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# ACCELERATED MODERNIZATION AND THE POPULATION EXPLOSION

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# ACCELERATED MODERNIZATION AND THE POPULATION EXPLOSION

by

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This paper is intended as a contribution to investigating how much, in the less developed countries, intermediate to high rates of economic growth unaided by population control policies can bring down fertility and defuse the population explosion. The approach followed consists in simulation experiments using a long run model of economic growth with population endogenous.[1/] In the model (1) the growth of GNP per capital contributes to the declines of fertility and mortality according to equations with parameters estimated from empirical data, which are designed to reflect major aspects of the historical experience, and (2) the growing population contributes to the economic sector via labour inputs which are related to population size and sex-age composition. The paper focusses upon two growth performances, referred to as normal modernization (NM) and accelerated modernization (AM), and upon a range of ideal less developed countries with distinct initial levels of fertility and development.

The model used is made of demographic and economic modules. The demographic module takes an initial population differentiated by sex

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and into seventeen age classes and projects it over time. The technique is well known: it consists in multiplying a projection matrix by a population vector to obtain a new population vector which specifies the number of people by sex and age classes at the end of a five years interval. The coefficients of the projection matrix are age specific fertility rates, and survival coefficients. The latter indicate which fraction of each sex-age class will be alive after five years. In this study the coefficients of the projection matrix are not time invariant. Instead the age specific fertility rates and the survival coefficients are respectively function of the gross reproduction rate G, and of the life expectancy at birth E. Both G and E are functions of level of development, represented by GNP per capita y, and of time t. The parameters of the functions relating G and E to y and t, have been estimated from a time series of cross sections spanning the period 1860 to 1959. In particular, the G equation may be presumed to reflect the effects of economic growth on fertility in a context characterized by the absence of population control policies.

Summing up, the demographic module inputs time, a population vector and GNP per capita, and outputs an updated population vector specifying the population by sex and age classes five years later.

The economic module was based on the following assumptions. Growth of GNP results from growth of capital and labour inputs, and from neutral technolgical progress.

A labour force equation converts population vectors into measures of labour force by multiplying each age-sex class by time invariant labour force participation coefficients. Capital formation results from gross savings minus capital consumption, and no capital movements across international boundaries are allowed. The fraction of GNP that is saved increases as GNP per capital increases. The contribution of the growth of labour inputs to the growth of GNP is also assumed to increase as GNP per capita increases. Returns to scale are constant.

The technological progress is low at low level of GNP per capita; as GNP per capita increases, it increases up to a maximum level of 8 percent. For levels of GNP per capita beyond a threshold the rate of technological progress declines until it reaches a lower limit of 2 percent. The rationale of these assumptions is that the rate of technological progress depends upon the existence of a stock of technologies that a country has not applied, and upon the country's ability to begin or to extend their application. At low levels of GNP per capita a large stock of unused technologies is available but the ability to take advantage of them is very limited. Throughout the development process the ability to apply existing scientific and technological knowledge increases but the stock of unused technologies decreases, so that countries become increasingly dependent upon the extension of the existing stock of scientific and technological knowledge, rather than upon the application of unused portion of it. In the limit, the developed countries' rate of technological progress is set at 2 percent per year, which is assumed to correspond to the rate of growth of the aggregate stock of scientific and technological knowledge. In this study two schedules of rates of technological progress versus GNP per capita were used, which differ in the extent to which at lower levels of development, increases in GNP per capita bring about an increase in rates of technological progress (Table 2). The schedule with lower rates corresponds to a state of affairs in which traditional ways and structures yield more slowly to modernizing pressures. The other one instead identifies a phase of accelerated progress corresponding to a situation in which the resistence of a country's traditional society to modernization has been broken down, and a modernizing elite is firmly in control of the country's socio-political structures. The two schedules identify the normal and accelerated modernization (NM and AM).

The economic module inputs a population vector and time and outputs a measure of GNP per capita. The simulation experiments that form the object of this paper generate a time path of a number of economic and demographic variables corresponding to the normal and accelerated modernization, over a time horizon of 100 years starting with the year 1970. The effects of modernization are explored for less developed countries with initial levels of GNP per capita ranging from one to four hundred U.S. 1970 dollars and with initial gross reproduction rates ranging between 2.5 to 3.25.

The basic questions asked may be phrased as follows: within the framework considered are optimistic rates of economic development enough to reduce significantly the initial "explosive" rates of population growth within a 100 years time span? How much do populations increase in the process? How sensitive the simulation results are to differences in the initial conditions concerning fertility and level of development?

## The Demographic Equations

First, the general structure of the demographic module will be outlined. Then, the functional relations in it will be specified and the procedures for the estimation of their parameters described. A closed system is assumed, with no immigration or emigration.

Let P(t) be a vector specifying numbers of people by sex and age classes. Let

$$P^T(t) = (F^T(t),\ U^T(t)) \tag{1}$$

$$F^T(t) = (F(1,t),\ F(2,t), \ldots\ldots F(17,t)) \tag{2}$$

$$U^T(t) = (U(1,t),\ U(2,t), \ldots\ldots U(17,t)) \tag{3}$$

where the superscrip T stands for "transpose", the vectors F(t) and U(t) indicate respectively the number of females and males in 17 five years age classes at time t, and F(i,t) and U(i,t) are the elements of these vectors and specify the female and male population in the ith age class at time t. The age classes range from the first, including people aged 0 to 5, to the 17th, with people aged 80 to 85. Time is measured in five years time intervals. The relation between the population at the beginning and at the end of five years time intervals is given by the following matrix equation:

$$P(t+1) = AP(t) \tag{4}$$

where A is a projection matrix. Indicate by the notation

$$A = A(G, E) \tag{5}$$

that the elements of A are a function of gross reproduction rate G and of life expectancy at birth for both sexes E, so that the projection matrix A at time t is specified if the values of G and E at time t are given. Both G and E are assumed to be function of GNP per capita y and time t.

$$G = G(y,t) \tag{6}$$

$$E = E(y,t) \tag{7}$$

Given (a) a specification and parametrization of the relations listed above, (b) an initial population vector P(0), and (c) values of y and t at five years intervals, a population projection can be generated. Here y is "endogenous" since it is determined by economic variables and parameters, and by labour inputs generated using labour participation coefficients and the vector P(t). The matrix equation (4) incorporates two sets of dynamic relations which specify respectively (a) the flow over time of the surviving members of each age class into the next age class, and (b) the addition of new born male and female babies to the population. The structure of the projection matrix A will not be discussed in detail. The reader is remainded to the exhaustive treatment of the subject by Keyfitz (1968, p. 27 ff.) which has been followed here. It will suffice to note that the non zero entries in A are based on (a) age specific female fertility rates indicating the number of female children born over a 5 years period to females in the ith age class, (b) survival coefficients specifying the population of the male/female population in the ith age class at time t which will be alive 5 years later, at time t+1, and (c) a constant indicating the ratio of the male new borns to the female new borns (set to 105 males to 100 females). The age specific fertility rates were defined as the product of the schedule of age specific female fertility rates corresponding to a gross reproduction rate of one times the actual value of G. The age specific female fertility rates used in this investigation are annual female births per woman corresponding to a gross reproduction rate of one, and to a mean reproductive age of 29 years, published in Coale and Demeney (1966, p. 30) and shown in Column 5 of Table 1.

The survival coefficients were assumed to be a function of life expectancy at birth for both sexes E. These functions are defined "empirically" as follows. The survival coefficients of the "West" Model Life tables published by Coale and Demeny for mortality levels 13, 15, 17, 19, 21, 23, and 24 were used. For each mortality level the mean of the female and male life expectancy at birth indicated in the life tables, was calculated. The following E values were obtained for the mortality levels 13 to 24 listed above: 48.56; 53.42; 58.24; 63.11; 68.01; 73.09; 75.70. For life expectancies corresponding to these values the survival coefficients were taken from the corresponding life table; while for other values of E the survival coefficients were calculated by linear interpolation between two consecutive life tables. In other words, the survival coefficients for each age class and sex was defined as a piecewise linear function of values of E ranging from 48.56 and 75.70. At the beginning of each of the five years intervals for which the simulation was carried out the values of G and E were calculated from values of y and t, on the basis of these the age specific fertility values and survival coefficients were evaluated, and then the population vector was projected across the interval. The total population at time zero (the year 1970) was assumed to be one million people. Its disaggregation by sex and into age classes was accomplished using the female and male stable age distribution and the percentage female and the percentage male in the stable age distribution, corresponding to the West model life table, for a mortality level 13, a gross reproduction rate of 3, and an average reproductive age of 29 years (Coale and Demeny 1966, p. 98, 194). A listing of the elements of the initial population vector is given in Table 1, columns 3 and 4. The same vector was used as initial condition also for the simulation runs involving gross reproduction rates different from 3.

## The G and E Equations

Let us consider the G equation first. In order to derive an equation suitable to describe the dynamics of the gross reproduction rate let us begin by assuming that G is some well behaved function of product per capita [2/] and time:

$$G = G(y,t)$$

Time is included so that the relation between G and y be not required to be time invariant. In fact, the empirical analysis discussed later in this paper appears to justify such inclusion. Here and hereafter a hat superscript indicates the instantaneous percentage rate of change of the superscripted variable with respect to time, so that, for instance

$$\hat{G} = \frac{1}{G}\frac{dG}{dt}$$

Taking the derivative of G with respect to time and after a few manipulations we have

$$\hat{G} = \eta_{G,y}\hat{y} + \hat{G}_t \qquad (8)$$

where $\eta_{G,y}$ is the elasticity of the G with respect to y:

$$\eta_{G,y} = \frac{y}{G}\frac{\partial G}{\partial t}$$

and

$$\hat{G}_t = \frac{1}{G}\frac{\partial G}{\partial t}$$

In the specification of the G equation let us consider first the elasticity term of equation (8). In investigations of the relation between GNP per capita and fertility the literature has distinguished between short and long run effects of economic growth, and between GNP per capita as index of households income and as index of the structural changes associated with economic growth (Simon 1969, 1974; Heer 1966).

A short run increase in GNP per capita reflects an increase of households' income unaccompanied by changes in preferences or in socioeconomic structure. If children are regarded as superior goods and households maximize the satisfaction of their preferences subject to budget and time constraints, (Becker 1960; Willis 1973; De Tray 1973) an increase in income, everything else being equal, should bring about an increase in fertility. In fact, empirical research has confirmed that short run increases of GNP per capita are associated with increases in fertility (Galbraith and Thomas 1941; Kirk 1956; Silver 1966; Basavarajappa 1971; Ben Porath 1973).

The long run effects of growth of GNP per capita hinge on a host of structural changes which appear to be responsible for two opposing effects on fertility. On one hand modernization and economic growth (1) increase the income of households, which may lead to increased demand for children, (2) it dissolves traditional structures and mores some of which had fertility inhibiting effects and (3) it brings about improved health which leads to higher fertility (Habakkuk 1953; Krause 1957; Petersen 1966; 1969 p. 608 ff.). On the other hand they (1) lead to a preference for smaller families, (2) raise the cost of children including opportunity costs in all kinds of social structures, and (3) involve a transfer of large masses of people out of social strata and environments that, because of values, preferences or costs, are characterized by high fertility. The fertility enhancing and fertility depressing effects perhaps coexist throughout the process of development with the former ones being stronger and dominant in the first, and, perhaps, in the last (Easterlin 1962) stages of the development process. These considerations suggest that the fertility elasticity of development should include additive terms representing respectively a fertility enhancing effect and a fertility depressing effect such that at least for low y's the first would dominate. However, the data did not suggest any significant fertility-enhancing effect, perhaps because "noise" obliterates it. Consequently, it was decided to use a specification which includes only the fertility depressing effects of development, and for simplicity $\eta_{G,y}$ was set equal to a negative constant.

Also the term $\hat{G}_t$ of equation (8) was specified as a negative constant in order to allow for declines of G that do not depend upon economic development in the country in which they take place, and that perhaps linked to the acceleration of the "demographic transition" suggested by Kirk (1971).

The specification of equation (8) selected on the basis of the considerations above is

$$\hat{G} = -p_G\hat{y}-q_G \qquad (9)$$

where p and q are positive constants. In order to derive a suitable life expectancy equation a similar approach will be followed. First a well behaved function of y and t is assumed.

$$E = E(y,t)$$

then, its total derivative with respect to time is derived:

$$\hat{E} = \eta_{E,y}\hat{y}+\hat{E}_t \qquad (10)$$

where, again $\eta$ is an elasticity, and $\hat{E}_t = (1/E)\partial E/\partial t$

As regards equation (10) we should require (1) that $\hat{E}_t$ be greater than zero to allow for an increase in life expectancy even in the absence of increases in GNP per capita; (2) and the $\eta_{E,y}$ be greater than zero since improved health sanitation and nutrition associated with economic growth have been factors of the historical decline in mortality. The simplest specifications of equation (10) satisfying these requirements is that in which $\hat{E}_t$ and $\eta_{E,y}$ are positive constants, namely

$$\hat{E} = p_E\hat{y} + q_E \qquad (11)$$

In the course of the estimation of the life expectancy's equation, however, it seemed appropriate to experiment with transformations of E designed to force the life expectancy to remain within asymptotic limits, which were set to 20 years and 74 years respectively. The formulation using the transformed variable TE (transformed life expectancy) is

$$\hat{TE} = -p_{TE}\hat{y} - q_{TE} \qquad (12)$$

where

$$TE = \frac{74 - E}{E - 20} \qquad (13)$$

The solution of (12) and (13) is:

$$E = \frac{54}{1+e^{C-qt}\,y^{-p}} + 20 \qquad (14)$$

where C is an integration constant. Clearly, according to equation (14) life expectancy E approaches 74 years as y and t are increased and tends to 20 years as y goes to zero and t approaches minus infinity. Equation (12) was eventually chosen for use in this study because it seemed more satisfactory from a theoretical point of view and also gave better fits to the empirical data.[3/]

Estimation of the Parameters of the Demographic Equations

Direct estimation of p's and q's in equations (9) and (12) from percentage change data was discarded because the amplification of noise produced by the differentiation of a noisy signal appeared to be especially relevant here. Instead the estimation procedure employed consisted in fitting functions which are the solutions of equations (9) and (12). These solutions are:

$$\ln G = -p_G \ln y - q_G t - C_{G_i} \qquad (15)$$

$$\ln TE = -p_{TE}\ln y - q_{TE}t - C_{TEi} \qquad (16)$$

The subscripts i in the integration constant $C_{Gi}$ and $C_{TEi}$ are introduced to indicate that equations (15) and (16) relate gross reproduction rates and life expectancy on one hand and GNP per capita on the other in an individual country labelled i. That is to say, since the "general" aspects of the demographic relations are specified by the differential equations (9) and (12), the constants $C_{Gi}$ $C_{TEi}$ bring into the demographic functions initial conditions specific to each country. The estimation of the parameters of equations (15) and (16) by a time series of cross sections could be accomplished through the use of n-1 dummy variables for n countries (Hoch 1962; Johnson 1964). This however would decrease considerably the degrees of freedom and possibly produce groups of dummy variables' coefficients not significantly different from one another. Therefore, it was decided to use dummy variables differentiating countries by continents or groups of continents (Janovitz 1973).

The parameters of equations (15) and (16) were estimated using cross sectional data on per capita incomes in 1953 U.S. dollars for the years 1860, 1880, 1900, 1913, 1952-53, 1959 (Zimmerman 1962) and data on gross reproduction rates and life expectancy at birth for both sexes for same years and countries (UN 1955, 1958; Vielrose 1965; Arriaga 1968; Keyfitz and Flieger 1968; Kuczynski 1969; Population Index 1970, p. 253 ff., p. 559, 1973 p. 285 ff).

The regression results are given in Table 2. Both the p and q coefficient are significant at the 1 percent level in the G equation and in the TE equation. By differentiating these regression equations with respect to time the following demographic differential equations were obtained.

$$\hat{G} = -0.18007\ \hat{y} - 0.02180 \tag{17}$$

$$\hat{TE} = -0.81131\ \hat{y} - 0.14875 \tag{18}$$

which show that the changes of both gross reproduction rates and life expectancy result from an income effect and from a time effect. These differential equations were then solved for a range of initial conditions setting for t=0, G to 2.5, 2.75, 3.0, 3.25, E to 48.56 years, and y to 100, 200, 300, and 400 1970 U.S. dollars.

The solution of equations (17) and (18) with all combinations of initial conditions indicated above were used in the various simulation runs to generate the values of G and E which in turn determined the coefficients of the projection matrix A. A "limiter" was employed to prevent G to fall below a level of 1.02386 which corresponds to a net reproduction rate of one for a life expectancy of 74 when the Coale and Demeny West Model Life Tables are used. This limit insures that the population of the system will approach asymptotically a net reproduction rate of one.

## The Economic Equations

Assume that the instantaneous percentage rate of change of GNP

$(\hat{Y})$, of capital inputs $(\hat{K})$ and of labor inputs $(\hat{L})$, and the rate of technological progress b are related as follows

$$\hat{Y} = b + (1-a)\hat{K} + a\hat{L} \tag{19}$$

If a and b are constants, equation (19) corresponds to a Cobb-Douglas production function with constant returns to scale. However, here both a and b are assumed to be non constant function of level of development. a is the labor elasticity under the assumption of constant returns to scale and also the contribution of the growth of labor inputs to the growth of GNP. There seems to be a consensus in the literature that for the developed countries a is between .7 and .8 (Denison 1967 p. 38; Chenery 1971 p. 35), while for the less developed countries it becomes as low as .5 (Chenery 1971 p. 35; Bruton 1967; Williamson 1969 p. 96, pp. 108-109). In this study it was assumed that a has a value of .5 for a GNP per capita of 100 dollars or less, of .8 for a GNP per capita of 2000 dollars or more, and increases linearly between these values as y increases from 100 to 2000 dollars. Namely

$$a = \begin{cases} .5 & \text{if } y \leqslant 100 \\ .4842 + .0001579y & \text{if } 100 \leqslant y \leqslant 2000 \\ .8 & \text{if } 2000 \leqslant y \end{cases}$$

where $y = Y/P$

Two functions $b_1(y)$ and $b_2(y)$ relating the rate of neutral technological progress b to level of development y were defined. Both functions involve low rates of technological progress at low levels of development and high levels of development, and higher values in between. However $b_1$ and $b_2$ differ in the acceleration of the rate of technological progress associated with development which is much greater for $b_2$. As indicated earlier $b_2$ is assumed to correspond to a successful modernizing revolution. Both $b_1$ and $b_2$ are empirically defined functions the coordinates of which are given in Table 3. The labor force equation is best written as a vector product

$$L(t) = (F^T(t), U^T(t)).(FLPR, ULPR) \tag{21}$$

where F and U are vectors specifying the age composition of the female and male population at time t, and FLPR, ULPR are vectors containing respectively the female and male labor participation rates by age, listed in columns 6 and 7 of table 1. These rates are the ones used in the Enke-Tempo model (TEMPO 1971, p. 50). They were chosen by the authors of that model as representative of the rates found in the 1967 Yearbook of Labor Statistics, International Labor Office, Geneva. The capital formation equation was assumed to be of the familiar type

$$\dot{K} = sY - \delta K \tag{22}$$

Here and hereafter a dot superscript denotes the derivative of the superscripted variables with respect to time. s is a saving ratio, and $\delta$ is a depreciation coefficient. Dividing both sides of (22) by K we have the equation used in the simulations.

$$\hat{K} = s/R - \delta \qquad (23)$$

where R = K/Y is the average capital to output ratio. Empirical investigations and theoretical reasoning suggest that the fraction of aggregate income that is saved tends to increase with the level of income per capita (Mikesell and Zinser 1973). Landau (1963) using a time series of cross sections for 17 Latin American countries and five time periods beginning in 1950 estimated the following saving ratios-income per capita function

$$s = -n + .05605 \ln y \qquad (24)$$

where n is a constant differing in value for each country in the sample. The equation used in this study was obtained by taking the derivative of both sides of (24) with respect to time.

$$\dot{s} = .05065 \, \hat{y} \qquad (25)$$

The predictive ability of this equation was checked in the following manner. Between the period 1960-62 and 1966-68 the average saving ratio for the LDC's increased by 1.4 points, from 14.7 percent to 16.1 percent (U.N. 1971, p. 208 ff.). During the 1960's the percentage rate of growth of product per capita for the LDC's was 3.1 percent per year (AID 1972, p.1). Using equation (25) the increment in saving ratios over seven years is (.06065)(3.1)(7) = 1.1, which is close enough to the observed value 1.4 to justify some confidence in the use of this equation. The initial condition s(0) for equation (25) was set at the values of .13, .14,.15, and .16 in the runs in which the initial GNP per capita was set respectively at 100, 200, 300, and 400 dollars.

Following Kelley et. al. (1972, p. 347) the depreciation parameter $\delta$ was set at a value of 0.05 which implies that the capital stock loses approximately 50 percent of its value over a 15 years time span. In the actual computations the derivatives with respect to time appearing in (19) and (23) were approximated their differences, so that for instance

$$\hat{Y} \simeq (Y(t+1) - Y(t))/Y(t) \tag{26}$$

The initial conditions for Y,K and L were derived as follows. In the various runs y(0) was 100, 200, 300, and 400 U.S. 1970 dollars per person. It was assumed that P(0) = 1.0 million people, which determines Y(0) = y(0)P(0) in million of U.S. dollars. The average capital to output ratio (ACOR) at time zero was set equal to 2,[4/] which together with Y(0) gives K(0) in million dollars. The labor force at time zero L(0) was obtained from the labor force equation using vectors F(0) and U(0) the values of which are given in table 1, columns 3 and 4.

Results

The major results of this investigation are summarized in tables 4 through 7. Table 4 shows the time paths of population,GNP per capita, and natural increase in population at ten years intervals for the simulation runs characterized by an initial GNP per capita of 200 dollars and an initial gross reproduction rate of 3. The results corresponding to the normal rate of modernization and to the accelerated rate of modernization are placed in contiguous columns.

The second set of tables shows population levels, GNP per capita and rates of natural increase in population in the years 2020 and 2070, for NM and AM simulation runs corresponding to the 16 combinations of 4 levels of initial GNP per capita and 4 levels of gross reproduction rates considered in this investigation. In these tables also NM and AM results are placed next to one another.

Let us consider first the GNP per capita levels obtained from the simulation, which are given in table 5 and columns 2 and 3 of table 4. The projected increases in GNP per capita over a hundred years are clearly high for all simulation runs, as required by the objectives of the investigation. The investigation aimed at exploring the implications of optimistic growth performances on the population levels and population growth in a context in which fertility declines with development as it did, in the average, in the contemporary developed world. Here, the lowest level of GNP generated by the simulations for the year 2070 is about 7000 dollars per capita, from an initial 100 dollars per capita. This corresponds to an average percentage rate of increase of GNP of 4.2 percent per year. The highest 2070 GNP obtained is about 35000 dollars per capita. This latter increase corresponds to an average percentage rate of change of about 4.5 percent. These rates appear optimistic but not extremely so when compared with the rates of growth of GNP per capita of the more developed and less developed countries in the post World War II period, which average respectively about 3.1 and 2.5 percent per year (Pearson, p. 358; AID 1972, p. 1) Are these optimistic economic performances enough to reduce the rates of population growth and to prevent high population levels? As regards the future of explosive rates of growth of population the simulation results convey a somewhat optimistic message. Table 6 and columns 4 and 5 of table 4 show a decline of natural increase in population from the initial 22 — 28 per thousand, to less than 8 per thousand in one century. In fact 8 per thousand is the highest of all the projected rates of natural increase in population and most of the alternatives explored yield considerably lower terminal rates. Namely, within the framework considered, both a normal and an accelerated modernization induce fertility declines sufficient to reduce the initial explosive rates of natural increase in population to levels comparable to or lower than those of the contemporary developed countries. This reduction is produced even when the initial GNP per capita is low, when the initial gross reproduction rate is as high as 3.25, and when no accelerated modernization takes place. A comparison of the rates of natural increase in population at fifty years intervals, namely in the years 1970, 2020, and 2070 shows that the decline is slower during the first than in the second 50 years. This is due to the demographic inertia to which attention has been called by recent demographic research (Keyfitz 1971; Frauenthal 1975).

The difference between the rates of natural increase generated under the assumption of a normal rate of modernization and an accelerated rate of modernization are by and large minor.

As regards the projected population increases the simulation results are dismal. The figures in table 7 and in columns 6 and 7 of table 4 show large increases in population over 100 years in all cases, although the differences produced by the initial gross reproduction rates and by the NM and AM runs are considerable. The largest increase is by a factor of 10 and is generated by an initial GNP per capita of 100 dollars, an initial gross reproduction rate of 3.25, and a normal rate of modernization. The smallest increase is by a factor of 3.6. The other increases fall within this interval. These population increases are huge and it is open to question in which circumstances comparable increases can take place in the real world.

Population increases falling within the range suggested by this investigation in countries already crowded could very well bring famines, pestilences, civil convulsions, or international conflicts and alter drastically the structure of the system and its dynamics. As regards the projected population sizes the differences between NM and AM runs are not small: the AM runs produce 20 to 25 percent smaller population levels in the year 2070.

To sum up, the simulation experiments described in this paper seem to suggest the following: even economic performances that over a time span of 100 years would raise the GNP per capita from 100 - 400 dollars to 8000 - 35000 dollars, and that would be adequate to deflate explosively high rates of population growth would still generate much too high increases in population. So high, in fact, that it is doubtful whether the world can accomodate them without major catastrophies or major changes in the structure of societies and in their relations to each other.

As a closing note it is emphasized that this is a preliminary investigation. The results outlined above need to be specified and verified by embedding the fertility development relations used here in the context of simulations focussing up on specific countries One such analysis for India is in the process of completion.

TABLE 1

Demographic Data Used in the Simulations

| Age Class | Age Group | F(i,0) | U(i,0) | F(i) | FLPR(i) | ULPR(i) |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 0 - 5 | .086277 | .088581 | .0 | .0 | .0 |
| 2 | 5 - 10 | .070929 | .072777 | .0 | .0 | .0 |
| 3 | 10 - 15 | .060548 | .062208 | .0 | .0 | .0 |
| 4 | 15 - 20 | .051657 | .053148 | .018 | .3 | .7 |
| 5 | 20 - 25 | .043809 | .045045 | .042 | .4 | .9 |
| 6 | 25 - 30 | .037004 | .037949 | .056 | .5 | .99 |
| 7 | 30 - 35 | .031093 | .031809 | .044 | .6 | .99 |
| 8 | 35 - 40 | .025977 | .026524 | .028 | .6 | .99 |
| 9 | 40 - 45 | .021606 | .021894 | .010 | .6 | .99 |
| 10 | 45 - 50 | .017881 | .017817 | .002 | .6 | .95 |
| 11 | 50 - 55 | .014603 | .014243 | .0 | .6 | .95 |
| 12 | 55 - 60 | .001672 | .011022 | .0 | .5 | .90 |
| 13 | 60 - 65 | .008941 | .008204 | .0 | .4 | .70 |
| 14 | 65 - 70 | .006507 | .005687 | .0 | .0 | .0 |
| 15 | 70 - 75 | .004321 | .003523 | .0 | .0 | .0 |
| 16 | 75 - 80 | .002434 | .001013 | .0 | .0 | .0 |
| 17 | 80 - 85 | .001391 | .000956 | .0 | .0 | .0 |

Cols. (3) and (4) indicate respectively the initial female and male population disaggregated by age classes. The total and female population add up to about 1.0 million people (exactly to .999950 because of round off errors). The entries in cols. (3) and (4) were obtained from the stable age distribution for the West model life table, mortality level 13, G equal 3.0, multiplied by the percentage female and percentage male in the stable population (Coale and Demeny 1966, p. 98-194).

Column (5) f(i) is the age specific female fertility per year corresponding to a G of one and to a mean reproductive age of 29 years (Coale and Demeny 1966, p. 30).

Column (6) and (7) FLPR and ULPR are respectively female and male age specific labor participation rates. These rates are the same used in Enke-TEMPO model. See "Description of the Economic Demographic Model", 1971, p. 50.

Table 2

Parameter Estimates of the Gross Reproduction Rate

and Life Expectancy Equations

$$\ln G \;=\; \underset{(9.71)}{2.02079} + \underset{(8.79)}{0.61828D_1} + \underset{(4.20)}{0.29693D_2} \quad \underset{(5.40)}{0.00436t} - \underset{(4.64)}{0.18007} \quad \ln y$$

$R = .759$

$R^2 = .576$

$$\ln TE = \underset{(13.57)}{7.39265} + \underset{(7.97)}{1.14108D_1} + \underset{(2.35)}{0.45127D_2} + \underset{(2.39)}{0.59039D_3} - \underset{(14.50)}{0.02975t} - \underset{(7.73)}{0.81131}$$

$R = .892$

$R^2 = .797$

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G is gross reproduction rates, TE is a transformation of life expectancy: TE = (74 - E)/(E - 20) where E is life expectancy at birth for both sexes, 74 and 20 are asympototic limits between which life expectancy is assumed to vary.

y is GNP per capita in constant U.S. 1953 dollars.

$D_1$, $D_2$, and $D_3$ are dummy variables that have value 1 for countries respectively in Latin America, in North America, Australia and New Zealand, and in Asia, and zero otherwise.

t stands for time in years and is in deviation from the year 1800.

"t" values are in brackets under their respective egression coefficients.

Table 3

The $b_1$ and $b_2$ Functions

$b_1$ and $b_2$ are continuous piecewise linear functions of y defined by the coordinates of the points of the linear segments of which they are constituted. These coordinates are:

| y | $b_1$ | y | $b_2$ |
|---|---|---|---|
| 0 | 1.5 | 0 | 1.5 |
| 1750 | 7.0 | 500 | 8.0 |
| 3000 | 2.0 | 1500 | 8.0 |
| 10000 | 2.0 | 3000 | 2.0 |
| | | 10000 | 2.0 |

$b_1$ and $b_2$ are percentage rate of neutral technological progress in percent per year. They correspond respectively to a normal and to an accelerated modernization.

Table 4

Simulation Results

Values of GNP per capita, rates of natural increase in population, and population at 10 years intervals. Simulation runs with y(0) = 200 dollars and G(0) = 3

| Year (1) | NM y (2) | AM y (3) | NM NI (4) | AM NI (5) | NM P (6) | AM P (7) |
|---|---|---|---|---|---|---|
| 1970 | .20 | .20 | 27.60 | 27.60 | 1.00 | 1.00 |
| 1980 | .27 | .32 | 28.55 | 28.44 | 1.32 | 1.32 |
| 1990 | .39 | .59 | 28.45 | 27.52 | 1.76 | 1.76 |
| 2000 | .58 | 1.39 | 27.13 | 24.34 | 2.34 | 2.30 |
| 2010 | .95 | 3.36 | 22.97 | 20.11 | 3.05 | 2.90 |
| 2020 | 1.66 | 5.87 | 21.24 | 16.55 | 3.87 | 3.52 |
| 2030 | 3.21 | 8.40 | 17.32 | 12.99 | 4.74 | 4.11 |
| 2040 | 5.19 | 11.45 | 13.84 | 9.36 | 5.58 | 4.64 |
| 2050 | 7.23 | 15.22 | 10.50 | 6.70 | 6.36 | 5.06 |
| 2060 | 9.76 | 19.72 | 7.36 | 4.50 | 7.00 | 5.38 |
| 2070 | 12.89 | 25.22 | 5.35 | 2.44 | 7.50 | 5.59 |

y = GNP per capita, in thousand of 1970 U.S. dollars

NI = ratio of natural increase in population, in excess births per thousand people

P = population, in million people.

NM and AM indicate respectively "normal" and "accelerated" modernization runs.

Table 5

Simulation Results

Projected GNP per capita in the years 2020 and 2070

| y(1970) (1) | G(1970) (2) | NM y(2020) (3) | AM y(2020) (4) | NM y(2070) (5) | AM y(2070) (6) |
|---|---|---|---|---|---|
| .1 | 2.5 | .73 | 2.67 | 8.38 | 17.15 |
| .1 | 2.75 | .66 | 2.41 | 7.78 | 17.18 |
| .1 | 3.00 | .60 | 2.17 | 7.68 | 16.56 |
| .1 | 3.25 | .56 | 1.99 | 7.24 | 16.02 |
| .2 | 2.5 | 2.02 | 6.37 | 13.52 | 25.95 |
| .2 | 2.75 | 1.83 | 6.17 | 13.49 | 25.86 |
| .2 | 3.00 | 1.66 | 5.87 | 12.89 | 25.22 |
| .2 | 3.25 | 1.53 | 5.62 | 12.26 | 24.69 |
| .3 | 2.5 | 3.92 | 7.85 | 17.76 | 30.32 |
| .3 | 2.75 | 3.64 | 7.71 | 17.80 | 30.48 |
| .3 | 3.00 | 3.39 | 7.61 | 17.59 | 30.70 |
| .3 | 3.25 | 3.11 | 7.50 | 16.57 | 30.75 |
| .4 | 2.5 | 5.32 | 8.89 | 22.03 | 34.11 |
| .4 | 2.75 | 4.97 | 8.89 | 21.07 | 34.45 |
| .4 | 3.00 | 4.78 | 8.77 | 20.75 | 34.60 |
| .4 | 3.25 | 4.63 | 8.63 | 20.38 | 34.49 |

y(t) = GNP per capita in thousand of 1970 U.S. dollars in the year "t".

G(t) = Gross reproduction rate in the year "t".

Columns (1) and (2) indicate the initial conditions y(0) and G(0) for NM and AM runs.
The values of GNP per capita obtained in these runs are shown in columns (3) through (6).

Table 6

Simulation Results

Projected Rates of Natural Increase in Population in the Years 2020 and 2070

| y(1970) (1) | G(1970) (2) | NM NI(1970) (3) | NM NI(2020) (4) | AM NI(2020) (5) | NM NI(2070) (6) | AM NI(2070) (7) |
|---|---|---|---|---|---|---|
| .1 | 2.5 | 21.7 | 16.4 | 12.3 | 2.8 | .9 |
| .1 | 2.75 | 24.7 | 19.5 | 15.2 | 4.5 | 1.7 |
| .1 | 3.00 | 27.6 | 22.5 | 17.8 | 6.2 | 2.7 |
| .1 | 3.25 | 27.6 | 25.1 | 20.3 | 7.7 | 4.0 |
| .2 | 2.5 | 21.7 | 15.3 | 11.4 | 2.2 | .4 |
| .2 | 2.75 | 24.7 | 18.4 | 14.0 | 3.7 | 1.3 |
| .2 | 3.00 | 27.6 | 21.2 | 16.5 | 5.3 | 2.4 |
| .2 | 3.25 | 27.6 | 23.8 | 18.8 | 6.8 | 3.9 |
| .3 | 2.5 | 21.7 | 14.5 | 11.5 | 2.0 | .6 |
| .3 | 2.75 | 24.7 | 17.3 | 14.1 | 3.5 | 1.6 |
| .3 | 3.00 | 27.6 | 20.1 | 16.6 | 5.2 | 2.9 |
| .3 | 3.25 | 27.6 | 22.6 | 18.8 | 6.6 | 4.4 |
| .4 | 2.5 | 21.7 | 14.3 | 11.7 | 1.9 | .9 |
| .4 | 2.75 | 24.7 | 17.2 | 14.3 | 3.6 | 2.0 |
| .4 | 3.00 | 27.6 | 19.9 | 16.8 | 5.3 | 3.4 |
| .4 | 3.25 | 27.6 | 22.2 | 19.1 | 6.8 | 4.9 |

y(t) = GNP per capita in thousand of 1970 U.S. dollars in the year "t".

G(t) = Gross reproduction rate in the year "t".

NI(t) = natural increase in population in the year "t", in excess births per thousand people.

Columns (1) and (2) indicate the initial conditions y(0) and G(0) for NM and AM runs. The values of natural increase obtained in the runs are given in columns (4) through (7).

Table 7

Simulation Results

Projected Population in the Years 2020 and 2070

| y(1970) (1) | G(1970) (2) | NM P(2020) (3) | AM P(2020) (4) | NM P(2070) (5) | AM P(2070) (6) |
|---|---|---|---|---|---|
| .1 | 2.5 | 3.02 | 2.87 | 4.83 | 3.97 |
| .1 | 2.75 | 3.46 | 3.27 | 6.26 | 4.92 |
| .1 | 3.00 | 3.93 | 3.72 | 8.08 | 6.13 |
| .1 | 3.25 | 4.35 | 4.11 | 10.15 | 7.46 |
| .2 | 2.5 | 2.98 | 2.76 | 4.53 | 3.63 |
| .2 | 2.75 | 3.40 | 3.11 | 5.83 | 4.49 |
| .2 | 3.00 | 3.87 | 3.52 | 7.50 | 5.59 |
| .2 | 3.25 | 4.28 | 3.88 | 9.42 | 6.83 |
| .3 | 2.5 | 2.94 | 2.71 | 4.38 | 3.58 |
| .3 | 2.75 | 3.35 | 3.07 | 5.63 | 4.45 |
| .3 | 3.00 | 3.81 | 3.45 | 7.21 | 5.54 |
| .3 | 3.25 | 4.21 | 3.80 | 9.07 | 6.76 |
| .4 | 2.5 | 2.90 | 2.70 | 4.30 | 3.60 |
| .4 | 2.75 | 3.31 | 3.05 | 5.55 | 4.50 |
| .4 | 3.00 | 3.75 | 3.43 | 7.13 | 5.63 |
| .4 | 3.25 | 4.15 | 3.79 | 8.91 | 6.91 |

y(t) = GNP per capita in thousand of 1970 U.S. dollars in the year "t".

G(t) = Gross reproduction rate in the year "t".

P(t) = Population in the year "t", in millions.

Columns (1) and (2) indicate the initial conditions y(0) and G(0) for NM and AM runs. The values of population obtained in the runs are given in columns (4) through (6).

## Footnotes

1. Cfr. Kosobud and O'Neill (1974).

2. Within the context of cross sectional regression analyses in which measures of fertility are related to variables such as percentage labor force in agriculture, infant mortality, literacy, female labor participation and others, in addition to GNP per capita, GNP per capita has little or nil explanatory power and the sign of its coefficient is not stable (Weintraub 1968; Adelman 1963; Heer 1966; Friedlander and Morris 1967; Drakatos 1969). However, whenever a measure of fertility is regressed against GNP per capita only, the latter represents the dominant long run effects of development on fertility. On the other hand, when a number of other variables including GNP per capita are used, the latter represents only those aspects of development that are not reflected by these other variables, which instead, reflect dominant long run effects of development on fertility.

   An analysis using time series of cross section including a number of determinants of fertility was discarded partly because of data considerations, and partly because of the questions that have been raised concerning the usefulness, for the purpose of prediction, of regressions such as the determinants of fertility analyses (Okun 19651 Rao and Dey 1968; Janowitz 1973). It has been suggested that even though these regressions are capable of explaining cross sectional variability of fertility, not necessarily same variables and equations explain the temporal variation of fertility. For instance Janowitz (1973) has shown that the percentage rate of change of birth rates is only related to percentage rate of change of GNP per capita and not to that of other variables that had explained a high proportion of the cross sectional variability of CBR.

3. The specification of E(y,t,) for the less developed countries could be probably improved by incorporating into it a change in "regimen" beginning in the early fifties, in addition to the gradual shift over time used here. The introduction of a regimen should make little difference in the context of the forward projections carried out in this study. However it would be quite important if backward projections are attempted.

4. Concerning the ACOR for less developed countries cfr. Kelly Williams and Cheetham 1972, pp. 102, 241; Tempo 1971; p. 54; Lewis 1965, p. 202.

References

Adelman I., 1963, "An Econometric Analysis of Population Growth", American Economic Review, vol. 53, pp. 314-339.

AID, Gross National Product, Growth Rates and Trend Data, May 10, 1972, Document RC-W-138.

Arriaga E.E., New Life Tables for Latin American Populations in the Nineteenth and Twentieth Centuries, Population Monograph Series No. 3, University of California, Berkeley, Call, 1968.

Basavarajappa K.G., March 1971, "The Difference of Fluctuations in Economic Conditions on Fertility and Marriage Rates, Australia 1920-21 to 1937-38 and 1947-48 to 1966-67", Population Studies, Vol. 25, pp. 39-53.

Becker G., 1960, "An Economic Analysis of Fertility", in Demographic and Economic Change in Developed Countries, Princeton, National Bureau of Economic Research.

Ben Porath Y., 1973, "Short Term Fluctuations in Fertility and Economic Activity in Israel", Demography, Vol. 10, no. 2, pp. 185-204.

Bruton H.J., December 1967, "Productivity Growth in Latin America", The American Economic Review, Vol. 57, pp. 1900-1116.

Chenery H.B., 1971, "Targets for Development" in The Widening Gap, B.A. Ward, L.D'anjou, J.D. Runnals (eds.), Columbia University Press, New York.

Coale A.J. and Demeny P., "Regional Model Life Tables and Stable Populations", Princeton University Press, Princeton, New Jersey 1966.

Denison E.F., Why Growth Rates Differ, The Brooking Institution, Washington D.C., 1967.

De Tray D.N., March/April 1973, "Child Quality and the Demand for Children", Journal of Political Economy, Vol. 81, No. 2, pp.S70-S95.

Drakatos C.G., 1969, "The Determinants of Birth Rate in Developing Countries; An Econometric Study of Greece", Economic Development and Cultural Change, Vol. 17, pp. 596-604.

Easterlin R.A., 1962, "The American Baby Boon in Historical Perspective", National Bureau of Economic Research, Occasional Paper No. 79.

Frauenthal J.G., "Birth Trajectory under Changing Fertility Conditions", Demography, Vol. 12, No. 3, August 1975, pp. 447-454.

Friendlander S. and Morris S., 1967, "A Quantitative Study of the Determinants of Fertility Behavior", Demography , Vol. 4, pp. 30-70.

Galbraith V. and Thomas D.S., 1941, "Birth Rates and the Interwar Business Cycles", Journal of the American Statistical Association, Vol. 36, pp. 465-476.

Habakkuk H.J., 1953, English Population in the Eighteenth Century", Economic History Review, Vol. 6, No. 2, pp. 117-33.

Heer D.M., 1966,"Economic Development and Fertility", Demography Vol. 3, pp. 423-444.

Hoch I., 1962, "Estimation of Production Function Parameters Combining Time Series and Cross-section Data", Econometrica, Vol. 30 No. 1, pp. 34-53.

Janowitz B.S., April 1973, "An Econometric Analysis of Trends in Fertility Rates", The Journal of Development Studies, Vol. 9 No. 3 pp. 413-25.

Johnson P.R., February 1964, "Some Aspects of Estimating Statistical Cost Functions", Journal of Farm Economics, Vol. 46, No. 1, pp. 179-187.

Kelley A.C., Williamson J.G. and Cheetham R.J., 1972, Dualistic Economic Development, University of Chicago Press, Chicago and London.

Keyfitz N., Introduction to the Mathematics of Population, Addison-Wesley, Reading, Mass. 1968.

Keyfitz N., and Flieger W., World Population, An Analysis of Vital Data, The University of Chicago Press, Chicago, Illinois, 1968.

Keyfitz N., "On the Momentum of Population Growth, Demography, Vol. 8, No. 1, February 1971, pp. 71-80.

Kirk D., 1956, "The Relation of Employment Levels to Birth in Germany", in Demographic Analysis, J.J. Spengler and O.D. Duncan (eds.) Free Press, Glencoe.

Kirk D., 1971, "A New Demographic Transition", in Rapid Population Growth, Vol. 2, National Academy of Science, John Hopkins Press, Baltimore, pp. 123-147.

Kosobud R.F., and O'Neill W.D., May 1974, "A Growth Model with Population Endogenous", The American Economic Review, Vol. 64, No. 2, pp. 27-32.

Krause J.T., 1957, "Some Implications of Recent Work in Historical Demography", Comparative Studies in Society and History, Vol. 1, pp. 164-188.

Kuczynsky R.R., 1969, The Measurement of Population Growth, Method and Results, Gordon and Breach Science Publisher, London, Paris.

Kuznets S., 1971, Economic Growth of Nations, Harvard University Press, Cambridge, Mass.

Kuznets S., 1972, "Problems in Comparing Recent Growth Rates for Developed and Less Developed Countries", Economic Development and Cultural Change, Vol. 20, pp. 185-209.

Landau L., Saving Functions for Latin America, in Studies in Development Planning, H.B. Chenery (ed). Harvard University Press, Cambridge, Mass. 1971.

Mikesell R., and Zinser J.E., "The Nature of the Savings Function in Developing Countries: A Survey of the Theoretical and Empirical Literature, Journal of Economic Literature, Vol. 11, March 1973, no. 1, pp. 1-26.

Lewis W.A., 1965, Theory of Economic Growth, Harper and Row, N.Y.

Okun B., 1965, "The Birth Rates and Economic Development: An Empirical Study - Comment", Econometrica, Vol. 33, No. 1, p. 245.

Petersen W., 1966, "The Demographic Transition", American Sociological Review, Vol. 25, pp. 334-347.

Petersen W., 1969, Population, Second Edition, the MacMillan Co., N.Y.

Pearson L.B., 1969, Partners in Development, Report on the Commission on International Development, Praeger, New York.

Population Index, April/June 1970, Vol. 36, No. 2, p. 253-261.

Population Index, October/December 1970, Vol. 36, No. 4, pp. 559-566.

Population Index, April 1973, Vol. 39, No. 2, p. 285-294.

Rao V.V.B. and Dey B.R., June, 1968 "Birth Rates and Economic Development. Some Observations from Japanese Data", Sankhya, Series B., Vol. 30, pp. 149-156.

Silver M., 1966, "Births, Marriages, and Income Fluctuations in the United Kingdom and Japan", Economic Development and Cultural Change, Vol. 14, No. 3, pp. 302-315.

Simon J.L., 1974, The Effects of Income on Fertility, Carolina Population Center, Chapel Hill, N.C.

Simon J.L., No. 1969, "The Effects of Income on Fertility, Population Studies, Vol. 23, No. 3, pp. 327-341.

Tempo, 1971, Description of the Economic Demographic Model.

United Nations, Department of Social Affairs, Population Branch, Age and Sex Patterns of Mortality, Model-Life-Tables for Under-Developed Countries, New York 1955.

U.N. World Economic Survey, 1969-1970, New York 1971.

United Nations - Recent Trends in Fertility in Industrialized Countries, Population Studies No. 27, N.Y. 1958.

Vielrose E., Elements of the Natural Movement of Population, Pergamon Press, Oxford, London, N.Y., 1965.

Willis R.J., March/April 1973, "A New Approach to the Economic Theory of Fertility Behavior", Journal of Pblitical Economy, Vol. 81, No. 2, pp. S14-S64.

Williamson J.G., "Dimensions of Philippine Postwar Economic Progress", Quarterly Journal of Economics, Vol. 83, Feb. 1969, pp. 93-109.

Zimmerman L.J., 1962, "The Distribution of World Income 1860-1960" in Essay on Unbalanced Growth, E. Devries Ed.