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OPTIMAL RESOURCE ALLOCATION: AN APPLICATION TO THE PHILIPPINE FAMILY PLANNING PROGRAM

by

Rolando A. Danao

ABSTRACT

A dynamic linear programming model has been devised for a family planning program offering five contraceptive methods. It can be used to test the consistency of family planning program plans and to select future goals consistent with projected resources together with the optimal strategy for accomplishing those goals. Applied to the Philippine family planning program, it shows that a reduction in proposed budget estimates for the years 1978-1982 is possible while achieving crude birth rates lower than the targets. This is accomplished by stressing the use of IUDs together with a limited number of sterilizations.

INTRODUCTION

Countries with high population growth rates have the immediate goal of achieving the greatest reduction in birth rates within the shortest time. This goal is accomplished by means of direct contraceptive methods such as pills, IUDs, condoms, rhythm, and sterilization. However, limited resources (e.g., operating budgets) and behavioral factors (e.g., acceptance and continuation of contraception) constrain a family planning program. Moreover, differences in method costs as well as method effectiveness necessitate the most cost-effective allocation of resources.

Studies dealing with this problem include a simple allocation model (Reinke, 1970) which indicates how family planning variables could be introduced into an optimization problem. Correa and Beasley (1971) developed a basic static allocation model that maximizes pregnancies avoided subject to a budget constraint. Several modifications of this model were presented by choosing different objective functions. Going beyond these general considerations, Lawrence, Mundigo, and ReVelle (1972) devised a linear programming model of resource allocation specifically adapted to the Honduras national family planning program. Although this model is simple in the sense that only one contraceptive method (pills) is involved, it incorporates the essential features of a family planning program including its dynamic characteristics which are especially important since continuation rates and recurring costs influence cost-effectiveness. This model was later expanded (Lawrence et al., 1973) to include two contraceptive methods (pills and IUDs) and was applied to the Dominican Republic's family planning program.

This paper formulates a linear programming model of the Lawrence-Mundigo-ReVelle (LMR) type for Philippine Family Planning (PFP). However, it differs from the LMR model in several respects. First, it is designed for a planning horizon not exceeding fifteen years. This means that fertility changes made by the program will not affect the population of women who become fertile during the planning horizon. (Fertility is assumed to begin at age 15). Second, the PFP model minimizes total births instead of total female births. Third, it has no constraint requiring that the terminal crude birth rate (CBR) be less than or equal to a given target CBR since we want to use the model in selecting the CBR targets. For each set of resource and behavioral parameters, the model gives an optimal solution from which the associated CBR for each period is computed. By experimenting with various levels of resources and various changes in the behavioral parameters, a set of CBRs can be obtained from which administrators can select future goals together with the course of action to accomplish those goals. Computationally, the absence of a CBR constraint makes the linear programming problem always feasible with an optimal solution. Consequently, if the decision-maker's prespecified CBR targets are infeasible, the model tells him how far he is from his targets.

THE PHILIPPINE POPULATION PROGRAM

When the Philippine government launched the National Population Program in 1970 the population was growing at 3.01% a year (Concepcion, 1978) with a CBR of 40-43 per thousand population (De Guzman, 1978). Administered by the Commission on Population (POPCOM) the program initially offered four contraceptive methods namely pills, rhythm, IUDs, and condoms, adding sterilization in 1975.

Since its inception the program has been clinic-based although other approaches to reinforce the clinic were later instituted. In 1975 the Total Integrated Development Approach (TIDA) was introduced to integrate family planning with other development activities. At the same time the Outreach Project was organized in response to the discovery of an urban bias in contraceptive use. A year later this was adopted nationwide to extend the program more fully to the rural areas where 70% of the married women in the reproductive ages reside.

Table 1 shows the level of new acceptances for three selected years. New acceptances steadily increased from 1971 to a peak in 1974 and declined after that. Continuin users grew to an estimated number of 1.39 million in the first quarter of 1977 (Laing, 1977b). Meanwhile, the grow rate in 1975 was estimated at 2.79% (Concepcion, 1978) anc the average crude birth rate for 1970-1975 was estimated at 37.4 per thousand population (De Guzman, 1978).

THE MODEL

The model considers only the population of married women in the reproductive ages 15-44 (MWRAs). Contracepto are classified according to the five contraceptive methods offered by the Philippine family planning program. In addition we distinguish between beginning and continuing contraceptors since the costs of providing service to them differ. A five-year planning horizon (1978-1982) was chos to coincide with the Five-Year Philippine Development Plan The model minimizes the expected number of births from the MWRAs during the planning horizon subject to the following constraints: budget, clinic capacity, beginner eligibility continuation, and accounting identities.

Table 1. New Acceptors by Method: Philippines, 1971, 1974, 1977

Method	1971 (in 000's)	1974 (in 000's)	1977 (in 000's)
Pills	136.5	336.3	194.4
Rhythm	29.9	45.7	21.5
IUDs	63.6	85.4	43.1
Condoms	7.5	130.1	122.0
Sterilization	-	-	68.6
Others	6.7	21.1	7.6
Total	244.2	618.6	457.2

Note: Data was based on POPCOM estimates and adjusted for over-reporting.

Source: Pernia-Danao (1978), Table 7.

The Objective Function

Notations: n: noncontraceptors,

b: beginning contraceptors,

c: continuing contraceptors,

i: age, $i = 15, 16, \ldots, 44$,

m: method, m = 1(pills), 2(rhythm), 3(IUDs), 4(condoms), 5(sterilization),

t: year, $t = 1, 2, 3, 4, 5$,

N = number of noncontraceptors,

X = number of contraceptors,

β = births per woman per year.

The objective is to minimize the total number of births over the planning horizon, i.e.,

$$\text{minimize} \quad \sum_i \sum_t \beta_i^n N_{it} + \sum_i \sum_m \sum_t (\beta_{im}^b X_{imt}^b + \beta_{im}^c X_{imt}^c). \qquad (1)$$

Note that in the above summation the beginning contraceptors start at $i = 15$ while the continuing contraceptors start at $i = 16$.

The Budget Constraints

The total yearly cost of providing service to all contraceptors must not exceed the year's budget, i.e.,

$$\sum_i \sum_m (C^b_{mt} X^b_{imt} + C^c_{mt} X^c_{imt}) \leqq B_t, \tag{2}$$

where C = yearly cost of providing service to a contraceptor,

B = budget.

Clinic Capacity Constraints

First, we point out that sterilizations are done in specially designated centers which are separate from the family planning clinics. Hence, we treat them separately.

Clinic capacity may be expressed in terms of available clinic personnel time. Typically, a family planning clinic has a doctor, a nurse, and a midwife. Since nurses and midwives have overlapping duties, no distinction is made between them and they will be referred to as nondoctors. We then have two clinic capacity constraints, one for doctors and another for nondoctors. Let

h = yearly doctor hours required by a contraceptor,

H = total doctor hours available in a year,

$\bar{h}$ = yearly nondoctor hours required by a contraceptor,

$\bar{H}$ = total nondoctor hours available in a year.

The doctor and nondoctor hours required by a contraceptor are method-specific but age-independent and are assumed to remain constant over the planning horizon. For each year the total number of doctor hours required by all contraceptors must not exceed the total doctor hours available in that year, i.e.,

$$\sum_i \sum_{m \neq 5} (h_m^b X_{imt}^b + h_m^c X_{imt}^c) \leq H_t, \tag{3}$$

Similarly,

$$\sum_i \sum_{m \neq 5} (\bar{h}_m^b X_{imt}^b + \bar{h}_m^c X_{imt}^c) \leq \bar{H}_t. \tag{4}$$

Sterilization centers are mostly located in hospitals where newly sterilized patients stay for 4-5 hours after the operation. (The sterilization mobile units are being phased out.) Consequently, hospital bed capacity as well a doctor's time are the relevant physical resources since staff support for the sterilization doctor is always available in the hospital. Let

- h^s = doctor hours required for one sterilization,
- H^s = total doctor hours available for sterilization in a year,
- $\hat{h}^s$ = number of hospital post-operation hours required by a sterilized patient,
- $\hat{H}^s$ = total number of hospital bed-hours availabe for sterilized patients in a year.

The sterilization capacity constraints are then given by the following inequalities:

$$\sum_i h^s X_{i5t}^b \leq H_t^s, \tag{5}$$

$$\sum_i \hat{h}^s X_{i5t}^b \leq \hat{H}_t^s. \tag{6}$$

Beginner Eligibility Constraints

Beginning contraceptors are drawn from the population of eligible women which consists of the MWRAs who are not currently using a method or are not pregnant. In addition, for particular methods, beginning contraceptors must not be disqualified by illness (e.g., heart disease precludes the use of pills) or by policy (e.g., having fewer than three living children disqualifies a couple from sterilization). Let

M_{it} = number of MWRAs of age i in year t,

p_i^n = probability that a noncontraceptor of age i becomes pregnant in a year,

M_{it}^e = number of MWRAs of age i eligible to begin using a method in year t,

M_{imt}^e = number of MWRAs of age i eligible to begin using method m in year t,

ε_{imt} = proportion of M_{it}^e who are eligible to begin using method m in year t.

We then have

$$M_{it}^e = (1 - p_i^n)\,(M_{it} - \sum_m X_{imt}^c), \tag{7}$$

$$M_{imt}^e = \varepsilon_{imt}\, M_{it}^e. \tag{8}$$

The number of beginning contraceptors of age i using method m in year t must not exceed M_{imt}^e, i.e.,

$$X^{b}_{imt} \leqq M^{e}_{imt}. \tag{9}$$

At the same time the total number of beginning contraceptors of age i in year t must not exceed the number eligible MWRAs of age i in year t, i.e.,

$$\sum_{m} X^{b}_{imt} \leqq M^{e}_{it}. \tag{10}$$

Continuation Constraints

The continuing contraceptors in a particular year come from those who began contraception in previous years. They consist of continuous users, resumers, and shifters.

Continuous users and resumers in the same method are taken together. The reason is that a new type of continuation rate defined by Laing (1977a), called the super-extended continuation rate, incorporates resumption of use after pregnancy. The use of this continuation rate simplifies the model.

Although a shifter to another method may be a beginne in that method we include her among the continuers. This justified by the fact that the costs of inducing a potenti contraceptor to accept contraception had already been attr buted to the shifter. Moreover, the 1974 National Accepto Survey (NAS) showed that shifters had about the same use-effectiveness with later methods as those whose first method was the same (Laing, 1977a). As an added simplifyi assumption, we draw shifters in year t from the beginners in year $t-1$ since a contraceptor who had been using a method must have found it suitable and hence, is unlikely to change methods. We also ignore those who resume and shift to another method since the incidence of changing to other methods by drop-outs is low (Laing, 1977a). Shifters to sterilization, however, are counted as beginners; otherwise, including them immediately among the continuers will omit their sterilization costs since we have assigned a zero cost to a continuing sterilization contraceptor.

The continuing contraceptors in the base year $t = 0$ (1977) ~~have~~ to be treated in a special way. First, we note that this group has used contraception for varying lengths of time with a minimum of one year. Second, the superextended continuation rates remain fairly stable after the first year (Laing, 1978). Hence, it is reasonable to regard all continuers in year $t = 0$ as beginners in year $t = -1$. Let

κ_{mj} = probability that contraceptors who begin using method m will be using it after j years,

$\sigma_{m'm}$ = probability that a contraceptor using method m' shifts to method m in a year,

s_i = probability that a female of age i survives to age $i + 1$.

For each of the first four methods (pills, rhythm, IUDs, and condoms) the continuing contraceptors in year t consist of the continuous users and resumers in the method plus the shifters to the method from year $t-1$ plus the shifters in years previous to $t-1$ who are continuing in th method, i.e.,

$$X^c_{imt} = \sum_{j=1}^{t+1} \kappa_{mj} X^b_{i-j,m,t-j} + \sum_{m' \neq m,5} \sigma_{m'm} X^b_{i-1,m',t-1}$$

$$+ \sum_{j=2}^{t+1} \sum_{m' \neq m,5} \kappa_{mj} \quad {}_{m'm} X^b_{i-j,m',t-j}, \quad m=1,2,3,4.$$

Note that in (11) there is no shifting from sterilization as this operation is irreversible. The continuing sterilization contraceptors consist of the sterilized contraceptors who survive from the previous year, i.e.,

$$X^c_{i5t} = s_{i-1}(X^b_{i-1,5,t-1} + X^c_{i-1,5,t-1}). \qquad (12)$$

Accounting Identities

The following equations express the fact that the population of MWRAs of age i in year t is partitioned in noncontraceptors, beginning and continuing contraceptors in the various methods:

$$N_{it} + \sum_m (X^b_{imt} + X^c_{imt}) = M_{it}. \qquad (13)$$

These equations are incorporated in the constraints to preclude obtaining the trivial optimal solution where the decision variables N_{it} and X^b_{imt} are assigned zero values

MODEL INPUTS

Four types of inputs are required by the model: demographic data, contraceptors data, family planning costs, and family planning program resource projections.

Demographic Data

The demographic data include female survival rates, age distribution of the female population, age-specific marital fertility rates, and nuptiality projections.

Female survival rates for five-year age groups were obtained from published life tables (National Economic Development Authority, 1975) from which year-to-year survival rates were computed by linear interpolation. These computed rates were used to project the female population by single year age classification for the years in the planning horizon based on the 1975 Census (National Census and Statistics Office, 1978).

No data on age-specific marital fertility rates (ASMFR) of noncontraceptors are available. However, the ASMFRs of MWRAs as well as the post-acceptance ASMFRs of contraceptors were estimated for the period 1968-1972 (Laing, 1977a). Using the contraceptive prevalence during that period, the following relation gives the ASMFRs of noncontraceptors:

$$\pi_i(MFR_i^c) + (1 - \pi_i)(MFR_i^n) = MFR_i, \qquad (14)$$

where π_i = proportion of MWRAs of age i who are curren[tly] using contraception (contraceptive prevalenc[e]),

MFR_i^c = marital fertility rate of contraceptors of a[ge] i (post-acceptance marital fertility rate),

MFR_i^n = marital fertility rate of noncontraceptors o[f] age i,

MFR_i = marital fertility rate of MWRAs of age i.

Projections of the MWRAs were obtained by using the moderate series of the "percents currently married" projections made by Encarnación, et al. (1974). Values for the years in the planning horizon were linearly interpolated.

Contraceptors Data

Estimates of the number of beginning contraceptors by method for the base year were obtained from POPCOM and were adjusted for over-reporting (Pernia-Danao, 1978). To estimate the number of continuing contraceptors in the base year, we assumed that 25% of the beginning contraceptors in 1977 accepted in the first quarter of the year, an assumption based on records of monthly acceptances in previous years (Nortman-Hoffstater, 1976). We then subtract these beginners from the first quarter estimate of current users made by Laing (1977c).

The age distribution of beginning contraceptors were based on the "age at acceptance date" table obtained from the 1976 NAS for pills, rhythm, IUDs, and condoms. We assumed that the continuers were similarly distributed. Since the 1976 NAS has no such data for sterilization contraceptors, we used an age distribution based on a random sample of 5000 new acceptors during the period July, 1977 - March, 1978. The sample was provided by the Management Information Systems at POPCOM.

Age-specific twelve-month accidental birth probabilities (average for the first three years following acceptance) were provided by Dr. John E. Laing of the University of the Philippines Population Institute while superextended continuation rates were obtained from Laing (1978). Dr. Laing's estimates were based on the 1976 NAS. Since shifting rates were not available, we used the 1976 NAS data on second method percentages by first method accepted as an approximation.

Family planning practices determine eligibility to accept a method. While no restrictions are made regarding rhythm and condom use, there are certain restrictions specific to pills, IUDs, and sterilization by reason of illness or policy. For example, cancer in the genital tract disqualifies a woman from using an IUD. But the prevalence of this disease is not known. Regarding pill use, women 35 or older are dissuaded from using pills while continuous pill contraception beyond four years is discouraged. The 1976 NAS, however, showed that 19% of pill users were at least 35 years old while 8% used pills continuously for more than four years. Some sterilization centers require sterilization acceptors to be at least 35 years old while others specify an age bracket of 27-43. Sampled data on sterilization acceptors showed that 12% were aged 24 and below. Thus, lack of data or the absence of uniformity in practice made us ignore these restrictions.

However, in the case of sterilization, the Office of Clinic Services at POPCOM believes that no sterilization for the purpose of family planning is done in the 15-19 age group. Consequently, this group was excluded from the potential sterilization contraceptors. In addition, steri ization contraceptors must have at least three living chil ren. The 1973 National Demographic Survey (NDS) showed th 66.5% of MWRAs had at least three living children (Special Committee, 1978). This percentage is unlikely to change very much during the planning horizon. (By way of compari son, 66.1% of the acceptors in the 1976 NAS had at least three living children). This implies that the number of potential sterilization contraceptors is large. (The esti mated number of 1977 MWRAs in the 20-44 age group was abou five million). Since sterilization is the most cost-effec ive method for multi-period planning horizons, the model will choose to sterilize all acceptors. As this is socia infeasible, we limited the maximum number of sterilization acceptances using POPCOM sterilization targets as upper bounds. No such restrictions were imposed on the other four methods since, as Lawrence et al. (1972) point out, imposing them would establish the pattern of acceptances and limit the model's prescriptive usefulness.

Family Planning Cost Data

Family planning cost data were gathered from various sources including (1) a sample survey of family planning clinics across the country, (2) agencies participating in the family planning program, (3) the Commission on Population, and (4) the Report of the Special Committee to Review the Philippine Population Program. The data obtained were used to estimate the yearly cost of providing service to a beginning and continuing contraceptor for each method.

To determine the yearly cost per contraceptor by method, we separate the clinic costs from the nonclinic costs. Clinic costs are those incurred directly in the operation of the clinic while nonclinic costs include administration, training, research and evaluation, IEC (information, education, and communication), TIDA/Outreach, and others.

Clinic costs are categorized into method-specific costs and method-joint costs. The method-specific clinic costs consist of the cost of clinic personnel time spent with the contraceptor and the cost of contraceptive materia (In the case of sterilization, the method-specific cost is the payment to the sterilization center). It is determined from the following information: (1) average salary per hou of doctors and nondoctors, (2) average annual number of cl visits made by a beginning (continuing) contraceptor, (3) age annual time spent by a doctor and a nondoctor to servic a beginning (continuing) contraceptor, (4) annual amount c contraceptive materials used by a beginning (continuing) cc traceptor, and (5) unit cost of contraceptive materials.

The method-joint clinic costs consist of the clinic operation costs that are not directly attributable to any method such as travel, repairs and maintenance, noncontraceptive supplies, communication and other costs. To alloca this joint cost to the different contraceptors, we used the average annual time spent by the contraceptors in the clini as basis for determining their proportionate shares, i.e., a contraceptor spending more time in the clinic bears proportionately more of the joint costs.

Sterilization centers were paid 92 pesos per tubal ligation and 50 pesos per vasectomy. Since the model has n separate variables for male and female sterilizations, we took the weighted average cost based on the ratio of male to female sterilizations in 1977. We have assumed that women whose husbands have been sterilized are sterilization contraceptors and the male to female sterilization ratio remains constant during the planning horizon.

Nonclinic costs are regarded as joint costs. Moreover, since nonclinic activities are supportive of all methods, it is more appropriate in this case to allocate nonclinic costs proportionately according to the number of contraceptors in each method who availed of program services.

Family Planning Resource Projections

The POPCOM resource projections and targets are shown in Table 2. Because most family planning clinics are integrated with health units offering other services, the total clinic personnel time is not entirely available for family planning services. The time for family planning was estimated by taking the ratio of family planning clients to the total number of clients. This ratio was obtained by examining logbooks of the surveyed clinics and where no logbooks are kept the estimates of clinic personnel were obtained. On the average about 25.7% of clinic clients were family planning clients.

The Full-Time Outreach Workers, included in Table 2, enhance clinic capacity since they also provide clinic-related services such as dispensing contraceptives.

Table 2. Family Planning Targets and Projected Resources: Philippines, 1978-1982

	1978	1979	1980	1981
Total expenditures[a]	173,504	218,788	304,345	318,967
Family Planning Clinics	3,553	3,553	3,553	3,553
Full-time outreach workers	2,941	2,997	3,102	3,102
Crude birth rate[b]	35	35	34	33

a - In thousand pesos at current prices.

b - Per thousand population.

Source: Special Committee (1978).

As no sterilization resource projections were available we took the POPCOM sterilization targets as representative of the maximum sterilization capacity projected by the program. Accordingly, constraints (5) and (6) were replaced by the following constraints:

$$\sum_i Y^b_{i5t} \leq S_t, \qquad (15)$$

where S_t is the targetted number of sterilizations in year t.

RESULTS

The main objective of this study was to determine the mix of contraceptors that minimizes the number of births over the planning horizon 1978-1982 for a given set of resources and assuming that continuation rates and use-effectiveness prior to the planning horizon continue to prevail. Additionally, we sought to determine (1) the feasibility of the POPCOM targets, (2) other feasible targets with the same resources, and (3) other targets together with the resources that are linked to the targets in an optimal way.

Three plans were considered. Plan A incorporates POPCOM resource projections and assumes prices to increase at the rate of 10% every year. The optimal results are shown in Table 3. All sterilization targets are attained except on the last year when no sterilization is planned, a consequence of the fact that cost-effectiveness on the last year, being measured only for that period, does not take account of the lagged effects of sterilization. At the same time, the attainment of all sterilization targets up to the fourth year implies that sterilization becomes the most cost-effective method within two years. Obviously, sterilization cost-effectiveness improves as the planning horizon is lengthened because of 100% effectiveness and no recurring costs.

As Table 3 shows the optimal pattern of new acceptances involves only sterilization and IUD acceptors. The projecte budgets are large enough to take care of the predicted continuing contraceptors as well as a large number of new ones bringing CBRs down from 25 in year 1 to 21 in year 5. The shadow price of the financial resource, given in births averted per peso (please see Appendix), averaged 0.0047. Equivalently, it will cost 212 pesos (in 1977 prices) to avert one birth. This is 25% lower than the 1977 cost per FBA (future births averted) estimated to be 282 pesos (Pernia-Danao, 1978). (It must be mentioned that the primal problem implicitly assumes that the MWRAs are homogeneous; hence, the dual problem assumes that if a contraceptor were not contracepting, her fertility would be that of a noncontraceptor. In actual fact, contraceptors tend to have a

Table 3. Optimal Results

	1978	1979	1980	1981	1982
Plan A					
Budget[a]	173.5	218.8	304.3	319.0	340.6
Beginning Contraceptors[b] (in 000's)					
IUDs	712.5	520.3	708.5	107.4	243.3
Sterilization	69.6	63.3	99.7	110.2	0
Continuing Contraceptors (in 000's)	1544.8	2195.8	2585.1	3262.0	3332.0
Births Averted Per Peso (1977 prices)	0.0043	0.0046	0.0046	0.0049	0.0051
CBR[c]	25.1	22.8	19.6	20.6	21.3
Plan B					
Budget[a]	150.0	187.5	234.4	281.2	323.4
Beginning Contraceptors[b] (in 000's)					
IUDs	402.6	311.5	209.1	140.3	252.2
Sterilization	69.6	63.3	99.7	110.2	0
Continuing Contraceptors (in 000's)	1544.8	1900.5	2146.3	2387.2	2588.6
Births Averted Per Peso (1977 prices)	0.0043	0.0046	0.0047	0.0050	0.0054
CBR[c]	27.6	26.6	26.2	25.6	25.3

Table 3 ...

	1978	1979	1980	1981	1982
Plan C					
Budget[a]	150.0	187.5	234.4	281.2	323.4
Beginning Contraceptors[b] (in 000's)					
IUDs	385.7	308.7	258.8	137.5	274.8
Sterilization	69.6	63.3	99.7	110.2	0
Continuing Contraceptors (in 000's)	1544.8	1884.3	2053.0	2356.6	2557.3
Births Averted Per Peso (1977 prices)	0.0042	0.0044	0.0046	0.0049	0.0054
CBR[c]	27.8	27.4	26.5	25.9	25.4

a - In million pesos at current prices.

b - Pills, rhythm, and condoms have zero entries.

c - Per thousand population.

higher fertility rate than the rest of the MWRAs (Laing, 1977a). Hence, the number of births averted, as is the shadow price, tends to be underestimated).

Although not shown in Table 3, the results showed that the budget constraints are binding throughout the planning horizon while the clinic capacity constraints are not, indicating that financial resources are more scarce relative to the physical resources. At the same time there is a surplus of eligible women. Obviously, where there is excess clinic capacity and a large number of eligible women budget constraints will be binding since more contraceptors can be obtained as long as funds are available. This, of course, will be true provided the annual budgets are internally consistent, i.e., the budget in year t should be able to support at least the predicted number of continuing contraceptors in that year. Otherwise, the model will choose a smaller number of contraceptors prior to year t (creating surplus budgets in those years) in order that continuers in year t may be supported by its budget. This demonstrates the usefulness of the model in testing the consistency of program plans.

Because the CBRs in Plan A are very much lower than the POPCOM targets and because the levels of new acceptors in the early years of the planning horizon are much higher than the 1977 level (and thus may not be easily achievable) we considered a reduced set of annual budgets (averaging a

14% reduction) with a declining growth rate (Plan B). At the same time prices were assumed to increase by 15% per annum. As expected the CBRs increased but are still below POPCOM targets. Compared with Plan A the CBRs in Plan B decline more smoothly while the annual levels of new acceptors are below that of 1977 making them more achievable targets.

One of the problems in meeting sterilization targets is the availability of doctors willing to participate in the program. As an inducement, sterilization payments can be increased. In Plan C payment per sterilization is increased from 87 pesos (1977 average for vasectomies and tubal ligations) to 110 pesos, a 25% increase. Plan C assumes the budgets and price increases in Plan B. The effect is to increase CBRs by an average of only 1% while remaining below POPCOM targets.

Figure 1 shows the CBR trends under the three plans considered above. Also shown as benchmark are the CBRs if there were no family planning, ie., if the fertility rates were those observed in 1968-1972.

CONCLUDING REMARKS

The following conclusions emerge from the preceding results: First, the projected resources for 1978-1982 are

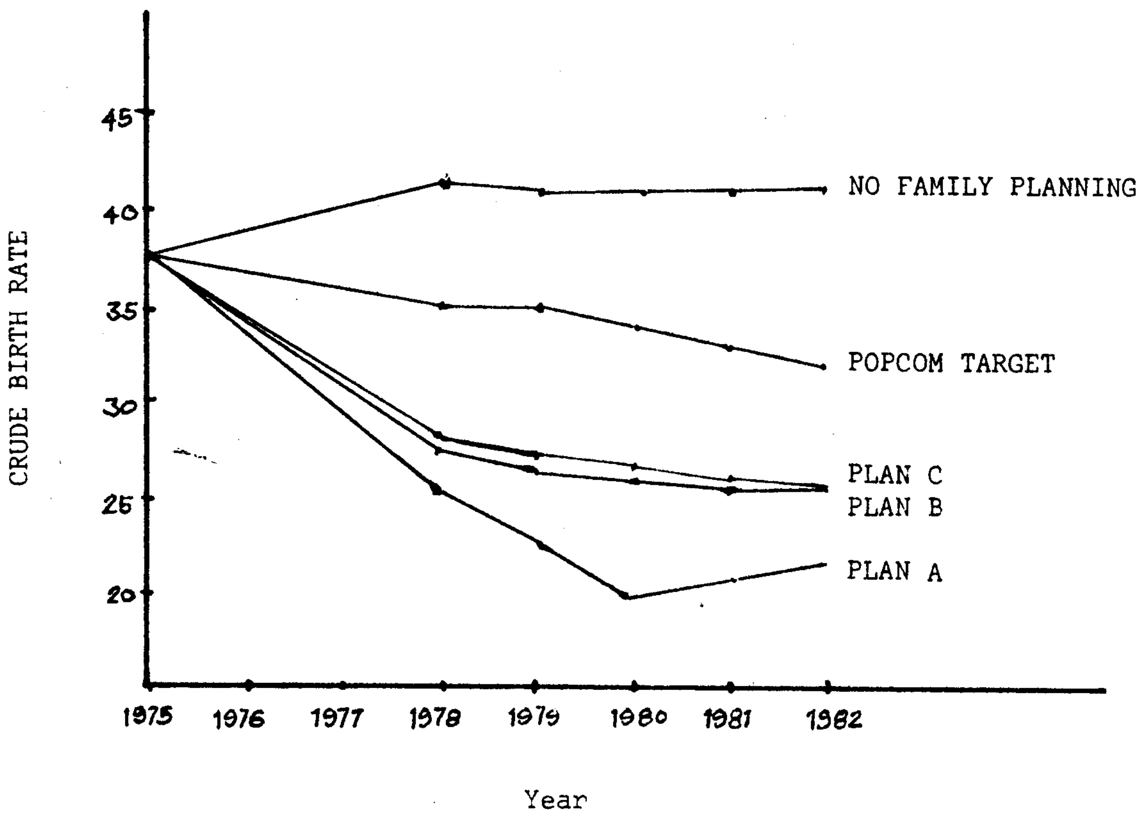

Figure 1. Crude Birth Rate Projections

Source: Tables 2, 3

sufficient to achieve the crude birth rate targets specified by POPCOM. The findings show that even with reduced budgets crude birth rates lower than the targets are attainable. A second conclusion, which should be viewed in relation to the first one, is that the lower crude birth rates can be achieved if new contraceptors accept only IUDs and sterilization. This suggest strongly that the program should stress the use of these two methods. Third, increasing sterilization payments to ensure the achievement of sterilization targets results in a correspondingly small rise in crude birth rate. A 25% increase in sterilization cost results in a 1% rise in crude birth rates.

The usefulness of a mathematical planning model improves by iteration that includes refinement of the model, updating of data, and feedback from policy-makers. In succeeding studies we suggest the following:

(1) It would be useful to look at other sets of policy alternatives by incorporating upper bounds on IUD acceptances.

(2) The endpoint problem of no sterilizations at the end of the planning horizon can be remedied by extending the horizon by one period. However, this could be costly in terms of computation since constraints repeat by the addition of a period. A cheaper way out would be to specify the number of new sterilizations at the terminal period.

(3) With a maturing family planning program the cost

of recruitment of new acceptors increases as the program tries to reach the less susceptible segment of the eligible population. Hence, the costs of beginning contraceptors should reflect not only increases in price but also the rising cost of recruitment.

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APPENDIX: INTERPRETATION OF THE DUAL PROBLEM

We examine a simple linear programming model and inter-pret its dual within the context of family planning. To do this we need the following duality theorems from linear programming theory (Chiang, 1974):

Duality Theorem 1: If either the primal or the dual h an optimal solution, then the other has an optimal solution and the optimal values of their objective functions are equal.

Duality Theorem 2: If a primal (dual) variable is non zero, then the corresponding dual (primal) constraint is an equality.

To keep the size of the problem small we present a one-period two-method model that minimizes births subject to budget and clinic capacity constraints. We use the foll ing notations:

W = set of women under consideration,

w = number of women in W,

N = number of contraceptors in W,

β_0 = proportion of noncontraceptors who bear a child in one period,

X_m = number of method m contraceptors, $m = 1,2$,

β_m = proportion of method m contraceptors who bear a child in one period,

c_m = cost of providing service to a method m contraceptor for one period,

b = budget for the period,

h_m = number of clinic personnel hours required to service a method m contraceptor in one period,

h = total number of clinic personnel hours available during the period.

Primal Problem: Minimize $\beta_0 N + \beta_1 X_1 + \beta_2 X_2$

Subject to

$$\begin{aligned} c_1 X_1 + c_2 X_2 &\leq b \\ h_1 X_1 + h_2 X_2 &\leq h \\ N + X_1 + X_2 &= w \\ N, X_1, X_2 &\geq 0. \end{aligned}$$

Dual Problem: Maximize $bY_1 + hY_2 + wY_3$

Subject to

$$\begin{aligned} Y_3 &\leq \beta_0 \\ c_1 Y_1 + h_1 Y_2 + Y_3 &\leq \beta_1 \\ c_2 Y_1 + h_2 Y_2 + Y_3 &\leq \beta_2 \\ Y_1 \leq 0,\ Y_2 \leq 0,\ &Y_3 \text{ free.} \end{aligned}$$

We note that the primal problem has a feasible solution $N = w$, $X_1 = X_2 = 0$ and since the problem is bounded it has an optimal solution (N^*, X_1^*, X_2^*). By Duality Theorem 1 the dual problem has an optimal solution (Y_1^*, Y_2^*, Y_3^*) and

$$\beta_0 N^* + \beta_1 X_1^* + \beta_2 X_2^* = bY_1^* + hY_2^* + wY_3^*. \qquad \text{(A)}$$

Since the primal objective function denotes births, then each term on the right hand side of (A) denotes births.

If budget b is in pesos, then Y_1^* must be expressed in per peso. Similarly, Y_2^* represents births per hour of personnel time and Y_3^* represents births per woman (fert

The fact that $Y_1^* \leqq 0$ and $Y_2^* \leqq 0$ suggests that $bY_1^* + hY_2^*$ represents births averted. This can be seen as follows. We may assume that there is at least one noncon-ceptor, i.e., $N^* > 0$. By Duality Theorem 2 the first dual constraint is binding, i.e., $Y_3^* = \beta_0$. Consequently, $wY_3^* = w\beta_0$ represents the total number of births from all women in W in the absence of contraception. Since the left hand side of (A) represents births with contraceptio it follows that $bY_1^* + hY_2^*$ represents births averted.

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