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Estimation of Proximate Variables to Achieve Required Level of Fertility in Bangladesh: Modeling Approach

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Abstract Proximate determinants influence level of fertility in a society. The aim of this study were to estimate the total fertility rate (TFR) for a given level of contraceptive prevalence rate (CPR) and estimate the CPR, some indices and factors for achieving the target TFR. For this, data were extracted from Bangladesh contraceptive prevalence survey, Bangladesh fertility survey and Bangladesh demographic and health survey. Linear regression analysis and revised Bongaarts' models were used to estimate proximate determinants for achieving target TFR. The regression coefficient demonstrated that TFR has been decreasing while CPR increasing during the investigated period with highly negatively associated between TFR and CPR ($p<0.01$). The results indicate that to achieve replacement level of fertility at 2.1 births per woman it should be increased the CPR, singulate mean age at marriage, duration of breastfeeding and amenorrhea period at 68%, 20.80 years, 37 months and 2.37 months respectively.

Keywords Target fertility, Fetal wastage, Amenorrhea period, Breastfeeding, Bongaarts' model

1. Introduction

The study of determinants of human fertility is a very complex process. Human fertility influence population growth, which has consequences towards pressure on resource, employment situations, health and other social facilities and savings and investment, such consequences, in turn, great bearing on the demographic and socio-economic variables that affect fertility behavior. The level of fertility in a society is directly influenced by a set of variables called intermediate variable or proximate determinants [1]. In general, the biological and behavioral factors through which demographic, socio-economic, culture and environmental variables affect fertility called an intermediate fertility variable. The primary characteristics of an intermediate fertility variable are its direct influence on fertility.

Bongaarts' [2] revised the original classification and provide a simple analytical method accounting framework, which permits a quantitative assessment of the contribution of different proximate determinants to give fertility levels or change. Bongaarts' [3] demonstrated that most of the variation in fertility is due to four intermediate variables or proximate determinants. These are proportion married, contraception, abortion and lactational infecundability. If a proximate determinant such as contraceptive use changes, then fertility necessarily changes also (assuming the other proximate determinants remain constant), though this is not necessarily the case of socio-economic determinants. As a result, fertility differences among populations and changes in fertility of a population over time can always be traced to variations in one or more of the proximate determinants.

Historical studies about fertility change have shown that, as societies being to undergo the transformation from natural to deliberately controlled fertility, significant changes in the overall levels of total natural fertility, total marital fertility and total fertility being occur [4]. Such changes can be traced to one or more proximate determinants, such as, an increase in contraceptive use for stopping and spacing purposes a rise in age at first marriage, a decline in the proportion married, prolonged breastfeeding and fetal wastage [5].

To improve our understanding of the fertility change, we critically examine the effect of major proximate determinants: proportion married contraception, fetal wastage and lactational infecundability on fertility and their changing effects. Again, since fertility is the resultant of multiplicity of factors, studies have attempted to identify these factors, which have important bearing for policy intervention in altering the level of fertility [6, 7, 8].

Many developing countries like Bangladesh emphasize the importance of reducing fertility as part of her overall strategy to bring down the growth rate of population. Family planning programs at work in the country in order to achieve demographic goals through the reduction of fertility. The

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demographic goals of accepters of different family planning methods are to be recruited in each case.

There is always been a gap between the target fertility and its achievement at the terminal year of the target period in all its plan periods. The country has never gained either the desired level of fertility or the contraceptive prevalence rate (CPR) at achieving the target fertility [9]. For example, during the plan period 1980-85 the target fertility has been 4.1 children per woman (total fertility rate: TFR) and the desired level of CPR has been 38%, the achievement have been a (TFR) of 5.55 and CPR of 25%. Similarly, TFR and CPR are also found during the plan period of 1985-90 [10]. Such gaps have raised questions about the estimation equation used to project CPR in order to achieve TFR at a desired level at the end of a plan period. It was found that all the proximate indices were showing downward trend caused by increasing the effectiveness use of contraception and in between 1997 and 2007, the amount of decrease in the total fertility rate is about 17% and about 10% from 2004 to 2007 [11].

The aims of this paper are to (i) estimate the TFR for a given level of CPR, (ii) estimate the CPR for achieving the target fertility level (TFR) taking into account the trends in a few proximate determinants of fertility, (iii) estimate the indices of proportion married (C_m), non-contraception (C_c), lactational infecundability (C_i), and fetal wastage (C_{fw}), for achieving the target fertility and (iv) estimate the mean age at marriage, amenorrhea period, and duration of breastfeeding for desired level of fertility.

2. Data and Methods

The study uses data available from surveys as Bangladesh Contraceptive Prevalence Surveys of 1979, 1981, 1983, 1985 [12, 13, 14, 15] and Bangladesh Fertility Surveys of 1975, 1989 [16, 17] also Bangladesh Demographic and Health Surveys of 1994, 1997, 2000, 2004 and 2007 [18, 19, 20, 21, 22]. These surveys cover the nationwide representative sample and the data provided by these surveys are taken to be of good quality.

2.1. Target Setting Model of CPR to Achieve Required TFR

Estimate of TFR for given level of CPR is made by fitting a simple regression model of the form TFR = α + β CPR + ε, where, α and β are two parameters and ε is the error term of the model. Estimate of α and β are made by the method of Least Squares using longitudinal data of TFR and CPR from 1979 to 2007. The practice of fitting regression equation to the data of TFR and CPR of which TFR is a dependent variable is not a new one. Bongaarts` [23] examine the strength of relationship between TFR and CPR by fitting a regression line of TFR on CPR.

Again, projection of CPR for the attainment of a specified level of fertility is made by means of Bongaarts` proposed [24] target setting model. The model is derived as Bongaarts` original multiplicative model relating TFR with a few proximate determinants of fertility, the model is therefore; $TFR = C_m \times C_c \times C_{fw} \times C_i \times TF$, where C_m, C_c, C_{fw} and C_i are the indices of proportion married, non-contraception, fetal wastage and lactational infecundability respectively and TF, the total fecundity rate. Each of the four indices various from 0 to 1, the model can be applied for target setting for the target year t with respect to the base year 0. That is,

$$\frac{TFR(t)}{TFR(0)} = \frac{C_m(t) \times C_c(t) \times C_{fw}(t) \times C_i(t) \times TF(t)}{C_m(0) \times C_c(0) \times C_{fw}(0) \times C_i(0) \times TF(0)}$$

The above equation indicates that the reduction in fertility from TFR (0) to the target level depends on the trend in all of the indices of proximate variables. The base year may be the present or some recent year. Under the assumptions of no change in total fecundity, absence or negligible effect of fetal wastage and trends in the indices of C_m and C_i compensate each other the equation reduces to the form,

$$\frac{TFR(t)}{TFR(0)} = \frac{C_c(t)}{C_c(0)},$$

$$or, 1 - \frac{TFR(t)}{TFR(0)} = 1 - \frac{C_c(t)}{C_c(0)} \quad or \ \mathrm{PRF} = 1 - \frac{C_c(t)}{C_c(0)}$$

Where PRF is the proportionate reduction in fertility, i.e, $PRF = \frac{TFR(0) - TFR(t)}{TFR(0)}$. Now, since $C_c = 1 - 1.08 \times u \times e$,

where u = contraceptive prevalence rate,

e = effectiveness of contraception, then

$$PRF = 1 - \frac{C_c(t)}{C_c(0)} = 1 - \frac{1 - 1.08 \times u(t) \times e(t)}{1 - 1.08 \times u(0) \times e(0)}$$

$$or, \ 1 - PRF = \frac{1 - 1.08 \times u(t) \times e(t)}{1 - 1.08 \times u(0) \times e(0)}$$

or, $(1 - PRF)(1 - 1.08 \times u(0) \times e(0)) =$ $1 - 1.08 \times u(t) \times e(t)$.

Since $u(t)$ is the CPR among married woman at the beginning of target year t, in which we are interested, we have,

$$u(t) = \frac{1 - (1 - PRF) \times (1 - 1.08 \times u(0) \times e(0))}{1.08 \times e(t)}.$$

On the assumption of equal effectiveness of contraception between the base and target years, we have,

$$u(t) = \frac{1 - (1 - PRF) \times (1 - 1.08 \times u(0))}{1.08}.$$

Thus, the data required for the estimation of u(t), the CPR at the target year t and u(0), the CPR at the base year and PRF. Fitting the regression line and incorporating the target-setting model for the population of Bangladesh we estimate the CPR to achieve required target fertility.

2.2. Models of Target C_m, C_i and C_{fw} Indices

Our proposed model can also be used to estimate the projection of indices of proportion married (C_m), lactational infecundability (C_i) and (C_{fw}) fetal wastage by using proportional reduction in fertility (PRF).

From the proposed model it can be written as:

$$C_m(t)\times C_c(t)\times C_i(t)\times C_{fw}(t) = (1-PRF)\times C_m(0)\times C_c(0)\times C_i(0)\times C_{fw}(0) \quad (1)$$

Now, if we eliminate the effect of fetal wastages during time period, i.e $C_{fw}(t) = C_{fw}(0)$ then the equation becomes,

$$C_m(t)\times C_c(t)\times C_i(t) = (1\text{-PRF})\times C_m(0)\times C_c(0)\times C_i(0) \quad (2)$$

If the lactational infecundability is constant over time then equation (ii) becomes,

$$C_m(t)\times C_c(t)=(1\text{-PRF})\times C_m(0)\times C_c(0) \quad (3)$$

Again, if the index of non-contraception is constant over time, i.e., use of contraception may not be changed then the equation (iii) becomes:

$$C_m(t) =(1\text{-PRF})\times C_m(0) \quad (4)$$

Again, if all the indices except the index of C_c are constant over time then the index of non-contraception becomes,

$$C_c(t) = (1\text{-PRF})\times C_c(0) \quad (5)$$

Similarly, the index of lactational infecundability becomes,

$$C_i(t) = (1\text{-PRF})\times C_i(0) \quad (6)$$

and the index of fetal wastage becomes,

$$C_{fw}(t)=(1\text{-PRF}) \times C_{fw}(0) \quad (7)$$

Using the equation (iv) to (vii) we can estimate the values of $C_m(t)$, $C_c(t)$, $C_i(t)$ and $C_{fw}(t)$ for the required level of fertility.

2.3. Estimated Duration of Breastfeeding (B) for Target Fertility with Given Value of Amenorrhea

From the equation of relationship between the duration of breastfeeding and amenorrhea period, we can estimate the breastfeeding duration. The average duration of amenorrhea period is given by

$$i = 0.1753 \exp (0.1396B-0.001872 B^2) \quad (8)$$

Taking log on the both sides,

$$\log (i/0.1753) = 0.1396 B-0.001872 B^2 \quad (9)$$

$$c= 0.1396 B -0.00187 B^2 \quad (10)$$

where c = log i/0.1753 or, $0.00187 B^2 -0.1396 B +c =0$, this is a quadratic equation in B. This can be converted in the standard form,

$$ax^2+ bx+ c =0 \quad (11)$$

where a = 0.00187, b = -0.1396 and x= B (duration of breast feeding). The roots of this equation are,

$$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

Using this solution we estimate the duration of breastfeeding and amenorrhea period.

2.4. Model Validation Technique

To determine the validity of the fitted models over the population, the CVPP, ρ_{cv}^2, is applied. The mathematical formula for CVPP is

$$\rho_{cv}^2 = 1-\frac{(n-1)(n-2)(n+1)}{n(n-k-1)(n-k-2)}(1-R^2);$$

where, n is the number of classes, k is the number of explanatory variables of the model and the cross-validated R is the correlation between observed and predicted values of the dependent variables [25]. The shrinkage coefficient of the model is the positive value of (ρ_{cv}^2 - R^2); where ρ_{cv}^2 is CVPP and R^2 is the coefficient of determination of the model. The estimated CVPP akin to their R^2 and shrinkage coefficients are shown in the respective figures and places which show that the fitted models are better fit due to shrinkage coefficients. It is noted that this technique is also used as validation technique of model in several studies [26-44].

3. Results and Discussions

The CPR and TFR from 1979 to 2007 are given in Table 1, yielded a regression line of $T\hat{FR} = 7.742 - 0.087CPR$ (R^2=0.96, ρ_{cv}^2 =0.947 and shrinkage=0.012963) or $C\hat{P}R = (7.742 - TFR)/0.08\ 7$. $Excess\ TFR = TFR - T\hat{FR}$. In this case, shrinkage=0.012963 indicates the best fit of this regression model.

The degrees of correlation seems to be high (r = -0.98) and significant (at 10% level of significance). Thus the temporal variation in fertility explain by CPR may be attributed to the 96%, remaining 4% of the total variation unexplained by CPR which may attributed to the effect of other socio-economic and demographic variables. Deviations from the regression line (execs fertility) are due partly to measurement errors and partly to variations in the other proximate determinants of which marriage is an important one. According to the regression, the TFR equals, on average 7.742 births per woman in the absence of contraception (CPR=0), and fertility declines at a rate of approximately 1.0 birth per woman for each 9% increment in the contraceptive prevalence rate. Under such relationship between TFR and CPR, we can assess the required contraceptive prevalence level to achieve replacement level fertility. The regression equation of TFR on CPR suggests that a TFR of 2.4 births per woman can be achieved if the level of CPR is raised to 61% and if the level of CPR is raised to 65% it is possible to achieve a target level of 2.1 births per woman (Table 1).

Table 1. Observed and estimated TFR and CPR from 1979-2007 and excess fertility (TFR) in Bangladesh

Year	TFR	CPR	TFR (estimated)	CPR (estimated)	Excess TFR
1979	6.56	12.7	6.64	13.59	-0.0611
1981	6.35	18.6	6.12	16.00	0.2422
1983	6.08	19.1	6.08	19.10	0.0157
1985	5.55	25.3	5.54	25.20	0.0251
1987	5.30	29.6	5.17	28.06	0.1492
1989	4.90	30.8	5.06	32.57	-0.1464
1991	4.3	40.0	4.26	39.56	0.054
1993-94	3.4	45.0	3.83	49.91	-0.411
1996-97	3.3	49.0	3.48	51.06	-0.163
1999-2000	3.3	54.0	3.04	51.06	0.272
2004	3.0	58.0	2.70	54.51	0.32
2007	2.7	56.0	2.87	57.95	-0.154

Table 2. Estimated contraceptive prevalence level require to achieve target fertility with a given level of contraceptive effectiveness relative to base year 2007 (TFR = 2.7, CPR = 0.56, e = 0.85 & e = 0.90)

Target TFR	PRF	Required CPR u(t) to achieve TFR with contraceptive effectiveness e(t)	
		e = 0.85	e = 0.90
2.60	0.03704	0.57960	0.57736
2.56	0.05556	0.58940	0.58804
2.50	0.07407	0.59920	0.59472
2.45	0.09259	0.60901	0.60340
2.40	0.11111	0.61881	0.61209
2.35	0.12963	0.62861	0.62077
2.30	0.14814	0.63841	0.62945
2.25	0.16666	0.64822	0.63813
2.20	0.18518	0.85802	0.64681
2.15	0.20370	0.66782	0.65549
2.10	0.22222	0.67762	0.66417

Estimation of contraceptive prevalence rate required to each different level of target fertility shown in table 2. These rate are recurring Bongaarts` target setting model taking 2007 as the base year when TFR is observed to be 2.7 and the contraceptive prevalence and effectiveness are 0.56 and 0.85 respectively [21]. The prevalence rates are computed at the effectiveness levels of 0.85 and 0.90. The results in the table indicate that if a TFR of 2.6 is to be achieved with 0.85 contraceptive effectiveness has to be raised to around 58% and with effectiveness of 0.90, 57% and that a TFR of 2.3 can be achieved CPR level of approximately 64% and 63% with 0.85 and 0.90 effectiveness of contraceptive respectively. The model demonstrate that the contraceptive prevalence rate of nearly 68% with an effectiveness of 0.85 and 66% with 0.90 effectiveness to achieve a target fertility around 2.1. According to model estimate the CPR would be around 58% in 2007 instead of 56% as observed for a TFR of 2.7. Contrarily, if the observed CPR is true then the model estimate of TFR would be 2.87 births per woman instead of 2.7 births, a reduction of 0.17 births per woman (Table 2).

3.1. Singulate Mean Age at Marriage and Total Fertility Rate

The values of SMAM and TFR was calculated by regression equation

TFR = 15.37- 0.638 SMAM (R^2=0.682, ρ_{cv}^2=0.610 and shrinkage=0.07186) or SMAM = (15.37 - TFR) / 0.638. In this case, shrinkage=0.07186 indicates the better fit of the model.

According to this regression equation, the total fertility rate on the average is equal to 15.37 births per woman in the non-increasing of age at marriage and fertility declines at a rate of 6.3 birth per woman for each 10% increment in singulate mean age at marriage. It also indicates that singulate mean age at marriage explains about 68.20% (R^2 = 68.20%) of the variation in the total fertility rate. Deviations from the regression line are partly due to measurement errors and partly to variations in other determinants. This is a statistical relationship, but in most developing countries like Bangladesh, the increase in contraceptive use also might be a factor for declining fertility. From the relation we can determine the SMAM of females for desired level of fertility (Table 3).

Table 3. Female singulate mean age at marriage (SMAM) and total fertility rate (TFR) for different times in Bangladesh

Year	TFR	SMAM
1975	6.34	15
1980	4.99	15
1982	5.21	17.5
1984	4.83	17.2
1985	4.71	16.95
1986	4.7	17
1987	4.42	17.9
1988	4.39	16.9
1989	4.35	17.7
1990	4.33	16.5
1991	4.3	18
1993	3.4	17.4
1996	3.3	18.7
1999	3.3	18.8
2004	3	18.9
2007	2.7	18.95

Source: BBS [45], BDHS, Statistical Pocket Book of Bangladesh 2006.

Table 4 indicates that singulate mean age at marriage increases for the decreases of target fertility. For the achievement of the replacement level fertility 2.1 SMAM would be increased at 20.80 years. It is a common belief that age at marriage is inversely related to fertility, particularly in countries with no popular effective use of contraceptive [9]. This means that delayed marriage increases the interval between generations and hence puts an independent barrier to longer-range population growth by reducing the proportion of married female in the reproductive ages relative to the total population. As a result, society develops, desired family size decline, because of the influences of different socio-demographic and socio-economic determinants. The evidence for this view of the reproductive behavior includes the high degree of negative association (r = -0.826) between the total fertility rate and the singulate mean age at marriage.

Using the value of PRF we estimate the indices of $C_m(t)$, $C_c(t)$, $C_i(t)$ and $C_{fw}(t)$ which are presented in table 5. The values of C_m in table 5 and figure 1 indicate that the target fertility would be declined when the index of proportion married would be declined. The value of C_c in table 5 and figure 2 summarizes that the trend of the index of non-contraception is decreasing and the target fertility is also declining.

Table 4. Estimated singulate mean age at marriage with given level of target fertility

Target TFR	SMAM
2.60	20.01
2.56	20.09
2.50	20.17
2.45	20.25
2.40	20.33
2.35	20.41
2.30	20.48
2.25	20.56
2.20	20.64
2.15	20.72
2. 10	20.80

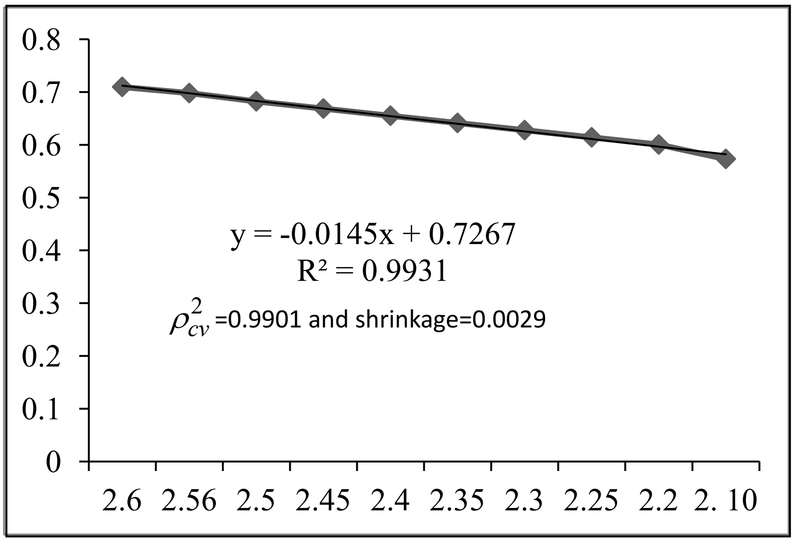

Figure 1. The regression line of the index of proportion married with given level of target fertility

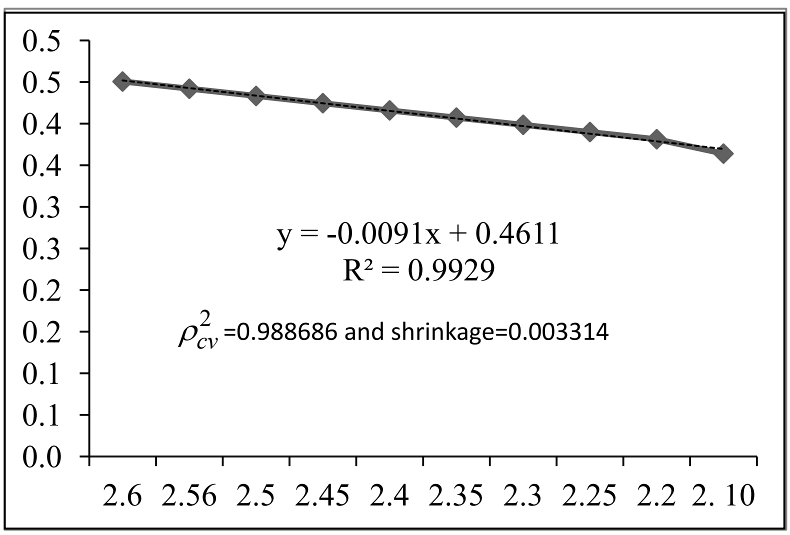

Figure 2. The regression line of the index of non-contraception with given level of target fertility

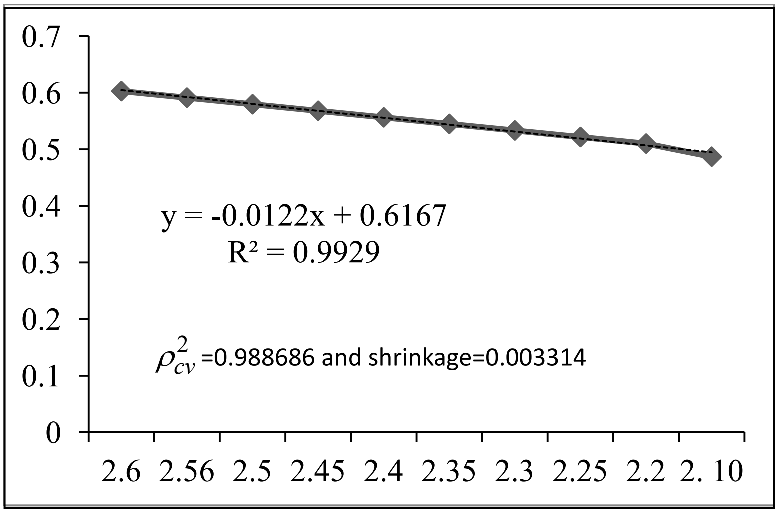

Figure 3. The regression line of the index of lactational infecundability with given level of target fertility

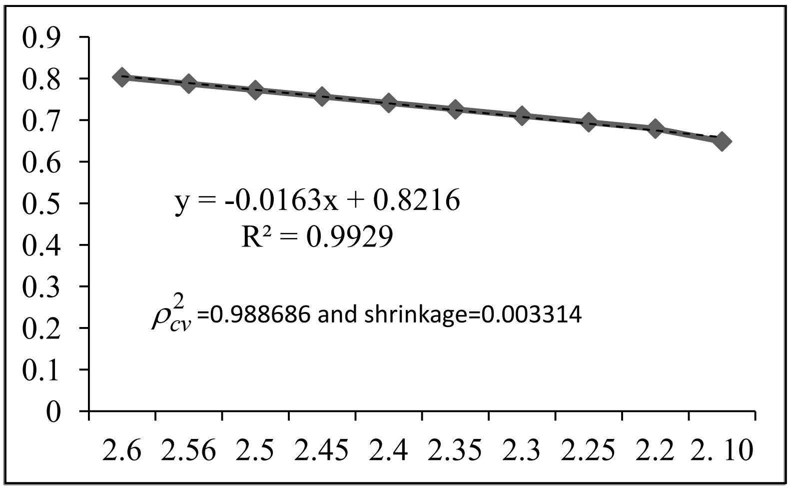

Figure 4. The regression line of the index of fetal wastage with given level of target fertility

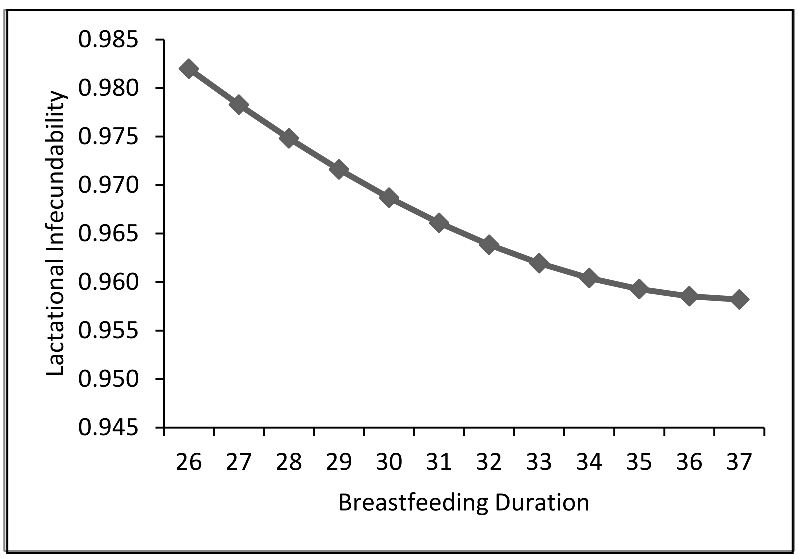

Figure 5. The graph of the index of estimated lactational infecundability with given level of breastfeeding

The value of C_i in table 5 and figure 3 indicates that if the mothers increase their breastfeeding duration then the target fertility would be decline. The value of C_{fw} in table 5 and figure 4 summarizes that with decreasing the index of fetal wastage target fertility would be declining.

Hence, if we achieve our replacement level of fertility, the age at marriage, lactational infecundability and the level of CPR would be increase. But unfortunately in Bangladesh the CPR may not exceed 65%, for instance in 2004 and 2007 it was 58% and 56% respectively. So it is important to take necessary step on other two important proximate factors proportion married and lactational infecundability, that is, singulate age at marriage and duration of breastfeeding should be increased. With the intention that, we can achieve to the replacement level of fertility.

Table 5. Estimated values of the indices C_m, C_c, C_i, and C_{fw} with given level of proportional reduction in fertility for target TFR

TFR	PRF	$C_m(t)$	$C_c(t)$	$C_i(t)$	$C_{fw}(t)$
2.60	0.03704	0.709704	0.450667	0.602815	0.803111
2.56	0.05556	0.698056	0.442000	0.591222	0.787667
2.50	0.07407	0.682407	0.433333	0.579630	0.772222
2.45	0.09259	0.668759	0.424667	0.568037	0.756778
2.40	0.11111	0.655111	0.416000	0.556444	0.741333
2.35	0.12963	0.641463	0.407333	0.544852	0.725889
2.30	0.14814	0.627815	0.398667	0.533259	0.710444
2.25	0.16666	0.614167	0.390000	0.521667	0.695000
2.20	0.18518	0.600519	0.381333	0.510074	0.679558
2. 10	0.22222	0.573222	0.364000	0.486889	0.648667

Table 6 indicates that duration of breastfeeding and duration of amenorrhea period are increasing for the decreasing of target fertility. For the achievement of the replacement level fertility 2.1 the duration of breastfeeding and amenorrhea period would be increased to about 37 months and 2.37 months respectively (Fig. 5).

Table 6. Estimated lactational infecundability for assumed breastfeeding duration

B (Assume)	i	C_i
26	1.866796	0.981990
27	1.943934	0.978285
28	2.016702	0.974816
29	2.084384	0.971610
30	2.146296	0.968697
31	2.201796	0.966100
32	2.250301	0.963841
33	2.291287	0.961941
34	2.324311	0.960416
35	2.349009	0.959278
36	2.365108	0.958538
37	2.372427	0.958202

4. Conclusions

The estimates of CPR to achieve certain level of fertility at a stipulated time using two models, viz., linear regression and Bongaarts' (Proposed model) target setting models are found to be inconsistent for obvious reasons. Apart from methodological differences the estimate of CPR using linear regression model is based completely on the face values of TFR and CPR and takes into account of the trends of both the factors while the estimate made by Bongaarts' target setting model heavily depends only on the level of contraceptive use of the most recent year and ignores the effect of the two important proximate variables of marriage pattern and lactational infecundability. There seems to be a change in marriage pattern in the country and also exists a norm of long duration of breastfeeding practice - the effects of which can not be ignored to achieve target fertility. A high degree of correlation between TFR and CPR bears the implication that it is possible to achieve a replacement level of fertility if the present pace of progress in contraceptive practice is maintained.

To achieve the replacement level of fertility we have to attain a contraceptive level of around 68% with effectiveness 0.85 and 66% with effectiveness 0.90 and increase of nearly 12% and 10% respectively relative to the base year which is perhaps a far reaching target. To reach the desire level of target fertility it would be increased the use of contraceptives, duration of breastfeeding, singulate mean age at marriage and amenorrhea period. To achieve replacement level of fertility at 2.1 births per woman we should increase the CPR, SMAM, duration of breastfeeding and amenorrhea period by 68%, 20.80 years, 37 months and 2.37 months respectively.

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