy anovulatory immunity [an important subgroup of (ii)].

(iv) Temporarily sterile - With no probability of conception, for pathological, but reversible, reasons, or husband sterile.

(v) Permanently sterile - With no probability of conception, either for non-reversible pathological reasons, for example surgical intervention, or because of termination of the capacity to conceive as a result of the passage of time.

(vi) Pregnant.

The use of contraception by a woman in any but the first state will have zero effect on the probability of future births or conceptions.

The problem of determining the state of any individual woman during any individual month of contraceptive use is not susceptible to practical solution. For cohorts of women, however, estimates of the numbers at any one time in states (iii), (v) and (vi) can be derived, while the proportions in any one month in states (i), (ii) and (iv) can be subsumed within general estimates of conception probabilities.

Married women, women who have never been delivered of a live birth, women at the time of acceptance of contraception and users of contraceptives form four identifiable groups amongst whom the distribution of these six states is different.

3. *THE AGE OF A WOMAN* is strongly correlated with the monthly probability of her having a conception leading to a live birth. A number of mechanisms are involved:

a) There appears to be an age-related fecundity curve—defined as the probability of conception under standard conditions—which rises steeply to a maximum from menarche to late teens, flattens in the early twenties and declines continuously thereafter.

b) As a general rule, frequency of intercourse declines progressively with increasing age, particularly for men. In stable unions this decline will, of course, be parallel for women. The effect of reduced frequency of intercourse within limits is to reduce fecundability or the real monthly probability of conception.

c) The mean duration of post-partum infecundity for groups of women shows a progressive increase with age (Potter, 1963).

d) Foetal wastage rates increase with age of the expectant mother.

e) The incidence of pathological permanent sterility and presumed physiological permanent sterility are cumulative and accelerative so that at each age a larger proportion of women is in those states than at younger ages, and during each month of consecutive contraceptive use, higher proportions of older women become permanently sterile than of younger women.

f) The proportion of women already using contraception or otherwise ensuring or attempting to ensure that they will bear children only at will is found to vary with age.

g) The effectiveness of contraceptive methods, whether dependent on or independent of the diligence with which they are used, has been found to vary with age [see (1) above].

4. *SUBSTITUTION.* This term is used to describe the situation where the adoption of contraception in the program context replaces the use of other methods of birth control outside the program. What we might term a second derivative of substitution is the adoption of contraception inside the program by people who would have adopted contraception outside the program if the program had not existed.

Neither of these two forms of substitution can be accurately measured. At any given time a population of acceptors can be divided, with reasonable accuracy, into three categories—past users, present users and never users. A uniform finding of studies of family planning acceptors, against the background of the population of married women of reproductive age, is that previous contraceptive use predisposes to acceptance, although a large part of this effect is attributable to the generally higher parity of previous contraceptive users and the strong positive correlation between parity and acceptance of program contraceptives (Wolfers, 1970a: 62). To establish that a woman was using a non-program method of contraception up to the time of acceptance, or, still less, at some time before acceptance, is not, however, to establish that she would have continued to use it either for any time, or for as long a time as she uses the program method, had she not become an acceptor. The proportion of ever-users who are also current users of contraception has been found to vary greatly, both between and within countries. Thus amongst Ecuadorian women interviewed in 1971, S. Scrimshaw (1973: 175) found that past experience of contraception was reported by 44.5 per cent of the female population and current experience by only 26.5 per cent; for men the respective figures were 62.5 and 26.4 per cent. The West Malaysian Family Survey (National Family Planning Board, 1968) revealed that in rural areas only half of the 6 per cent of women who had ever used contraception were current users. In the towns, where practice was much more common (40 per cent for large towns and 28 per cent for small ones), current users amounted to 75 per cent of ever-users. In Singapore, 72 per cent of acceptors in 1963 were still (or again) using contraceptives in 1967, 88.5 per cent of them obtaining supplies from the sources provided by the government program which began in 1966 (D. and H. Wolfers, 1968). On the other hand, as Freedman and Takeshita (1969: 304) have demonstrated for Taiwan and Wolfers (1970a: 111) for Singapore, discontinuers from within a program are very likely to continue to use birth control, either by different methods within the program, or by methods from outside it.

These figures demonstrate that the past or current use of contraception is no reliable guide to future practice and that the appearance of substitution may be very misleading. Before the introduction of oral contraceptives and IUDs, the discontinuation rates of conventional contraceptives, particularly in developing countries, were very high indeed. Mean periods of use of diaphragm, foam and condom respectively in the Singapore clinic referred to were 4.0, 6.5 and 9.5 months.

It is therefore almost a safer hypothesis that when a current contraceptor changes to a program method, she was on the point of abandoning the old one than that she would have continued to use it. The quantification of this and the more conditional second derivative of substitution remains an effort of judgement rather than a result of factual knowledge. Over-elaborate attempts at quantifying substitution effects serve only to lend spurious verisimilitude to births-averted calculations without adding to their realism.

5. *SOCIAL VARIABLES.* Although they take effect through intermediate variables, the influence of certain social variables on the birth-preventing value of contraceptive use is sufficiently consistent and important to warrant their consideration as a separate phenomenon. The significant variables include ethnic group, education and social class. In different categories under these headings are likely to be found differences in:

a) effectiveness of contraceptive practice;

b) persistence or continuation of use;

c) previous contraceptive practice and hence weight of substitution factors;

d) age-distribution of acceptors;
e) baseline fertility values.

POTENTIAL FERTILITY

As the unit of contraceptive use has the dimension of time—one month—it is helpful in non-simulation exercises to express fertility parameters in the same dimension. While the normal fertility measures are calculated as births per unit of time, it is conceptually more correct for calculations of births averted that these be inverted to become time per birth. To achieve this, Potter (1969a) has devised a measure termed "duration per birth" (see above), Lee and Isbister have accepted a direct inverse relationship between age-specific marital fertility rates (ASMFRs) and birth intervals, while Wolfers (1969) has worked directly with observed birth interval data.

The actual relationship between fertility measures expressed in births per unit of time and units of time per birth is far more complex than at first appears. Louis Henry (1961) appears to have made the first statement on the subject:

> "Le taux de fécondité des couples fertiles est à peu près égal à l'inverse de la moyenne des intervalles dont le début ou la fin ou les deux tombent dans le groupe d'âges considéré. . . ."
> [The fertility rate of fecund couples is as a close approximation equal to the reciprocal of the mean of those (live-birth) intervals of which the beginning, the end or both fall in the age-group considered. . . .]

This statement has been occasionally misread (e.g. Lee and Isbister, 1966: 746) as implying that the average birth interval "is given by the inverse of the fertility rate", while in reality it does not reveal any usable relationship between the two quantities except under unrealistic conditions (Potter, 1970). Henry speaks of the "fertility rate of fecund couples" which is a non-measurable abstract concept. Fertility rates can be calculated for all sorts of selected groups, but not for fecund couples specifically, for these cannot be identified. In addition, the group of birth intervals described, commencing or terminating within a certain age-group, does not correspond to the measure of future potential fertility required for birth-averted calculations where only future (or prospective) intervals, i.e., those commencing at the specified age, are relevant.

The baseline fertility characteristic, duration per birth, will be taken or derived from some known fertility parameter(s) of the population to which the cohort belongs. The selection of baseline potential fertility is, of course, crucial to the realism of the quantitative results of a model, but the controversy over how this should be done is far from being resolved. Among the problems besetting this area are:

(1) *GENERAL*

a) Differential fecundity. As a generalization, women adopting contraceptives have more children for age and duration of union than all women with otherwise similar characteristics. This suggests, but does not establish, that they have a higher than average potential fertility.

b) Substitution. Women who have previously used contraceptive methods, abortion or abstinence are over-represented amongst acceptors of contraceptive programs. These women can properly be assumed to have a lower than average potential fertility. Likewise, acceptors may be assumed to include a disproportionately large number of women shortly due to engage in birth-limiting practices, even without the program's facilities.

c) Trend. In rapidly moving social panoramas, spontaneous changes in fertility behaviour are common. Attempts to give validity to assessments of the achievements of a program involve making allowance for pre-evident trends in fertility values. It cannot be assumed, without running the risk of performing a mere abstract mathematical exercise, that baseline fertility values derived for an initial year will remain applicable for future years.

(2) *FERTILITY RATES*

a) *Alignment.* At the time of adopting contraception, women are not mixed in physiological states in the same way as the general population who form the denominator for the ASMFRs, but are highly selected for being either fecundable or in a state of post-partum anovularity. The proportion of contraceptors who are permanently sterile and those who are pregnant will be very much smaller than in the population at large.

b) *Parity.* Nulliparous women do not form part of contracepting populations in developing countries, but the contribution of first births to ASMFRs at early ages is quantitatively important. The mathematical relationship between age-specific marital fertility rates and "duration per birth" is modified in a major way by the proportions of first births contributing to the fertility rates (Wolfers, 1973).

(3) *BIRTH INTERVALS*

Truncation effect. Average prospective birth intervals become shorter at older ages because potentially longer intervals are not realizable due to the intervention of permanent sterility. The use of birth intervals therefore exaggerates potential fertility in older age groups.

(4) *COMPUTER SIMULATION MODELS*

Derivation. Where fecundability values are employed to measure baseline fertility, these are, by nature of the quantity, secondary deductions from other fertility data. They are derived by fitting to the known fertility schedules of a population sets of parameters for fecundability, post-partum anovularity, sterility, widowhood etc., which when fed into a computer model will closely duplicate the fertility schedules. For any fertility schedule, there is an unlimited number of solutions, so that the fecundability estimates are in some degree arbitrary. Where hard data can be derived for some parameters —post-partum anovularity or foetal wastage for example—the range of realistic values available for fecundability shrinks and more confidence can be placed in the deductions from such systems (see Venkatacharya, 1971b). The questions of how much heterogeneity of fecundability and anovularity to introduce into these models are also important, but require arbitrary solutions.

STERILITY

Our knowledge of the way in which permanent sterility intervenes to terminate the reproductive life is very incomplete. Only three items of secure knowledge exist:

a) a small proportion of women in all societies are primarily sterile—i.e., do not, despite active sexual lives, produce children;

b) there is a risk of the development of sterility at every age of child-bearing life and, because of the permanence of sterility, the proportion sterile is cumulative with age;

c) the risk of development of sterility increases with age, so that the rate of change of proportions sterile accelerates throughout the child-bearing ages, becoming steep at ages over 40 and reaching 100 per cent sterile at about age 52.

Questions which have still to be answered include:

(i) What are the parameters of the incidence and prevalence of sterility in specific communities and what are the factors (for example, ethnic, geographic/climatic, dietary, demographic, social, morbid) which determine them?

(ii) Does childbirth itself engender a significant additional risk of sterility?

(iii) Does pregnancy provide a period of immunity from the risk of sterility?

(iv) Does induced abortion heighten the risk of the development of sterility and if so, how much of this is dependent on the way the abortion is performed?

The direct measurement of sterility is not at present possible, there being no diagnostic criteria to distinguish the fecund from the sterile in the absence of specific pathological states.

Barrett (1971) has shown that truncation effects are present in the case of sterility measurements whether derived by analysis of proportions of marriages childless by age at marriage, or by analysis of age at last child birth. The effect of these is always to overestimate the proportions sterile.

The importance of sterility to calculations of births averted lies in the self-evident fact that contraceptive use by sterile women has no birth-averting effect. Women who believe they are sterile do not adopt contraception, but this is by no means the same proposition as saying that women who are sterile do not adopt contraception. Women who adopt contraception usually lose the capacity to form an opinion of whether or not they have become sterile.

TIMING

One problem in the analysis of births averted which has either been neglected or inadequately treated in early studies is the time element in averted births. In the models of Potter and Wolfers, while a net value has been placed on the births averted, no indication is available of the fluctuations in numbers of births to be expected in a community as a function of elapsed time. This is indeed a thorny problem. 1,000 units of use of a 100 per cent effective contraceptive in 1,000 fecund women for the month of January will prevent a number of births (say between 100 and 200) which would have taken place in or around October. If contraceptive use stops there, secondary effects will be that those women who would have given birth in October will now have the possibility, generated by their contraceptive use, of giving birth at a later date. The 100-200 missing births in October will be compensated for by approximately the same number of additional births spread over the ensuing months. The deferment of these births will lead as a natural consequence to the deferment of the next births to the women concerned and hence to a reduction of births at a later period, followed again by a compensatory excess (see Figure 6.1). While neat theoretical probability models can be used to demonstrate that this oscillation will persist to the end of the reproductive lives of the women involved, in practice the multiple irregularities ensure that these damp down within at most two or three birth intervals (Barrett, 1972).

While the task of determining the timing of averted births attributable to a single unit of contraceptive practice, when solved, does not yield useful information, the more realistic problem of timing births prevented from aggregates forming a continuum of contraceptive use is at once of more practical value and easier to analyse.

K. Venkatacharya (1971a, 1972) has devised matrices indicating the annual probabilities of births to women coming under observation in susceptible (fecundable) states at different ages, which can be derived from age-specific marital fertility rates. These tables can be used to establish the timing of births prevented by sterilizations and, with a little more labor, those averted by contraceptive use of limited duration. Although the actual model used by Venkatacharya employs a number of simplifying assumptions which detract from its value as a tool for quantifying births averted, the distribution of these over time appears to emerge with reasonable precision.

An alternative solution to the timing of births averted lies in direct computer simulation by means of Monte Carlo type models from which the annual, or even the monthly, birth fluctuations induced by any specified birth control strategy can be obtained. This suggestion, together with an explicit consideration of problems of timing, is found in Chandrasekaran *et al.* (1971).

MEAN PERIOD OF USE

Data may be handled in one of two ways, either by the computation of a single value—the mean period of use (perhaps using several different sub-groups of acceptors)—or by making month-by-month calculations employing continuers in each month as the population of contraceptive users.

The former method, while mathematically neater, introduces an additional approximation into the calculation, the mean fertility of users being taken as the fertility of women at the mean age during use.(1) It also carries a heavy temptation to assume regular decay-

(1) The approximation will be valid provided either that:

(i) The change in fertility potential with age for the age-range of users is trivial (which will apply if mean duration of use is relatively short and range small, or if the middle age-range of reproduction only is involved).

or

(ii) The change in fertility potential with age follows a parallel path to the decay curve of contraceptive use (e.g. if both are exponential).

curves of continuation which may or may not correspond closely to reality (see section III.6).

In the case of sterilizations, the computation of mean periods of use (from operation to death, widowhood, separation or sterility, whichever is soonest) to derive mean age during use (for specific age-groups at operation) and hence a mean fertility, would lead to serious inaccuracy.

LONG-TERM AND INDIRECT EFFECTS

Some birth-averted calculations, used as justification for proposed programs, project births averted by a suggested continuing strategy into the long-term future—20 or 30 years. We would suggest that no trace of reality clings to such projections for the dimensions of substitution and trend in demographic indices must get entirely out of hand when looked at with such a perspective. This problem also casts a shadow over summary calculations of births averted by sterilization.

SECOND-GENERATION EFFECTS. The prevention of births which would otherwise have taken place reduces the number of potential parents in the next generation, and hence may be presumed to generate additional births averted some 20 years later. Indeed, carried to its illogical extreme, provided the net reproduction rate is greater than 1, any birth prevented generates an infinity of births prevented into the future. Happily not much effort has been spent on the numerical assessment of second and later generation effects, for this is not a field that lends itself to profitable exploitation. It is necessary in making such calculations to assume parameters for the fertility of the population 20 and more years into the future and, as the wreck of innumerable attempts at demographic prediction show, it is not possible to do this with any useful degree of accuracy.

Potter (1972a) has done some work on intergenerational effects, but not with any view to practical evaluation of programs.

III. DATA: METHODS OF HANDLING, SOURCES AND LIMITATIONS

FERTILITY

The problem of determining the fertility expectation of a group of acceptors, and expressing it as duration per birth, still has no agreed solution. Potter (1969a) has summed up the first part of the problem: "acceptors ... are doubly selected, having higher fecundity than average for their age class and partly for that reason also higher than average interest and initiative with respect to family planning". The second point relates to the unquantifiable second derivative of substitution [see above, section II.8(4)], while the first is very controversial.

Numerous writers, for example Ross (1965), Potter *et al.* (1968), Rele and Patankar (1969) and Jain (1969), have found that family planning acceptors have higher than national fertility rates or parity for age schedules. This is a fully expected finding, given that micro-demographic pressures play a prominent part in motivation to acceptance. It does not, however, follow that a group identified *post facto* as having higher than average past fertility also has higher than average current fertility nor if it has, is it clear to what extent its higher fertility is a result of higher fecundity and to what extent the result of non-systematic variability. As Ridley *et al.* (1969) have demonstrated with their computer simulation model, "Repsim", any plausible model of acceptance behaviour will lead to the development of substantial fertility differences between acceptors and non-acceptors even when they are given identical values for all probability parameters of reproduction. Brass (1970) has demonstrated in computer simulations with heterogeneous fecundability that the chance element heavily outweighs the systematic, especially for short marriage duration.

A large measure of the genuinely higher fertility expectation of acceptors derives from the exclusion from their ranks of women who assume themselves to be sterile. The longer the elapsed time since the last childbirth, the lower the probability that a woman will accept contraception. In the pioneer study of births averted, Lee and Isbister (1966) assumed a 20 per cent higher fertility of acceptors than for the general population, basing their figure on observations made in Taichung. The actual differential (between recent past fertility of acceptors and population marital fertility rates) was highly age-specific, ranging from 15 per cent at ages 25-29 to 64 per cent at ages 35-39 (Ross, 1965). At yet higher ages, as sterility becomes a majority phenomenon, very high values are reached. Later figures from Taiwan show differences soaring to 275 per cent at ages 40-44 (Chow, 1968). These differentials are very different at different ages, and their significance also changes with age. At young ages sterility contributes a minor part of the difference, its bulk flowing from differential fecundity and random variation. At high ages, sterility becomes overwhelmingly the most important factor. It is not feasible to disregard such differences, nor to ignore their age-specificity. One way of coping with the situation is that employed by Potter (1969a) which employs the reciprocal of the recent past age-specific fertility rates of acceptors only as the basis of computation. Not only is this method heavily demanding in terms of accurate data (readily available in Taiwan, but not in many other places) but it incorporates a bias towards the inclusion of women with high fertility performance as a random expression of normal fecundity leading to overestimation of potential fertility. Another way of separating fertile from infertile women and including only the experience of the former is Wolfers' (1969) use of birth intervals as a measure of future performance, also heavily data-dependent and subject to the bias introduced by truncation of birth-intervals at later ages.

Methods for elimination of these biases have been proposed recently by Wolfers (1973). The first of these involves the processing of age-specific marital fertility rates (from total populations) by a formula which is designed to eliminate the contribution of sterile women from the rate and to compensate for the proportion of first births:

$$D_j = \frac{36{,}000\,(1 - S_j)}{B_{j+2}\,(3 - N_{j+2})} \qquad (1)$$

where

D_j is duration per birth, in months, for women aged j years;
S_j is the proportion of women aged j who are sterile;
B_j is the age-specific marital fertility rate for age j;
N_j is the proportion of all births to women aged j which are first births.

The results of the application of this formula, which also corrects for the contribution to marital fertility rates made by first births and incorporates an automatic adjustment for the development of sterility during use, is to bring potential fertility estimates generally slightly *below* age-specific marital fertility rates up to age 30 or 35, and above marital fertility rates at more advanced ages.

The second methodological innovation is the use of a multiplier matrix to apply to birth-interval frequencies in order to eliminate truncation bias. The opportunity to examine the truncation correction matrix by applying it to data has not yet arisen.

The most common measure of potential fertility employed in calculations of births averted is the direct use of the reciprocal of age-specific marital fertility rates, either unmodified or subject to more or less arbitrary multiplication by a factor recognizing the higher fecundity of acceptors (Talwar *et al.*, 1969). This approach certainly has the advantage of simplicity.

Fundamental data from which the calculation of potential fertility can be made derive either from available vital statistics—ASMFRs or

ASFRs matched with proportions married—or from special studies designed to provide detailed fertility data.

1. *RATES*. The majority of countries do not produce ASMFRs on an annual basis—the vital registration data required for this being comprehensive and relatively complex. Needed annually are:

a) births by age of mother and legitimacy,
b) marriages and divorces by age of bride,
c) deaths by age, sex and marital status,

together with firm census data on age, sex and marital status and reasonable migration statistics.

Estimates are commonly made by dividing age-specific fertility rates by proportions of women married in each age group obtained from recent census data. Freedman and Adlakha (1968), using hospital records to determine the age distribution of women bearing children, have derived sets of ASFR and ASMFRs for Hong Kong (1965 and 1966) where birth registration is deficient in not recording age of mother.

Fertility rates are subject to all the inaccuracies which can affect enumeration and age-reporting in census and registers. Marital rates are characteristically less accurate than general rates, particularly in countries where formal marriage is uncommon. In most Latin American and Caribbean countries, marital fertility rates are seriously misleading. Rates derived from special registration areas are often very far from representative of whole countries.

2. *SURVEYS*. Special surveys require very meticulous sampling procedures in order to ensure that their results are representative, but on the whole provide the most reliable indices of fertility in developing countries. Retrospective fertility surveys show consistent decay in completeness the longer the period concerned. Surveys to establish contemporary age-specific fertility rates need not, however, probe further than one year into the past.

The investigation of the fertility rates of groups of acceptors isolated from the general population is dogged by artifacts related to the shorter open intervals of acceptors. Furthermore, a substantial but unknown proportion of the differences found between past fertility of acceptors and the population at large is of a chance nature and has no prognostic value.

3. *MATCHING STUDIES*, of which that of Chang *et al.* (1969) is almost the only example (the matching study of Haynes *et al.* (1969) was retrospective and used in default of adequate data on past fertility

of acceptors; it is therefore no more than a superior example of borrowed data.) Follow the *subsequent* fertility of a group of non-acceptors after matching for age, parity, open interval and education of acceptors. In the circumstances of such a study, in which none of the matches is permitted to be pregnant on recruitment to the group, the future fertility of the matches will be oscillatory and not reach an asymptotic level for several years. It does not, therefore, provide a set of rates which can be used in "conventional" births-averted calculations.

If, as is done by Chang *et al.*, births averted are calculated by direct comparison of post-acceptance fertility of acceptors and matches, without regard to whether or not they continue or discontinue IUD use, become sterilized, have abortions etc., we find ourselves no longer studying births averted by use of a contraceptive method but instead, the differential fertility or two groups in a population distinguished by the decision made or not made at a particular time, that is, the significance as a predictor of future fertility of the decision to accept or reject the offer of an IUD.

The availability of data for matching studies of this kind depends on the pre-existence of very comprehensive and detailed registration data, such as are found in Taiwan and hardly elsewhere.

4. *BIRTH-INTERVAL DATA* are rarely found fortuitously. Increasingly, however, fertility surveys are being conducted in such a way that birth-interval data can be extracted from them, although memory bias may require that their results be accepted with caution.

The interval summaries required for the calculation of births averted are age-specific mean prospective intervals (births). Prospective intervals are those commencing at the given age and are not even approximately interchangeable with retrospective intervals (terminating at that age). Mean intervals for births are distinguished from mean intervals for women as the means of birth-interval distributions in elapsed time, i.e., the means of all intervals terminating between set dates (collected most readily from birth records or maternity hospital data). Mean intervals for women are collected in such a way that all women in a sample contribute equal numbers of intervals, for example, by recording the last birth-interval of all women surveyed. Mean intervals for births are always shorter than those for women. The relationship between the two is discussed in Wolfers (1968).

It is important to realize that for deriving fecundability estimates from birth intervals, mean intervals for women are required.

5. *FECUNDABILITY ESTIMATES.* In computer simulation mod-

els, fecundability estimates are required for sub-groups. It is perhaps easier to describe how such estimates cannot be made than how they can. Fertility rates, marital or otherwise, require extensive processing to exclude the components introduced by sterile women, contracepting women, women not exposed to the risk of pregnancy, post-partum amenorrhea (but not for nulliparous women), pregnancy duration, foetal loss, etc. In practice the task is too speculative to provide useful results. To use birth intervals more must be known of the distribution of post-partum amenorrhea and the time components of foetal loss than is usually available.

The direct and rigorous study of arithmetic mean fecundability is achieved by following groups of women, all ovulating, from the commencement of exposure to pregnancy risk until all (who are going to) become pregnant. This requires either virgin marriage cohorts or women who abandon contraception in order to conceive (Vincent, 1965; Westoff *et al.*, 1961). Such studies are meticulous research procedures and not suitable for field evaluation.

In practice, fecundability has been studied by observing the proportions of groups of women presumed to be ovulating who become pregnant in successive months over relatively short periods. Consistently, smaller proportions of non-pregnant remainders become pregnant with each succeeding month, a manifestation of the heterogeneity of fecundability in all populations.

By appropriate mathematical analysis, such data can be used to derive estimates of fecundability distributions, as well as mean fecundabilities. Mukerji and Venkatacharya (1967) have pointed out that true biological fecundability is not necessarily the most appropriate parameter for computer simulation and that a conception probability may be derived from ASMFRs "such that, when used with a set of other relevant input parameters, the simulated set should yield age-specific marital fertility rates as close to an assumed set as possible" and they have developed a method for doing this.

In general, neither denominators in the form of numbers married by age, nor numerators as births by age of mother, nor yet intervals between births by age, are accurately known. For a long time to come, births averted calculations will rely on crude estimates, sample surveys, or borrowed data. These deficiencies are, if anything, magnified when fecundability estimates are required, as for computer estimates.

POST-PARTUM AMENORRHEA

Particularly in post-partum contraceptive programs, adoption of contraception or sterilization frequently occurs while a woman is still

Table 6.1. *Computation of overlap between contraceptive use and post-partum anovularity*

Open interval	Proportion adopting	Proportion ovulating	Proportion ovulating by month after adoption											
			1	2	3	4	5	6	7	8	9	10	11	12
i	Y_i	Z_i	Y_iZ_i	Y_iZ_{i+1}	Y_iZ_{i+2}	Y_iZ_{i+3}	Y_iZ_{i+4}	Y_iZ_{i+5}	...	...	...	...	...	$Y_iZ_n = Y_i$
1	0.05	0	0	0.0025	0.005	0.0075	0.01	0.015	0.02	0.025	0.0325	0.04	0.045	0.05
2	0.05	0.05	0.0025	0.005	0.0075	0.01	0.015	0.02	0.025	0.0325	0.04	0.045	0.05	0.05
3	0.10	0.10	0.010	0.015	0.02	0.03	0.04	0.05	0.065	0.08	0.09	0.10	0.10	0.10
4	0.10	0.15	0.015	0.02	0.03	0.04	0.05	0.065	0.08	0.09	0.10	0.10	0.10	0.10
5	0.20	0.20	0.04	0.06	0.08	0.10	0.13	0.16	0.18	0.20	0.20	0.20	0.20	0.20
6	0.20	0.30	0.06	0.08	0.10	0.13	0.16	0.18	0.20	0.20	0.20	0.20	0.20	0.20
7	0.10	0.40	0.04	0.05	0.065	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10
8	0.10	0.50	0.05	0.065	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
9	0.05	0.65	0.0325	0.04	0.045	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
10	0.05	0.80	0.04	0.045	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
11	—	0.90												
12 (n)	$\sum_{i=n}^{i=\infty} Y_i$	1.00												
A Sum			0.2900	0.3825	0.4825	0.5875	0.695	0.790	0.870	0.9275	0.9625	0.985	0.995	1.00
Complements			0.7100	0.6175	0.5175	0.4125	0.3050	0.210	0.130	0.0725	0.0375	0.015	0.005	0.00
Sum of complements = mean overlap with anovulatory period = 3.0325 months														
Potter's method: Mean p.p.a. = 6.95 months. 0.2×4.95+0.5×1.95 = 1.965 months														
Wolfers' method: Mean open interval to acceptance = 5.5 months. Mean overlap = 2.85 months														
Mean duration of p.p.a. only for those ovulating			4.162	4.51	5.04	5.50	5.92	6.26	6.53	6.72	6.82	6.89	6.93	6.95

in an anovulatory state following her last delivery. The period of contraceptive use by a cohort which overlaps anovularity must be deducted from the total contraceptive use before this can be made a basis for calculating births averted. It is self-evident that use during such periods of overlap does not contribute to averting births.

Three methods of computing the loss in useful contraceptive effect due to overlap between contraceptive use and post-partum anovularity have been described. The first two of these are seriously inadequate:

(1) *POTTER (1969a)* computes mean overlap as follows:

a) obtain mean duration of post-partum amenorrhea;

b) class acceptors in 3-month groups by interval between last birth and acceptance;

c) subtract mid-points of these classes from mean amenorrhea (ignoring groups with mid-points greater than mean amenorrhea);

d) multiply each of the resulting values by the proportion of acceptors in the corresponding class and the proportion still effectively wearing the device at the point of mean amenorrhea;

e) sum to give mean overlap.

The flaw in this method can best be illustrated by assuming that all acceptance takes place within a three-month interval group after delivery whose mid-point coincides with mean post-partum amenorrhea. Then no allowance will be made for overlap, even though 50 per cent (approximately) of adopters will be amenorrheic at the time of adoption. The unstated underlying assumption that negative overlap cancels out positive overlap is not true.

(2) *WOLFERS (1969)* computes overlap, month by month after acceptance, by assuming that all women become adopters at the mean delivery-acceptance interval and matching this with an assumed distribution of post-partum amenorrhea by month after delivery. The correction is applied only to surviving effective users for the month in question.

When there is considerable spread in delivery-acceptance intervals, this method also underestimates overlap, although less seriously than the former method.

(3) *WOLFERS (1971)* proposed a method which is accurate provided that one can assume independence between the two distributions and is feasible when data for both are available. If only a mean value for post-partum anovulation is available, a theoretical distribution may be fitted and the method applied to this. It is illustrated in Table 6.1 for hypothetical distributions of delivery-adoption intervals and durations of post-partum amenorrhea.

In order to correct the mean overlap for discontinuation, it is merely necessary to multiply each entry in the "complements" row by the proportion of original acceptors still usefully retaining the device by the corresponding month after adoption. The last row in the table provides values, if required, for correcting durations per birth (see section IV.3).

Very often, information on the distribution of durations of this period is arbitrarily estimated or borrowed from (presumed) similar populations. A number of longitudinal studies from different areas do exist, and the distribution has also been studied by serial cross-section. The duration of post-partum amenorrhea has been shown to be very sensitive to breast-feeding practice and consequently, in mixed populations, has a bi-modal element (Sharman, 1966: 97; Potter *et al.*, 1965).

It is also likely that parity, nutrition, disease and post-delivery coitus customs all exert influence.

It is held by some (see Sharman, 1966: 70-87) that a variable number (with a mode of 1) of menstrual cycles after post-partum resumption of menstruation are anovulatory. If this is correct, anovulatory months should, of course, be added to amenorrheic months in allowing for overlap with contraceptive use.

ACCIDENTAL PREGNANCY

In handling pregnancies occurring accidentally during contraceptive use, Potter (1969a) has clearly demonstrated the correct approach. This is to assign for each pregnancy a "penalty" or deduction of months of useful contraception, equivalent to the mean period of ovulatory exposure to pregnancy risk required to yield one pregnancy in the absence of program contraception. This is calculated directly from durations per birth by subtracting nine months per pregnancy, the mean period of post-partum amenorrhea, and an allowance for the contribution of foetal mortality to durations per birth [set at one month for ages 20-34, 2 months for ages 35-39 ([2])]. This period of ovulatory exposure is then divided by the ratio of pregnancies to live births to avoid penalizing for pregnancies destined to end in abortion. Pregnancy rates are found by extrapolating from life-tables of contraceptive use-effectiveness.

([2]) Direct measurement on an Ecuadorian population gave values increasing from 0.9 months (age 15-19) to 3.3 months (age 40-45) (Wolfers and Scrimshaw, 1974).

FOETAL LOSS

Foetal loss is known to increase progressively with maternal age. Estimates of the proportion of pregnancies not terminating in live births are frequently made by arbitrary modification of values derived from the few (usually Western) detailed studies. Retrospective survey data of this quantity taken from high-fertility, low-education communities are likely to be almost worthless. Even neglecting (as is usual) miscarriages in the first six weeks of pregnancy, longitudinal prospective studies are very major undertakings.

STERILITY

Sterility estimates enter repeatedly into calculations of births averted:

a) In designating baseline fertility such that the selected rates or durations per birth relate to groups with proportions sterile approximating to proportions of acceptors sterile, or alternatively relate to non-sterile groups only. This has been discussed above in section III.1.

b) In computing the proportion of acceptors who are sterile at the time of acceptance. This has been dealt with in the literature in two ways:

(i) Potter (1969a) computes acceptors sterile at acceptance on the basis of a monthly risk of sterility applied to the mean period between last delivery and acceptance (taking the monthly risk as 1/60th of the proportion becoming sterile within a five-year age-group).

(ii) Wolfers (1969) applies a monthly risk of sterility (taken as 1 minus the 60th root of the proportion not becoming sterile within a five-year age-group) to the mean period between last *conception* and acceptance.

The additional nine months of risk of sterility allotted by Wolfers lead to significant differences between the two approaches at later ages—affecting total births averted to the extent of 3 per cent at age 35-39, 8 per cent at 40-44 and 36 per cent at 45-49.

c) In allowing for the development of sterility among acceptors during the currency of use. This has also been considered by both Potter (1969a) and Wolfers (1969), each of whom has applied a monthly conditional probability of sterility to achieve attrition of users. While Wolfers uses the same probabilities as for the computation of proportions sterile at commencement of use, Potter, whose method requires exponential expression (3) of competing risks of "end of useful retention of device" (EUROD), derives the probability as follows:

s, the monthly conditional probability of sterility is found from

$$S_{x+2.5,x+7.5} = 1 - e^{-60s} \qquad (2)$$

where

$S_{x+2.5,\ x+7.5}$ is the risk of developing sterility between ages $x+2.5$ and $x+7.5$, and applies to insertions at ages between x and $x+5$.

For a discussion of the merits of including the nine months of pregnancy in the development of sterility before adoption, see section V.

Understanding the nature and incidence of sterility continues to evade us. While it is easy to define sterility as zero fecundability persisting for the remainder of life, this definition does not lend itself to operational measurement. Operational definitions related to actual child-bearing performance leave difficult problems of adaptation to calculations and models.

Data for the proportion of couples sterile by age of the wife are almost universally lacking. Agarwala has computed data for India and Louis Henry for a group of European populations. Two methods have been described, employing

(i) the proportion of couples completing their reproductive lives childless by age at marriage,

(ii) the age at last childbirth for non-contracepting couples (Vincent, 1950; Henry, 1953a, b).

Barrett (1971) has demonstrated how, whatever operational measure of proportions sterile is employed, simple analysis of observed proportions sterile will lead to exaggerated estimates as proportions sterile rise with age. The best hope of achieving some accuracy in this area is by the use of computer simulation models to quantify the inevitable discrepancies. With sterility occurring either menopausally or pre-menopausally, an unknown proportion being attributable to sterility of the male partner and the contribution of disease as a cause little explored, the hope of finding a simple universally applicable formula is slim.

(3) Exponential decay curves employed in quantifying sterility and contraceptive continuation are convenient mathematical fictions to describe events which, epistemologically, are manifest in discrete monthly rates. The geometric series is conceptually more correct.

CONTRACEPTIVE USE

In this category of information is required:

a) Continuation rates by month after adoption,
b) Pregnancy rates by month after adoption.

While of interest, the further breakdown of discontinuation rates by, for example, removal, expulsion, medical/non-medical reason, to have another child, end of need for contraception, etc., has limited relevance to birth-averted calculations.

Rates of this kind cannot be obtained from service statistics derived from clinic records as the experiences of those who report back to clinics differ greatly from the experiences of those who do not. This applies in different ways to all forms of contraception. Sample surveys of acceptors at varying times after adoption are therefore required. It is feasible to amalgamate clinic reports (which will usually be the more reliable though less complete source) with survey information.

Life-table records of contraceptive use-effectiveness may, as discussed earlier, be employed directly for life-table calculations of births averted.

Where a summary mean duration of use is required the formula of Mauldin *et al.* (1967), modified by Potter (1969a), is usually applied. U, the mean span of use is given by:

$$U = \frac{1 - X}{P} \qquad (3)$$

where
X is the proportion losing the device etc. "immediately" and
P is the (presumed constant) monthly risk of discontinuation.

P is found by locating the value which fits the rate of discontinuation found between specified times after adoption. For example, the rate between the 6th and 24th months is given by:

$$\frac{U_{(24)}}{U_{(6)}} = e^{-18P} \qquad (4)$$

While X is derived after the P value is determined from:

$$(1 - X)\, e^{-24P} = U_{(24)} \text{ (4)} \qquad (5)$$

In these formulae, $U_{(n)}$ is the proportion retaining the device n months after acceptance.

(4) See footnote 3.

Other, cruder methods have been employed to assess continuation where life-table data are not available. I feel, however, that birth-averted calculations cannot be recommended in the absence of reasonably adequate follow-up information regarding contraceptive use.

The formula

$$U = \frac{1-X}{P}$$

was derived for IUDs, but seems equally applicable to other methods of contraception, though not to sterilization nor, of course, abortion. Until recently, the formula has received surprisingly little critical attention.

One study (Kelly, 1971a) demonstrated that the exponential formula was superior to a reciprocal formula for a (rather small) sample of Puerto Rican acceptors, but found additionally that P was significantly age-dependent. Kelly gave theoretical justification for the exponential formula as follows:

> "Contraceptive patients and their husbands are subject to a number of probabilistic personal events such as illness, death, divorce, migration, conscription, pregnancy, desertion, etc., all of which can take the patient out of contact with the program or remove the need for contraception. If these events can be assumed to be random, then some (constant) value can be assigned to the probability that a patient will continue or discontinue contraception during a given period."

There are, however, very strong theoretical grounds for not assuming that many of these, and other relevant events, are random over time.

The risks of illness and death are continually increasing due

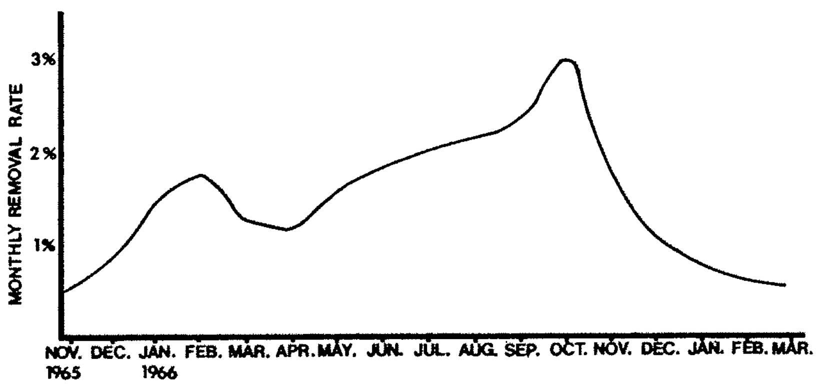

Fig. 6.2. *Removal rate (per unremoved IUD) by date of removal.*

to age, and the risk of pregnancy during use constantly decreases. The likelihood that a user will discontinue in order to have another child undoubtedly rises to a maximum somewhere between two and three-and-a-half years after adoption, so that "spacers" and "terminators" may be expected not only to have different risks of discontinuation, but to form continually changing proportions of all users. Expulsions of IUDs decrease with duration of use; medical complications have well-defined relationships to duration of use. Removals and discontinuations follow the spread of rumours and fashions in a population (see Figure 6.2). For detailed discussion of extrapolated continuation, see Chapter 3.

Estimates of contraceptive prevalence, both within programs and outside them, remain seriously inaccurate in many settings. With definitions of acceptor operationally different in different programs and follow-up requirements neglected or treated casually in many, life-table continuation rates cannot always be relied on, while the difficulties of determining what is happening with non-program contraception, abortion and sterilization in order to assess substitution and trend effects remain essentially insuperable.

MORTALITY, WIDOWHOOD AND DIVORCE

It is a moot point whether separate allowance for mortality, widowhood and divorce should be made for births averted by contraceptive use. The decision must rest upon whether these events are included in the bank of discontinuers in the compilation of use-effectiveness life tables.

On the other hand, for sterilizations (see below) consideration of these events is mandatory. While mortality risks may be taken unmodified from life-tables or age-specific mortality schedules, widowhood, divorce and (if attainable) separation rates must be modified by re-marriage probabilities and intervals to incur a penalty less than the whole of the remaining life-span of the sterilisand.

The practice of combining mortality risks of husband and wife on the basis of their mean age-difference (taken in India as 5 years), as was done by Venkatacharya (1971a) and Ram (1971) as follows:

$$P_x^{mf}(T) = P_x^f(T) \, . \, P_{x+5}^f(T) \qquad (6)$$

introduces additional inaccuracy by granting a mean age for all husbands of wives in each age-group. There the mean mortality risk of all the ages is not equivalent to the mortality risk at the mean age.

Mortality and widowhood are usually estimated from life tables, either specific to the population studied or fitted from model tables.

These provide separate annual probabilities of survival from age x to age x+n for males and females.

Divorce statistics are usually inadequate and estimates of the probability of a union being disrupted by divorce or separation during contraceptive use are made from cross-sectional surveys.

DURATION OF PREGNANCY, TIMING OF ABORTIONS AND DURATION OF POST-ABORTAL AMENORRHEA

These are usually arbitrarily set at nine months for a live birth, eight months for a still birth, three months for an abortion and one, one-and-a-half or two months post-abortal amenorrhea.

ACCEPTOR CHARACTERISTICS

All studies place acceptors in age-groups applicable at the time of acceptance. The intervals selected should correspond with the age-intervals of the fertility data to be used ([5])

While some workers have elected to neglect the change in fertility potential due to aging of the acceptor cohort, this cannot be recommended.

Potter (1969a) employs age-specific fertility expectations applicable to the mean age attained by acceptors (in each acceptor age-group) during use, i.e., if mean duration of use is two years, the mean age of acceptors at ages 25-29 will be taken as 28.5 years. Wolfers (1969), by employing single-year age data, ages his population annually.

The division of acceptors into groups according to age, previous contraceptive use, ethnic and social divisions, etc. is justified only insofar as other parameters employed in the calculations are distinguished for these groups. In particular this relates to continuation rates and fertility expectations. Separate runs of calculations will be required for each distinguishing group.

Other characteristics of acceptors, notably open interval to acceptance, are directly integrated into the calculations as described elsewhere.

Characteristics of contraceptive users are obtained (preferably) from service statistics where, at the time of acceptance, necessary items such as age, previous contraceptive use, social characteristics and open interval are recorded. While age will usually be computed

([5]) If the formula on page 19 is employed, acceptors should therefore be grouped in ages 18-22, 23-27, 28-32, etc.

in 5-year groupings, care needs to be taken with mean age within groups at the extreme ends of the child-bearing period. In the Singapore post-partum program, the mean age of acceptors 15-19 years old was 18.9 years—1.4 years higher than the mid-point of the interval; at 20-24 it was 23.0 years, at 40-44, 41.7 and at 45-49, 46.5 years (Wolfers, 1970a: 169).

Alternatively, this information, but with considerable loss of accuracy, may be collected by retrospective sample surveys.

INDUCED ABORTION

Somewhat different modes of calculation are required to compute the birth-averting powers of induced abortions and sterilizations.

Induced abortions, not being continuously employed strategies, do not lend themselves to the calculations of duration of use. Instead it is necessary to seek a quantity, "duration per abortion", to correspond to "duration per birth". This, like the common birth interval, will be composed of three parts: a period of ovulatory exposure, a period of pregnancy and a period of post-partum anovularity. The latter two quantities are subject to little variation and have mean values close to 3 months and $1\frac{1}{2}$ months respectively. The former may be derived from fecundability estimates, but these will not usually be available and so will commonly be "borrowed".

"Duration per abortion" now becomes the period corresponding to mean duration of contraceptive use, and its birth-averting effect is obtained from the formula:

$$\frac{\text{Duration per abortion}}{\text{Duration per birth}} = \text{births averted per abortion} \qquad (7)$$

(Potter, 1972b).

While this approach yields a satisfactory solution to the problem of attributing a birth-preventing value to abortions where they are the only form of birth control employed, this is not the common case. Usually abortion is used to supplement a more conventional method of contraception.

Under these circumstances, the duration per birth is that to be expected with the use of the contraceptive and the duration per abortion is correspondingly increased because of the elongation of the period of ovulatory exposure.

The appropriate duration per birth may be obtained by summing the duration per birth used in the calculation of births averted by contraceptive use for the age-group concerned and the mean prolongation of stay in the fecundable period calculated on the basis of their contraceptive use (see section IV, 2).

In respect of abortion, the necessity of taking post-period strategy into account is most clearly demonstrated. The impact of abortion in averting births has been extensively discussed by Potter (1972b) and Keyfitz (1971). Potter has also made a more theoretical mathematical exploration (1972c).

STERILIZATION

While there are serious substitution problems in computing births averted by sterilizations—the probability that sterilisands would have had recourse to other methods of birth control had sterilization not been available is very high—it is probably a healthy sign that they have been almost entirely ignored by writers on this subject. By the time we have taken into account that, but for sterilization, half our acceptors would have worn IUDs and but for IUDs half these acceptors would have been sterilized, our overscrupulousness is thrusting half the program into limbo!

Births averted by sterilization comprise all the remaining potential births to the couple involved. The important dimensions of the problem of quantification are:

a) the rates to be used—all women or past fertility of acceptors only;

b) ages at acceptance—and in this case, the use of mean age of acceptors is not satisfactory (see above);

c) mortality, widowhood and separation (see section III.7 above);

d) susceptibility status (physiological state) at time of sterilization.

The majority of studies of births averted by sterilization have been made using Indian experience. Gopalaswami (1962) based his calculations for India on Japanese fertility data, Agarwala (1966) employed ASMFRs, while Haynes *et al.* (1969) matched sterilisands in Kerala with controls by age, income, education, religion and number of living children and used the fertility rates of controls as their basis—finding a 10 per cent increase over ASMFRs estimated for the same period. Venkatacharya's calculations (1971a, 1972) have as their basis the ASMFRs of the 1954-55 Mysore study, for which two alternative sets of fecundability schedules are derived. Were they but available, the use of age-controlled parity progression ratios would provide an excellent theoretical basis for estimating births averted by sterilization.

Venkatacharya (1971a) claiming that almost all female sterilizations in India take place immediately after a delivery, makes specific allowance for a lengthy period of non-susceptibility in risk of conception at the outset of sterilizations, and a moderated allowance for vasectomies.

Future fertility estimations for sterilizations must take into account the low proportion of sterile acceptors but, this aside, it is doubtful if higher fecundity than average should also be assumed.

Even the best estimate of the effects of sterilization encounter the difficulty that effects are continuing for as long as two decades after the act, so that the validity of assumptions about expected fertility rates is always questionable.

SUBSTITUTION

In practice substitution must be handled by making the assumption that a certain (always to some extent arbitrary) proportion of acceptors is using the program method as a substitute for a non-program method, and assigning to them a lower potential fertility level (or zero potential fertility) than to the remainder.

The probability that acceptors in the program *would have* adopted non-program birth control strategies were it not for the program has also been addressed.

Potter (1969a) calculated alternative D-values (durations per birth) on differing assumptions regarding the probability that acceptors would have been sterilized if IUDs were not available, and Wolfers (1969) attempted to calculate the monthly age-specific proportion of married women becoming successful contraceptors outside the program and amalgamated this with sterility probabilities.

While at the heart of the question of how much realism resides in birth-averted calculations, the quantification of substitution effects remains elusive and becomes more so as societies develop, motivation for birth control grows and channels of supply of services multiply. In universally contracepting populations every episode of use is a substitute for some alternative that was or would have been used instead.

Of special importance in the case of abortions, but also relevant to the assessment of the effects of contraceptive use is the question of birth-control strategy to be employed after discontinuation of a program method.

Whether the concept of extended use-effectiveness of Tietze and Lewit (1968) should be employed to credit a program with the catalytic effect it has in keeping acceptors contracepting after leaving the program, or whether recognition of the fact that discontinuers have low fertility expectations should modify downward the estimates we make of births averted, will depend on our purpose in making the calculations—essentially a political, rather than a scientific, decision.

Substitution estimates will be based on data collected at the time of acceptance and survey information regarding duration and efficacy of contraceptive practice outside the program. The accuracy of the latter will rarely be great.

CHOICE OF BASELINE AND TREND

Calculations of the demographic effects of programs, whether by births averted or other computations, have been attacked, for example by Seltzer (1970), for failing to incorporate realistic assumptions as to what national fertility would have been without the program. Apart, therefore, from the substitution problems which exist in steady-state societies, there are•others, yet more speculative, which derive from trends already manifest at the time of introduction of the program. It is desirable, where sufficient data exist to do so, to incorporate assumptions based on these trends at least conditionally, or as alternatives, into computations of births averted. This will not entirely disarm criticism, for any particular sequence of falling fertility rates can be extrapolated in many different ways, but some extrapolation is desirable.

The simplest extrapolation is to assume an arithmetic rate of fall—for example, if ASMFR for age 20-25 has fallen by 50 per thousand from 350 to 300 per thousand in the past five years, to assume that it would have continued to fall at the rate of 10 births per thousand per year. More realistic is to assume a geometric or logarithmic rate of fall of 3 per cent per year. Other suggestions include allowance for an accelerating rate of fall. One method used by Wolfers (1970b) (although not in births-averted calculations) is first to compute an approximation of an ASMFR schedule for the population which corresponds to zero growth rate and then using this as the zero fertility level, render ASMFRs into "excess" fertility rates and find trends geometrically from there. Thus in the example given, if the zero growth ASMFR for age 20-25 is 150, the fall in "excess" fertility rate will have been from (350-150) to (300-150) or 25 per cent over five years, equivalent to a fall of 5.6 per cent per year.

Trends of this kind have not, to my knowledge, so far been incorporated into birth-averted calculations, except insofar as is possible in considering second derivative substitution effects, but it is desirable that they should be.

IV. ILLUSTRATED EXAMPLES

KOREA: LEE AND ISBISTER'S METHOD

Although earlier attempts to quantify the effect of contraceptive use do exist, the first full-scale computation of births averted was that of Lee and Isbister (1966), under the guidance of Ansley Coale. This pioneering calculation had the comprehensive aims of estimating:

a) the effects of a program on the fertility of individual future years;

b) the total effect that IUDs will have during all the years that they remain in use;

c) the scale of program required to achieve specified objectives.

The program used in the illustration was that of Korea and the method employed was essentially that of component projection, with future age-specific fertility rates calculated by using the formula:

$$f_{i,t} = \frac{F_{i,t} \cdot f_{i,0} - Q_{i,t}\, g_i}{F_{i,t}} \qquad (8)$$

where,

$f_{i,t}$ is the fertility of women aged i in year t ($t = 0$ for base year);
$F_{i,t}$ is the total number of women aged i in year t;
$Q_{i,t}$ is the number of women aged i in year t practising totally efficient contraception in year $t-1$ (on the assumption that contraceptive use averts births approximately one year later);
g_i is the potential fertility of women aged i on the assumption of non-use of (program) contraception. As indicated above (p. 177), g_i was taken in this study as $f_{i,0} + 20$ %.

Perhaps the most serious flaw in this method is that it takes no account of the initial "susceptibility status" (physiological status) of the women comprising the $Q_{i,t}$ group, leading to under- or over-estimation of future fertility rates depending on whether contraception was being adopted during post-partum amenorrhea or during the fecundable state.

Life-table methods of computing contraceptive use-effectiveness were not yet available when Lee and Isbiter formulated their proposals so that their method of calculating the size of the Q group leaves much to be desired. Anyone wishing to employ the method nowadays would employ life-table methods to calculate the numbers using contraceptives in specific years from annual data.

The method employed for determining births prevented in all years per IUD inserted is a simple adaptation of the fertility rate calculation, the survivors wearing IUDs being multiplied by appropriate g_i potential fertility rates until all have discontinued use.

Lee and Isbister computed that each IUD inserted prevented between 1.5 and 1.9 births, depending on the age distribution of acceptors.

Two very similar methods of calculating births averted were published in 1969, one by Potter, using Taiwan data, and one by Wolfers employing data from the post-partum IUD program in Singapore. Both endeavored to take into account a wider range of factors than were recognized in Lee and Isbister's work.

TAIWAN: POTTER'S METHOD

The rationale of Potter's method is expressed as follows:

> "For an estimate of births averted per segment of IUD, two kinds of statistics are needed. The first are estimates of the prolongations of stay in the fecundable state resulting from retention of the device. Second, to convert these prolongations into births averted it is necessary to divide them by a constant representing the average marriage duration per birth that might have been required by the couples had they not adopted IUD."

Two formulae are used:

$$I = F(R - A - PW) \qquad (9)$$

where

I = mean prolongation of stay in the fecundable period;

F = proportion of acceptors non-sterile at time of insertion;

R = mean time device is "retained" among couples fertile at time of insertion;

A = allowance for amenorrhea;

P = proportion becoming pregnant while believed to be retaining the device;

W = penalty for accidental pregnancy;

$$B = I/D \qquad (10)$$

where

B = births averted per first segment of IUD;

D = average duration per birth.

Amplifying,

R, the mean time of "retention" is defined as the mean interval from insertion to death, widowhood, divorce, onset of secondary sterility or loss of contraceptive effect through pregnancy, expulsion or removal, whichever occurs sooner. R is estimated by the technique of multiple decrement life-table analysis with each eventuality treated as a competing risk. Note, however, that where removal is ascertained by follow-up survey, and widowhood and divorce from population registration statistics, duplication may occur if care is not taken.

A is the mean overlap between use of IUD and post-partum amenorrhea, obtained as the weighted mean of the results of subtracting delivery-insertion intervals, grouped in three-month classes, from mean duration of amenorrhea which is taken (Mohapatra, 1966) as 8 months.

P is the proportion of acceptors fertile at insertion whose useful span of protection is terminated by pregnancy.

W is the mean fecundable period that would have been required for a pregnancy in the absence of an IUD. (As Potter points out, were IUDs substituting for more effective contraception, the IUD would in fact be shortening average stays in the fecundable period, the value of W would be high and PW would exceed R-A, exposing the fact that I, the prolongation of stay in the fecundable period, has a negative value and births are being encouraged rather than averted by the contraceptive program.)

Potter obtains births averted by years after insertion by subdividing I, the interruption of child-bearing, into sub-totals relevant to each year after insertion and dividing each of these by D. He does not recommend varying D as the remaining users age, holding that D changes (except towards the end of reproductive life) too slowly to justify such variation.

The mode of calculating proportions sterile at insertion and those becoming sterile during use is described in section III.5.

In calculating the mean span of useful retention of the IUD, Potter amalgamates the competing risks of pregnancy, expulsion and removal (PER) and secondary sterility and mortality (of either spouse). The method of handling PER risks is that described earlier, assuming a proportion losing the device immediately and a constant proportion of remaining users losing it in each subsequent month.

Mortality is treated by selecting approximations for the average death rates for each age class. (For ages 20-29, the death rates (r) in those classes are used; for ages 30-34 and 35-39, death rates for 30-39 and 35-44 are employed.) Based on these probabilities of survival for one year are approximated by $1-r$ and designated P_f and P_m for wives and husbands respectively. The monthly risk of death or widowhood is then given by M,

Table 6.2. *Computation of cumulative births*

(a) Ordinal month	(b) Surviving fecund users at 1st of month	(c) Month after delivery	(d) Probability integral	(e) Mean post-partum infecundity	(f) Effective population	(g) Continuation rate to end of month	(h) Continuation rate × modifying factor	(i) (h) × sterility factor
1	96668	1.5	0.0316	0.6	3055	0.918495	0.911396	0.908313
2	87805	2.5	0.0580	1.3	5093	0.970764	0.963261	0.960002
3	84293	3.5	0.0993	2.0	8370	0.972004	0.954491	0.961229
4	81025	4.5	0.1587	2.8	12859	0.958324	0.950917	0.94770
5	76787	5.5	0.2376	3.5	18245	0.974727	0.967103	0.963921
6	74017	6.5	0.3341	4.2	24729	0.96659	0.959126	0.955881
7	70751	7.5	0.4432	4.9	31357	0.974867	0.067332	0.964060
8	68208	8.5	0.3568	5.5	37978	0.974213	0.966683	0.963413
9	63712	9.5	0.6659	6.1	43758	0.977093	0.969541	0.966261
10	63495	10.5	0.7624	6.6	48409	0.978182	0.970622	0.967388
11	61421	11.5	0.8413	7.0	51673	0.987720	0.980086	0.976770
12	59994	12.5	0.9007	7.3	54037	0.980451	0.972873	0.969382
13	58169	13.5	0.9420	7.6	54795	0.988470	0.980830	0.977512
14	56881	14.5	0.9684	7.8	55064	0.989173	0.981528	0.978207
15	55622	15.5	0.9839	7.9	54726	0.990603	0.982847	0.979522
16	54483	16.5	0.9925	7.9	54074	0.989696	0.982047	0.978724
17	53324	17.5	0.9966	8.0	53143	0.992706	0.985033	0.981701
18	52348	18.5	0.9987	8.0	52280	0.995845	0.988148	0.984805
19	51553	19.5	1.000	8.0	—	0.990164	0.982511	0.979187
20	50486		1.000	8.0	—	0.993	0.987310	0.983970
21	49671		1.000	8.0	—	0.993	0.987310	0.983970
22	48875		1.000	8.0	—	0.993	0.987310	0.983970
23	48092		1.000	8.0	—	0.993	0.987310	0.983970
24	47321		1.000	8.0	—	0.993	0.987310	0.983970
25	46562		1.000	8.0	—	0.993	0.987310	0.991634
26	46178		1.000	8.0	—	0.993	0.987310	0.991634
27	45786		1.000	8.0	—	0.993	0.987310	0.991634
28	45403		1.000	8.0	—	0.993	0.987310	0.991634
29	45033		1.000	8.0	—	0.993	0.987310	0.991634
30	44646		1.000	8.0	—	0.993	0.987310	0.991634

The above table is an example for Singapore for the Chinese ethnic group aged 25-29 with no previous contraceptive history, and using the following factors:

averted per 100,000 women accepting contraception

(j) Women-months of use in month	(k) Corrected mean birth-interval	(l) Births averted (100 % effect)	(m) Probability of pregnancy	(n) Probability of pregnancy × live-birth prop.	(o) Births	(p) Corrected births averted	(q) Cumulative births averted	(r) Number sterile or discontinued in month
2915	17.8	164	0.001135	0.000793	79	63	85	8063
4991	18.5	270	0.002270	0.001590	159	111	196	3518
8207	19.2	427	0.001702	0.001191	119	308	304	3238
12522	20.0	626	0.002459	0.001721	172	454	958	4338
17915	20.7	865	0.001891	0.001324	132	733	1691	2770
24183	21.4	1130	0.001891	0.001324	132	993	2632	3266
30793	22.1	1393	0.002269	0.001583	150	1234	5983	3502
37283	22.7	1642	0.003215	0.002251	225	1417	5340	2493
43019	22.3	1646	0.002648	0.001854	185	1661	7001	2217
47618	23.8	2001	0.001136	0.000795	80	1921	8922	2074
51073	24.2	2110	0.001707	0.001195	119	1991	10913	1427
53215	24.5	2172	0.001905	0.001334	133	2039	12952	1325
54179	24.8	2185	0.000774	0.000542	54	2391	15083	1898
54464	25.0	2179	0.001840	0.001288	129	2630	17183	1238
54166	25.1	2158	0.000710	0.000497	50	2198	19341	1109
53499	25.1	2131	0.000312	0.000218	22	2109	21350	1159
52656	25.2	2090	0.001924	0.001347	135	1855	23903	976
51950	25.1	2062	0.000000	0.000000	0	2062	25267	733
51017	25.2	2024	0.000000	0.000000	0	2024	27391	1073
50076	25.2	1987	0.0006	0.00042	42	1945	20836	909
49273	25.2	1955	0.0006	0.00042	42	1913	31269	790
48485	25.2	1924	0.0006	0.00042	42	1862	38131	783
47701	25.2	1893	0.0006	0.00042	42	1851	34088	773
46942	25.2	1863	0.0006	0.00042	42	1881	36963	159
46367	25.2	1840	0.0005	0.00035	35	1885	38608	290
45979	25.2	1825	0.0005	0.00035	35	1780	40298	380
45594	25.2	1809	0.0005	0.00035	35	1774	48172	288
45213	25.2	1794	0.0005	0.00035	35	1732	43081	280
44835	25.2	1779	0.0005	0.00035	35	1744	45075	377
44439	25.2	1764	0.0005	0.00035	35	1783	47464	278

mean prospective birth interval (A) = 25.2 months; continuation modifying factor (B) = 0.992271; withdrawal factor (C) = 0.293653.

Table 6.2. *Computation of cumulative births averted*

(a) Ordinal month	(b) Surviving fecund users at 1st of month	(c) Month after delivery	(d) Probability integral	(e) Mean post-partum infecundity	(f) Effective population	(g) Continuation rate to end of month	(h) Continuation rate × modifying factor	(i) (h) × sterility factor
31	44872		1.000	8.0	—	0.993	0.987310	0.991634
32	43902		1.000	8.0	—	0.993	0.987310	0.991634
33	43535		1.000	8.0	—	0.993	0.987310	0.991634
34	43171		1.000	8.0	—	0.993	0.987310	0.991634
35	42810		1.000	8.0	—	0.993	0.987310	0.991634
36	42462		1.000	8.0	—	0.993	0.987310	0.991634
37	42097		1.000	8.0	—	0.993	0.987310	0.991634
38	41745		1.000	8.0	—	0.993	0.987310	0.991634
39	41396		1.000	8.0	—	0.993	0.987310	0.991634
40	41050		1.000	8.0	—	0.993	0.987310	0.991634
41	40707		1.000	8.0	—	0.993	0.987310	0.991634
42	40366		1.000	8.0	—	0.993	0.987310	0.991634
43	40028		1.000	8.0	—	0.993	0.987310	0.991634
44	39692		1.000	8.0	—	0.993	0.987310	0.991634
45	39360		1.000	8.0	—	0.993	0.987310	0.991634
46	39031		1.000	8.0	—	0.993	0.987310	0.991634
47	38704		1.000	8.0	—	0.993	0.987310	0.991634
48	38380		1.000	8.0	—	0.993	0.987310	0.991634
49	38052		1.000	8.0	—	0.993	0.987310	0.991634
50	37741		1.000	8.0	—	0.993	0.987310	0.991634
51	37425		1.000	8.0	—	0.993	0.987310	0.991634
52	37112		1.000	8.0	—	0.993	0.987310	0.991634
53	36802		1.000	8.0	—	0.993	0.987310	0.991634
54	36494		1.000	8.0	—	0.993	0.987310	0.991634
55	36189		1.000	8.9	—	9.993	0.987310	0.991634
56	35880		1.000	8.0	—	0.993	0.987310	0.991634
57	35680		1.000	8.0	—	0.993	0.987310	0.991634
58	35838		1.000	8.0	—	0.993	0.987310	0.991634
59	34993		1.000	8.0	—	0.993	0.987310	0.991634
60	34700		1.000	8.0	—	0.993	0.987310	0.991634

per 100,000 women accepting contraception (continued)

(*j*) *Women-months of use in month*	(*k*) *Corrected mean birth-interval*	(*l*) *Births averted (100 % effect)*	(*m*) *Probability of pregnancy*	(*n*) *Probability of pregnancy × live-birth prop.*	(*o*) *Births*	(*p*) *Corrected births averted*	(*q*) *Cumulative births averted*	(*r*) *Number sterile or discontinued in month*
44087	25.2	1749	0.0004	0.00028	28	1721	49125	270
43718	25.2	1735	0.0004	0.00028	28	1707	39858	387
43353	25.2	1720	0.0004	0.00028	28	1092	48524	304
42980	25.2	1706	0.0004	0.00028	28	1678	54808	261
42631	25.2	1698	0.0004	0.00028	28	1865	55866	252
42274	25.2	1678	0.0004	0.00028	28	1683	57516	501
41921	25.2	1654	0.0002	0.00014	14	1658	59165	382
41370	25.2	1650	0.0002	0.00014	14	1630	60808	340
41923	25.2	1636	0.0002	0.00014	14	1682	62484	348
40878	25.2	1623	0.0002	0.00014	14	1608	64932	340
40537	25.2	1609	0.0002	0.00014	14	1595	63827	361
40197	25.2	1595	0.0002	0.00014	14	1581	67398	328
39861	25.2	1582	0.0002	0.00014	14	1568	68776	335
39327	25.2	1569	0.0002	0.00014	14	1555	70321	388
39195	25.2	1565	0.0002	0.00014	14	1541	71272	329
38868	25.2	1542	0.0002	0.00014	14	1528	70406	327
38542	25.2	1529	0.0002	0.00014	14	1515	74913	384
38310	25.2	1517	0.0002	0.00014	14	1505	70418	261
37000	25.2	1504	0.0002	0.00014	14	1490	71290	318
37683	25.2	1491	0.0002	0.00014	14	1477	79384	210
37268	25.2	1479	0.0002	0.00014	14	1468	80650	414
36957	25.2	1467	0.0002	0.00014	14	1453	82898	210
36648	25.2	1484	0.0002	0.00014	14	1440	83760	360
36341	25.2	1442	0.0002	0.00014	14	1428	86371	208
36038	25.2	1430	0.0002	0.00014	14	1416	86567	293
35736	25.2	1418	0.0002	0.00014	14	1404	87901	390
35457	25.2	1408	0.0002	0.00014	14	1398	88383	290
35140	25.2	1394	0.0002	0.00014	14	1380	90763	280
34867	25.2	1383	0.0002	0.00014	14	1369	92182	302
34555	25.2	1371	0.0002	0.00014	14	1387	93689	289

where

$$P_f P_m = e^{-12M} \tag{11}$$

The use of three exponential expressions to denote the competing risks of PER (p), mortality (m) and sterility (s), together with the convention that a proportion, x, lose the device immediately, allows the estimation of the mean retention span R to be expressed by the simple expression

$$R = \frac{1-x}{m+s+p} \tag{12}$$

The proportions of EUROD attributable to each of the competing causes, m, s and p are then

$$\frac{(1-x)\,m}{m+s+p},\quad \frac{(1-x)\,s}{m+s+p} \quad \text{and} \quad \frac{x+(1-x)\,p}{m+s+p}$$

This last becomes useful as a basis for calculation of P, the proportion accidentally pregnant. P (age-specific) is obtained by multiplying this proportion of loss of useful IUD effect due to pregnancy, expulsion or removal by the ratio of accidental pregnancy to all events in the use-effectiveness life table. However, as the ratio of pregnancy to all events changes as a function of duration of use, Potter recommends a rather elaborate process to obtain an accurate estimate. The ratio, pregnancies to all events, is divided into R_1 and R_2, R_1 being the ratio for the first two years, R_2 for the subsequent life of the IUDs, with the overall ratio obtained by a weighted average of R_1 and R_2. Weighting is attained by total durations of use in those two periods. R_1 is obtained directly from the life table; R_2 is calculated on the assumption that no further expulsions occur after two years and that pregnancies form a duration-independent proportion of pregnancies and removals.

This extrapolation is rather artificial but is dictated by the absence of long-term life-table data. Its validity is heavily dependent on the reality of the formula for exponential decay in useful retention.

Calculation of penalty per pregnancy was described in Section III.

The basis for the calculation of durations per birth was, as discussed above, the pre-insertion birth rates of acceptors obtained by survey. Birth rates for the three years preceding the first interview were used. Meticulous care was required to ensure that appropriate time relationships were employed. The point of general relevance is that it is essential to employ the fertility rates appropriate to women of the ages that acceptors will have reached at the mid-point in time of their useful retention of IUDs. Durations per birth are derived from:

$$D_i = \frac{12{,}000}{b_i} \tag{13}$$

where
D_i is the duration at age i
and
b_i is the birth rate at that age.

Potter calculates a series of four alternative D-values employing different assumptions regarding the probability that IUD acceptors would have become sterilized if IUDs were not available.

Equation (10) above is then applied to yield births averted per IUD inserted. The method, when applied to Taiwan data, yielded estimates of this value ranging from 0.94 to 0.43, depending on which of the four alternative D values was used.

SINGAPORE: WOLFER'S METHOD

In contrast to Potter's method, which is characterized by the use of summary values for duration of use, post-partum amenorrhea and pregnancy rate, Wolfers employs a life-table approach to yield, in each ordinal month after acceptance, the proportions of original acceptors who are still usefully retaining the device and with what effect.

Data and calculations are assembled in a series of tabulations of the form shown in Table 6.2. In the example worked, separate tables are constructed for each population sub-group by age, ethnic group and previous contraceptive use. The three factors, (A), (B) and (C) in the note of the table are the distinguishing variables for sub-groups, and are obtained as follows:

(A) The mean prospective birth interval is obtained from direct questioning of the population, acceptors and non-acceptors, and is, as described above, a mean interval for births. It corresponds to Potter's D-values.

(B) The continuation modifying factor is a factor applied to life-table continuation rates computed by the method of Tietze and Potter in an attempt to make these specific for sub-groups. The sub-group proportions found to be continuing use in a follow-up survey some sixteen and a half months (on average) after acceptance were applied as correction factors to the general life-table rates. Thus while the proportion of the total population continuing use at 16.44 months was 0.66, the proportion of Malays aged 35-39 continuing use was 0.88 or 1.33 times as high as the average. The 16.44th root of this ratio - 1.01765 was then applied to each monthly continuation rate (up to the 24th month) to achieve a rate specific for that group.

(C) The withdrawal factor. Two alternative values are computed for this variable:

(i) represents only the monthly probability of the development of sterility (see section III.5), while

(ii) combines the probability of becoming sterile with the probability of ceasing to reproduce for other reasons and is derived from estimates made of the proportion of the population at each age, still engaged in reproduction. It represents an attempt to include second derivative substitution effects. These estimates are made by calculating an expected number of births for each age-group based on numbers married, proportion of first births, mean *retrospective* birth interval and estimated marriage-first birth interval. The formula employed is:

$$1.25B_1 + IB_+ = \text{Number of women married 9 months and longer,} \qquad (14)$$

where

B_1 is the number of first births

B_+ is the number of later births

I is the mean retrospective birth interval.

With knowledge of the ratio B_1/B_+, this equation can be solved to give the expected total births on the basis of the known married population. The actual/expected ratio gives the proportions of women in each age-group still reproducing and again, the 60th roots of five-year rates of change yield a monthly proportion not withdrawing from reproduction.

The calculation of births averted proceeds month by month as follows:

A notional cohort of 100,000 acceptors is first reduced to the number fertile at acceptance on the assumption that all were fertile at the *conception* of the last child (cf. Potter's assumption). Monthly probabilities of sterility (or withdrawal) are applied for nine months plus the mean length of the delivery acceptance interval. Thereafter, each subsequent month of use is treated similarly. For the nth post-acceptance month a computation is made of the proportion of the still fertile acceptors who are *not* experiencing post-partum amenorrhea in that month. The mean duration of post-partum amenorrhea for each sub-group was estimated by the formula

$$\overline{F} = 0.9\left(2\,(V/8)^{\frac{1}{2}} + 1\right) \qquad (15)$$

where

V is the total variance of birth-intervals in the sub-group

$\overline{F}$ is the mean post-partum amenorrhea.

Making the simplifying approximation that post-partum amenorrhea was normally distributed, and that the mean amenorrhea was twice the standard deviation plus one month, the proportions still amenorrheic in each month could be read from tables of probability integrals (areas under a curve to the left of each ordinate value). The use of an observed distribution, if available, would, of course, have been preferable.

By multiplying fertile acceptors by this integral, the number of women in the cohort who were neither sterile nor amenorrheic was obtained—the effective population. This number was then serially multiplied by the continuation rate to the end of the month (from the use-effectiveness life table), continuation modifying factor (B) and sterility or withdrawal factor (C) to yield continuing fertile users from this group at the end of the month. Adding half the month's decrement to this number gave woman-months of effective contraceptive use during that month.

Wolfers then argued that an earlier return of menstruation pretold shorter birth-intervals, assuming that the duration of post-partum amenorrhea remains fairly constant from birth to birth for any one woman (but see Barrett (1971) who takes a different view) and corrected the birth interval for the sub-groups by subtracting from it the mean post-partum infecundity of those women who had already resumed menstruation before the middle of the nth month. These values are also obtainable from probability integrals. This subtraction yields corrected intervals. Births averted by contraceptive use in the nth month are then obtained by dividing woman-months of use by the corrected mean birth interval and then subtracting the pregnancies occurring (obtained as 100,000 × pregnancy rate for month/n from life table) multiplied by the proportion of pregnancies terminating in a live birth (taken as 0.7). This method, by which pregnancies effectively carry a penalty equivalent to the full live-birth interval, is less accurate or justified than Potter's method.

The surviving fecund users for the next month $(n+1)$ are then obtained by multiplying the surviving fecund users for month n serially by the continuation rate for month n, the continuation modifying factor (up to 24 months only) and the withdrawal factor.

After a varying period, some of the columns in the table stabilize; i.e., the probability integrals tend towards a value of 1 indicating that all women have by then emerged from post-partum amenorrhea. When this value is reached, the effective population thereafter is equal to the surviving fecund users. The mean infecundity of the population already ovulating tends towards the mean infecundity of the whole population. When this value is reached, no further corrections of mean birth interval are indicated.

Continuation rates cease to vary after the limit of life-table evidence is reached and continuation modifying factors are dropped at 24 months, but recent evidence (e.g. Avery, 1973) suggests that these procedures could be improved.

Wolfers allowed pregnancy rates to decline up to three years after acceptance and then to level off. An improvement would have been to stipulate that after life-table experience was exhausted pregnancy rates—steady or declining—should be applied only to surviving fecund users instead of the cohort of initial acceptors.

Considerable attention is paid by Wolfers to the changing value of parameters as the population of effective users ages, and tabulations are made of the size of each sub-group for each year studied; single year age data are used in the reclassification. As users move from one age-group table to the next, transfer factors are employed to compensate for the differences in numbers of surviving effective users in the same month, n, in different age-groups. Thus, in the most extreme case, after 4 years' use there are still some 48,000 surviving fecund Malay users aged 40-44. When transferred to the table for women aged 45-49, they enter a line with only 3,458 survivors of 100,000 original entrants. The number transferred is therefore multiplied by 14.

Wolfers found in Singapore that one IUD averted (for the first three years after insertion) 0.57 births for Chinese women, 0.64 for Indian women and 0.79 for Malay women. Ethnic differences reflected higher fecundity, higher continuation rates and lower previous practice of contraception in the Malay groups. The weighted average was 0.59.

Wolfers' method is designed to yield births averted, by years after acceptance, in a program. It does not lend itself readily to computing births ever averted per contraceptive supplied.

COMPUTER SIMULATION

A fourth method of calculating births averted, one which in my view is likely ultimately to supplant all those described above (and the numerous variants to which reference has or has not been made) is the use of computer models to simulate the reproductive histories of cohorts of women from marriage to cessation of reproduction. Any desired family planning strategy can be introduced into such models and the results, in terms of births averted both in relation to items of contraceptive use and to time, can be derived by comparison with reproductive performance in the absence of the strategy. Ridley and Clague (1972) have demonstrated the technique in an intriguing experiment in which they tested each of the three methods described above—Lee and Isbister, Potter and Wolfers—against computer estimates obtained in this way. Family planning practice in the model was restricted to women over 35 so that the test was applied to women close to the end of reproductive life where truncation effects and assumptions regarding sterility and differentials between fertility of acceptors and the general population begin to assume major proportions in relation to results.

Over a five-year program period, Lee and Isbister's method overestimated births averted by 32 per cent and Wolfers' method by 8 per cent, while Potter's method underestimated by approximately 13 per cent. It is probable that had the test been performed on acceptors between 25 and 34, all three methods would have yielded results closer to those obtained by the computer and to each other's. The use of simulation models for direct computation of births averted in live programs, as distinct from their use as tools for the exploration of theoretical relationships, is handicapped at present by the scarcity of elaborated programs, workers available to employ them, and computer time.

In addition to the use of models made as realistic as possible by the selection of the most suitable parameters and the incorporation of all factors influencing reproduction, including death, divorce, widowhood, sterility, foetal wastage, etc., for which we are indebted to the work of Sheps and Perrin, Brass, Barrett, Potter, Ridley and Venkatacharya, another type of model, based on pure renewal theory, has been employed by Potter to explore the theoretical relationships involved in the calculation of births averted. This approach has been fruitfully employed in analyzing the effects of abortion (Potter, 1972c), the timing of IUD insertions (Potter *et al.*, 1973) and substitution effects (Potter, 1969b).

KELLY'S METHOD

W. J. Kelly (1971b) uses a method which computes the mean annual change in parity by age of acceptors—a numerator analysis approach. Because of the vastly differing probabilities for women of common age but differing parity becoming acceptors, it is difficult to accept that this value has any constant relationship to potential fertility.

OTHER

Apart from Venkatacharya's method, to which reference has been made in connection with the timing of births averted (section II.11), many other methodologies have been used, but these have mainly been either simplifying modifications of one or other of the methods described above or approaches seeking to solve somewhat different problems from that implied by the definition provided.

V. SYNTHESIS

It is feasible to combine some of the better features from these several approaches into a common system, more accurate and possibly simpler to employ, than any.

Every system needs to take into account:

a) "duration per birth" for each population sub-group;
b) use-effectiveness life-table continuation rates;
c) pregnancy rates and penalty per pregnancy;
d) proportion of acceptors sterile at acceptance;
e) development of sterility during use;
f) post-partum anovularity overlap;
g) substitution estimates.

Additional refinements, such as correcting durations per birth for shorter characteristic periods of post-partum amenorrhea, the consideration of mortality and widowhood, etc. separately from discontinuation rates, can safely be omitted without introducing serious inaccuracy.

Duration per birth cannot, in general field use, be calculated either from past fertility of acceptors or from birth intervals without costly and extensive surveys. A simpler derivation from available statistical estimates is essential for family planning programs without major research resources. Age-specific marital fertility rates, whether directly computed or estimated from age-specific fertility rates, will inevitably form their basis.

We would suggest the use of these rates modified as in equation (1) (page 178). This formula assimilates the development of sterility during use, and thus obviates the need for separate consideration of this possibility.

Life-table continuation rates may be used either in life-table form or converted into mean duration of use, depending on which general method of computation is selected.

Monthly pregnancy rates for periods covered by observation will be used, but their extrapolation beyond this period is a matter of judgement. Potter's suggestion for dealing with this appears to be somewhat cumbersome and it might be preferable to make an arbitrary estimate of the monthly risk of pregnancy related to the remainder of the population usefully employing the contraceptive during that month, and consistent with the life-table values.

Penalty per pregnancy should be computed, as described by Potter (see section III.3). In adapting the "penalty per pregnancy" concept to life-table use, an additional step between columns (n) and (o) of Table 6.2, in which the product of pregnancy rate, live birth ratio and population is further multiplied by penalty per pregnancy and divided by duration per birth, (A), or column (k), if it is employed, is required.

Whether arithmetic, logarithmic or exponential decay curves are employed in the calculation of monthly sterility risk makes little substantial difference except at ages over 40. Considerable difference does, however, result from the decision to include or exclude the risk of development of sterility incurred during the nine months of the last preceding pregnancy. Hard evidence to justify a recommendation is lacking, but theoretical considerations lead to the view that the probability of the development of permanent sterility is at least as high during an interval of time which embraces a pregnancy and live birth as during an equal interval which does not. Vincent (1950) and Henry (1953a) both consider that pregnancy imposes a sterility risk *additional* to the normal risk associated with aging. Henry (1953b) was able to confirm this for Norwegian women, but not for Japanese. I suggest, therefore, that proportions fertile at acceptance be calculated by applying monthly sterility risks to the period from the last conception to acceptance, i.e., open interval plus nine months.

Post-partum anovularity is best processed as described in Section III.2. If data are lacking, the process should nonetheless be performed on an artificial distribution of anovularity duration ([6]) with a mean consistent with whatever information about the population is available.

Adopters who are reported, in service statistics, as currently practicing other forms of contraception at the time of adoption may be assigned longer durations per birth than others. The modification should reflect an informed estimate of the likelihood that these couples would have continued to use the other method and for what

([6]) Potter (Potter and Masnick, 1971) follows Barrett (1969) in his most recent papers in assuming a Pascal distribution for post-partum amenorrhea.

mean length of time, as well as the use-effectiveness of the contraceptives involved. Very crudely, this could be achieved by calculating roughly the prolongation of stay in the fecundable state attributable to the non-program contraceptive and subtracting this from prolongations of stay achieved by the program contraceptive.

Thus, if it is estimated that a proportion, p, of current users would have continued to use non-program methods for a mean period of m months with a failure-rate of r pregnancies per 100 woman-years of use, a sub-group comprising p times the number of known "substituters" should be formed and assigned a new I value (see section IV, 2) for substituters, I_s, equal to:

$$I_s = I \pm F\left[A - \left(m - \frac{r}{100} \cdot \frac{m}{12} \cdot W\right)\right] \tag{16}$$

A, the mean post-partum amenorrhea value which was subtracted in calculating mean prolongation of stay, I, is restored for the substituting group value I_s on the assumption that current contraceptors are not amenorrheic, and certainly will not be when the assumed mean duration of use with the old method has elapsed.

For life-table calculations, a table for substituters is prepared in the normal way, but omitting allowance for amenorrhea. A separate negative summary, based on m months of use without attrition by discontinuation, but incorporating the estimated pregnancy rate with penalty, is prepared to yield the births that would have been averted by use of the first contraceptive method had substitution not occurred. This is deducted from net births averted. (See however, the conclusion of Section II.8(4).)

In choosing between the two principal methods available of performing the final calculations on the data, it would be invidious for the present author to pronounce. The summary calculations of prolongation of stay are mathematically neater and more sophisticated, but consequently less flexible and more fragile than the life-table approach.

Where the same parameters for durations per birth, proportions fertile at insertion, continuation and pregnancy rates are fed into the models, the results should differ little unless:

(i) continuation patterns depart radically from the exponential,
(ii) mean duration of use is long (over 5 years), or
(iii) a high proportion of users accepts near the end of reproductive life.

In these circumstances, the life-table approach seems the better adapted.

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