POPULATION OF THE WORLD AND ITS REGIONS 1975-2050

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PREFACE

"The world population is now passing the four billion mark, and at the present rate of increase it would double twice to about fifteen billion by the year 2050. Yet there are those who say that it will do well to maintain its present level. Many individuals already born will be alive in 2050; it is hardly very informative to know that they will be accompanied by between 4 and 15 billion people."

This is how Nathan Keyfitz opens his discussion on world population in the following paper, written during his stay at IIASA in September 1976. He concludes that the total is likely to lie in the range of 6.5-8.5 billion people.

Dr. Keyfitz' considerations have been important for IIASA's Energy Systems Program attempting to put together the wealth of knowledge on energy and related matters, in order to obtain a comprehensive view of the global long- and medium-term energy problem.

On the occasion of our forthcoming final report on Phase I of our activities, we feel that it is worthwhile therefore to publish Dr. Keyfitz' paper, making it accessible to a wider audience.

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SUMMARY

Low and high estimates are calculated for three categories of less developed countries (LDCs). The low figure for the year 2050 is 5,099.5, the high one is 7,184.5, all in millions. Adding the 1,400 millions for the developed countries (on which all estimates agree closely) gives a range of 6,500 to 8,600 millions for the world population in the year 2050; the ultimate world population on this scheme would be very little higher. The low of 6,500 is based on mortality continuing to fall and replacement (two children per couple surviving to maturity) ing reached by 1995; the high estimate assumes this condition will be reached by 2015.

These numbers straddle the World Bank A figure, which is 8,136 million for the year 2050, and our high is slightly below the United Nations low figure. The result agrees with the implications of Lester R. Brown's (1976) paper. It represents a growing consensus that if birth rates have not dropped to replacement early in the 21st century, then death rates will rise substantially.

CONTENTS

INTRODUCTION
The Future is Uncertain
The Difficulties Start with the Present
How Fast is the World Population Increasing Now?
The Peaking of the Rate of Increase

METHODS OF POPULATION ESTIMATION
Geometric Increase
Declining Rate of Increase
Demographic Transition
The Principle of Momentum
Stationarity

HOW ACCURATELY CAN THE FUTURE BE KNOWN?

EXISTING FORECASTS BY REGION

THE DEVELOPED COUNTRIES
Distinguishing Fluctuations from Trends

THE LESS DEVELOPED COUNTRIES
Relation of Mortality and Fertility
Empirical Evidence on Fertility
The Demographic Transition

A GENERAL METHOD AND COMPUTER PROGRAM
Projecting the Components
Program for Life Table and Population Projection
Population, Deaths, and Births by Age

OTHER ESTIMATES

POPULATION OF THE WORLD AND ITS REGIONS, 1975-2050

INTRODUCTION

The world population is now passing the 4 billion mark, and at the present rate of increase it would double twice to about 15 billion by the year 2050. Yet there are those who say that it has already reached a ceiling and will do well to maintain its present level; that shortages of all kinds, especially of foodstuffs, will prevent further rise, even if birth control does not. Many individuals already born will be alive in the year 2050; it is hardly very informative to know that they will be accompanied on the earth by between 4 and 15 billion people. The following pages are an attempt to narrow the range.

The Future is Uncertain

Until that future date arrives, any statement predicting the number of people in the world or any part of its surface in the year 2050 is soothsaying. The best that can be done is to narrow the range somewhat, so that one does not have to take account of all the possibilities between 4 and 15 billion, but only of some of them. If the possibilities outside 7 to 9 billion could reasonably be excluded, we would have most of the knowledge of the 2050 now possible.

One way of limiting the range is to accept the high, medium, and low variants of future population as published by the United Nations, the World Bank, the United States Bureau of the Census, or some other agency. Evaluation of these is not easy. They are based on extrapolation of birth and death rates, and the calculation is elaborate and complex enough that its method is not easily summarized. It will be well to compare them with some simple calculations transparent enough for immediate understanding and criticism.

This paper will examine in what degree it is possible to put bounds on the future. We shall see, for example, that the population of the year 2000 cannot but be close to 6 billion, say with 500 million variation in either direction, if major famines and wars are avoided, and that the 2050 population can fall anywhere between 7 and 9 billion. The spreading horn that expresses our ignorance of the future is determined by the lesser uncertainty--at least up to now--of death rates than of birth rates. We can put narrower bounds on how many of the presently alive will survive than on how many new people will be born. That is why the horn spreads, and why it is impossible to penetrate the veil of ignorance that separates 9 from 7 billion.

Finally we will make our own projection for the years to 2075. It will be a long time before it is known whether it is better than the extant projections, an uncertainty all projections are subject to.

The Difficulties Start with the Present

Table 1 shows for the past and the near future the main facts of world population. During the last quarter of this millenium population as a whole increases about 8 times, population in the rich countries about 6 times. From there being 46 acres of the land surface of the planet for each of us in 1750, there is to be only 6 acres in the year 2000. When the presently rich countries were developing they grew very rapidly and came to be 35 percent of the earth's population. The poor countries are now more than catching up, and with 78 percent of the planet in the year 2000 they will have exceeded their proportion in the 18th century. Increases in the latter part of the 20th century are unprecedented in history, especially the increase of the poor countries at 22 per thousand.

Too much should not be made of this comparison of rich and poor based on present rates. Any competition between them has a very different locus from population numbers. Both groups have great impact on resources and hence on carrying capacity. A world population that rises at 18 per thousand multiplies sixfold in a century. If we project the rates for the poor (22 per thousand) and the rich (9 per thousand) separately for the following century we find an even greater increase: nearly 7 1/2 times. An estimate of the future always comes out higher when executed by separate components than projected as a total only.

But we can be sure that this amount of increase will not occur, and in fact the United Nations medium estimate of 6.2 billion for the year 2000 is probably high. The rich countries are barely increasing at all, and the poor countries have come to take birth control seriously. That the world total is likely to be close to 6 billion by the end of the century will be shown below.

Table 1. Summary of world population over 250 years.

	1750	1800	1850	1900	1950	2000
	Number in millions					
World	791	978	1262	1650	2501	6253
Rich countries	201	248	347	573	857	1361
Poor countries	590	730	915	1077	1644	4893
	Percent division between rich and poor countries					
Rich countries	26	26	28	35	34	22
Poor countries	74	74	72	65	66	78
	Per thousand annual increase					
Total	4	5	5	8	18	
Rich countries	4	7	10	8	9	
Poor countries	4	5	3	8	22	

Rich countries are Europe, Northern America, temperate South America, Australia, New Zealand, and Japan.
Estimates for 1750-1900 from Durand (1967); 1950-2000 from the United Nations (1975) medium variant.

Even before starting to project the future the would-be forecaster has difficulties. His first obstacle in the way of estimating what the world population will be in the 21st century is ignorance of its present amount and rate of growth. As of 1971 only 10 percent of the population of Africa, 6 percent of the population of Asia, and 20 percent of the population of South America were covered by complete birth registration. At that the definition of completeness was a modest one: that 90 percent of births be registered.

The seven largest countries as of now constitute 58 percent of the world's population (Table 2). Their totals at the jumping-off point are subject to errors of census-taking. In the case of the United States the shortfall is on the order of 2 percent, measured by careful re-enumeration. Other countries have less accurate censuses and are less conscientious in carrying out independent checks on enumeration. In some this may be offset by the better discipline of their populations. One can say on the whole that the numbers for 1970 in Table 2 are reasonably accurate, say well within 5 percent, but China is a conspicuous exception.

Since China contains between one fifth and one quarter of the world's population, its number and increase are of great importance. The International Statistical Programs Center of the U.S. Bureau of the Census (1976) gives 843 million for mid-1975, an increase of 12 million from mid-1974. AID (Ravenholt 1976) gives 7 million increase at one extreme, and John Aird is quoted as an authority by the Environmental Fund (1976) at the other extreme as estimating an annual increase of 22 million. The World Bank, quoting Chinese figures communicated to the World Population Conference at Bucharest,

Table 2. Seven largest countries as estimated by the United Nations (1976, medium variant) and projected to the year 2000 (millions of persons).

	1970	1980	1990	2000
China	772	908	1031	1148
India	543	694	876	1059
U.S.S.R.	243	268	294	315
United States	205	224	247	264
Indonesia	119	155	197	238
Japan	104	118	126	133
Brazil	95	126	166	213

gives 786 million as the mid-1972 level, and at a 1.8 percent growth rate China would be increasing at 14 million per year. The United Nations has 772 million for 1970 and 839 million for 1975, higher than the World Bank figure, as the following interpolation shows:

	Population (millions)	Annual increase (millions)
U.S. AID	about 840	7
U.S. Bureau of the Census	807	12
United Nations	798	13
World Bank	786	14
Environmental Fund		22

The United Nations figure apparently includes Taiwan with some 15 million, and yet it is lower than the U.S. Bureau of the Census estimate, which shows Taiwan as a separate entity.

The U.S. AID estimate is provided by R.T. Ravenhold (1976) and is pieced together from various items of recent evidence, including correspondence with Chinese officials, that shows China's birth rate to have dropped to 14 per thousand by 1975, the large drop being in the 1970s. The death rate is down to 6 per thousand on this calculation. It puts the level of the Chinese population at 876 million in 1975, higher than the others, but the absolute annual increase at only 7 million, which is about half of what has been generally thought. A difference of 7 million per year in China makes a difference to the Chinese and the world population by the end of the century of 175 million. Some resolution of the difference is plainly required.

Here and elsewhere there are signs that the United Nations estimate is high, that it has not caught up with recent indications of falling birth rates. One example is that the F.R.G., the G.D.R. and Austria, shown as increasing where in fact they have started to decrease. The medium variant gives for Austria a birth rate of 14.8 against a death rate of 12.4. In fact the births are well below the deaths for 1975. On the other hand the United Nations gives Nigeria a population of 55 million in 1970 and 63 million in 1975, while the World Bank gives it 70 million in 1972. United States births are shown at 16.2 per thousand by the United Nations for 1970-75 and at 17.2 for 1975-80. While no one can now say what the quinquennium will average, yet the fact that the 12 months ending August 1976 show a drop to 14.5 suggests that the 17.2 is hardly likely to be attained.

How Fast is the World Population Increasing Now?

The U.S. Bureau of the Census puts the total for mid-1975 at 3,996 million and the annual growth rate between 1.7 and 1.9, which would make the annual increment 68 to 76 million. The United Nations is at the upper end of this in respect of natural increase--it gives 18.7 for 1970-75 and 19.3 for 1975-80, an average of 19.0 per thousand, but it applies it to a smaller base, 3,967 million in 1975, making the increment 75 million. Especially to be noted is that this increment according to the United Nations medium variant goes above 101 million in the last five years of the century.

Once again the figures provided by R.T. Ravenholt and Brackett (1976) of U.S.AID are much lower. They find for 1974 a world population total of 3,880 million and a growth rate of 1.63 percent, or an increment of 63 million. And far from the increment being on the rise, it is well past its peak of 70 million reached in 1970 and is now headed downward.

The difference from the official UN and U.S.BC figures is dramatic. For even if there is no further fall, and the figure remains at the present 63 million, by the end of the century we will be 3880 + (63)(26) = 5518 million, rather than the 6-plus billion that is found in other estimates.

The Peaking of the Rate of Increase

All estimates agree that at least the rate of increase of world population is passing a maximum and starting to decline. The United Nations puts the maximum at 19.3 per thousand, and shows it as occurring in the quinquennium 1975-80, which is to say at the present moment. The developed countries have been falling since World War II, while the less developed countries as a whole reach their maximum of 23.6 in 1975-80. The several continents are also reaching maxima about now, except Africa, whose rate of increase keeps increasing until 1985-90, again according to the UN medium variant (Table 3).

Table 3. Annual rate of increase per thousand population, 1950-2000, United Nations medium variant, assessed in 1973.

	World	Developed countries	Less developed countries	Africa	Latin America	South Asia
1950-55	16.8	12.8	18.8	21.3	26.7	18.8
1955-60	18.3	12.6	21.1	23.1	28.0	22.4
1960-65	19.0	11.5	22.5	24.7	28.4	24.6
1965-70	18.6	9.0	22.9	25.8	28.0	24.9
1970-75	18.7	8.0	23.2	26.5	27.7	25.2
1975-80	19.3	8.0	23.6	27.7	27.8	26.1
1980-85	19.1	7.8	23.1	28.6	27.5	25.6
1985-90	18.2	7.0	21.9	28.8	26.6	24.1
1990-95	17.3	6.1	20.7	28.6	25.4	22.0
1995-2000	16.2	5.7	19.2	27.7	23.9	19.5

METHODS OF POPULATION ESTIMATION

Geometric Increase

Setting the 1975 world population P_{1975} at 4.0 billion and taking a rate of increase of 1.8 percent per year, gives for the year 2000

$$P_{2000} = 4.0(1.018)^{25} - 6.2 \times 10^{9} \quad .$$

This is equal to the latest United Nations number for the year 2000, and below the 6.5 billion presented earlier for that year. Yet one can argue that it is almost certainly too high.

For the present rate of 1.8 percent per year will go down. The time about now appears an historic high in the rate of increase of world population. The reason why the rate of increase must fall can be seen from the reason it has risen up to now.

The Net Reproduction Rate R_0 is the number of children expected to be born to a girl child just born,

$$R_0 = \int_0^\infty \ell(a)m(a)da \quad ,$$

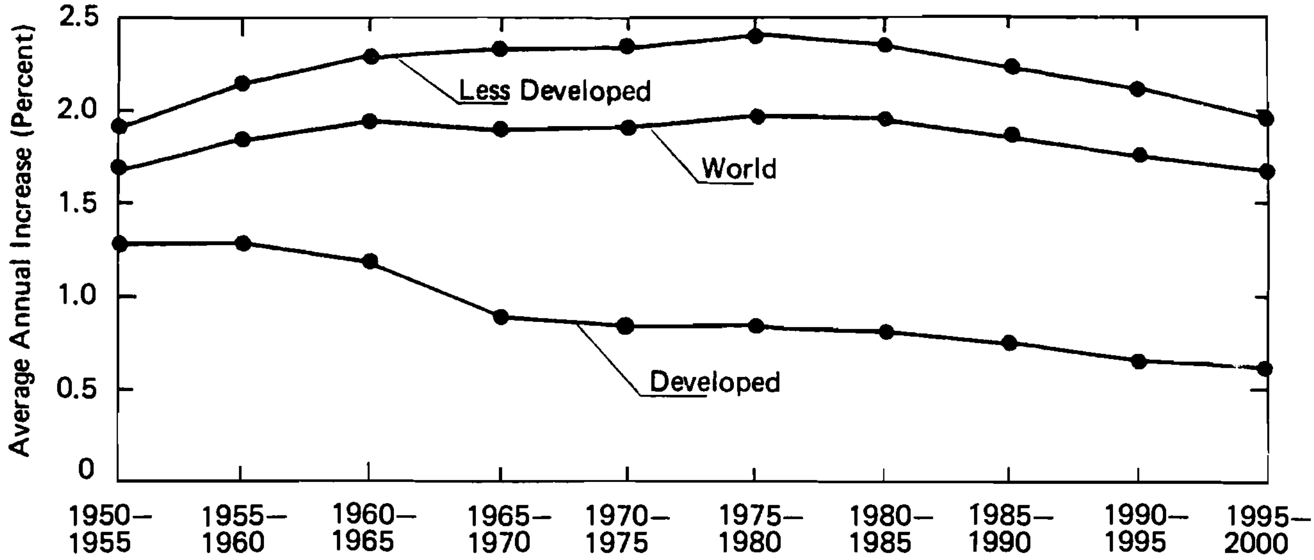

Figure 1. Population rates of increase, showing maximum now attained, United Nations.

where $\ell(a)$ is the probability that she lives to age a, m(a)da the chance that she then has a child before age a + da. R_0 is thus the ratio of the number living in one generation to the number living a generation before, as implied by the current rates of birth and death. If death is disregarded we have G_0, the Gross Reproduction Rate, as the same integral with the probability of surviving $\ell(a)$ omitted. If R_0 is the ratio of successive generations at the given rates of birth and death, then G_0 is the expected family size of survivors at the given birth rates.

Then if we write

$$R_0 = \left(\frac{R_0}{G_0}\right)G_0 \quad ,$$

the first factor on the right is the suitably weighted probability of survival to maturity, the second factor G_0 is a pure fertility indicator. Up to now the main change for many countries has been the fall in the first factor, survivorship, while the second factor, fertility, has remained constant or fallen slowly. The survivorship cannot go above unity, and further declines in mortality--those past childbearing ages--make no great difference to the rate of increase. The rich countries have attained a probability of survivorship to maturity of about 0.97; the poor ones of about 0.90, except in Africa. As the limit of unity is approached the rate of increase of survivorship is bound to slow down. Any increase in survivorship beyond the 1970s is almost certain to be offset by a greater fall in fertility. This is shown in Figure 1, taken from United Nations data.

The conclusion is that projecting the 1975 population at the 1.8 percent per year now shown, producing 6.2 million by 2000, must be an overstatement. Let us see what happens if we suppose a fall in the rate of increase.

Declining Rate of Increase

For dealing with changing rates of increase we need an expression that converts the trajectory r(t) of the rate of increase into a trajectory of the population. The definition of

of r(t) is $\frac{1}{P(t)} \frac{dP(t)}{dt}$, and hence

$$\ln P(t) = \int_0^t r(u)du + \text{constant} \quad ,$$

so therefore

$$P(t) = P_0 \exp\left(\int_0^t r(u)du\right) \quad . \qquad (1)$$

Use this to see what the ultimate world population would be if the rate of increase declined in a straight line to zero by the year 2050, starting at 1.8 percent in 1975. By the end of the century the rate would be 1.2 percent, by 2025 it would be 0.6 percent. The population at each point of time would be

t	$P_t/10^9$
1975	4.0
2000	5.8
2025	7.3
2050	7.9

Apparently the population in the year 2000 would be 5.8, and total subsequent increase for all time would be only a further 2 billion.

If everything is as above, except that the rate of increase drops to zero by the year 2025, we have lower figures:

t	$P_t/10^9$
1975	4.0
2000	5.6
2025	6.3

so the ultimate population is only 6.3 billion.

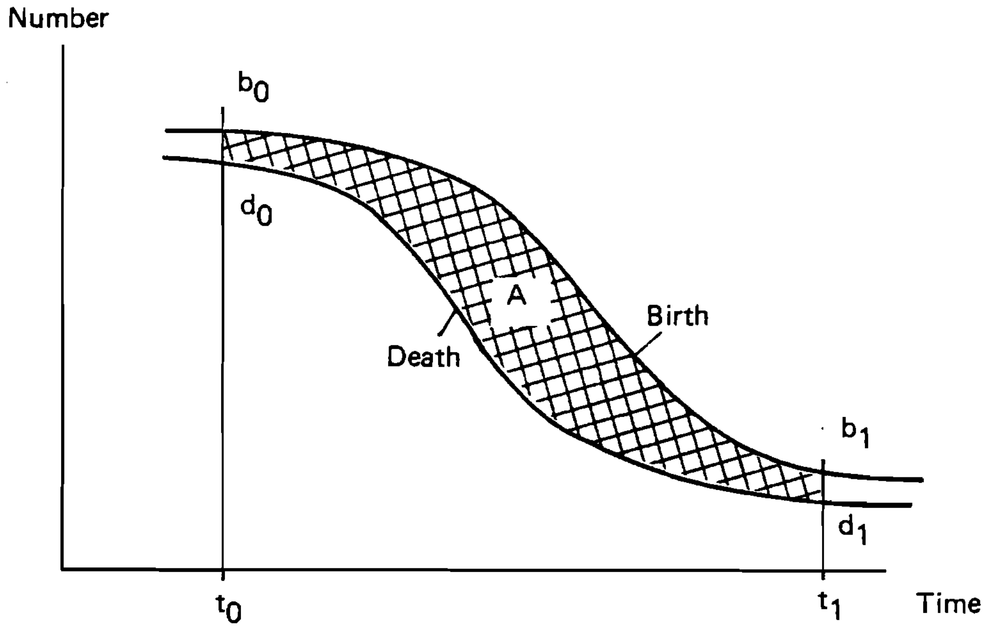

Figure 2. A stylized version of the demographic transition.

Breakdown into DCs and LDCs

How much difference does it make if we break this down into more and less developed countries (DCs and LDCs)? Any such division will raise the result. If the drop to stationarity by the year 2050 starts with the DCs increasing at 0.7 percent and the LDCs at 2.4 percent, we have in billions

1975	1.1	2.9	4.0
2000	1.3	4.8	6.1
2025	1.4	6.5	7.9
2050	1.5	7.1	8.6

Now the ultimate stationary world population is 8.6 billion. Recognizing heterogeneous subgroups has raised the outcome by 0.7 billion.

Demographic Transition

As a further approach, consider the demographic transition, in which in country after country mortality falls and this is followed after a longer or shorter time by a fall in fertility (Figure 2). Between time t_0 and $time_1$ the death rate d goes from d_0 to d_1 and the birth rate from b_0 to b_1 . Call A the area $b_0b_1d_1d_0$ in Figure 2. Then by virtue of (1), since $r(t) = b(t) - d(t)$ is the difference between births and deaths, and

$$A = \int_{t_0}^{t_1} r(t)dt = \int_{t_0}^{t_1} [b(t) - d(t)]dt \quad ,$$

then $P_1 = P_0e^A$ shows the increase from population P_0 at t_0 to population P_1 at t_1 . This is exact and does not depend on the similarity of the fall of births and deaths. But now let the birth and death curves fall in similar manner, so that b(t) is just d(t) displaced to the right. Let L be the lag in the fall of births behind the fall in deaths, and R be the common range of birth and death. Then $P_1 = P_0e^{LR}$. If the lag L is 20 years on the average and R = 0.03, we have

$$P_0 = 4.0e^{20(0.03)} = 7.3 \text{ billions.}$$

Let us disaggregate into less and more developed. Suppose 30 percent further increase for the developed, and 30 years' lag in the demographic transition of the less developed. Then

DCs	1.1×1.3	= 1.4
LDCs	$2.9 \times e^{30(0.03)}$	= 7.1
	Total	8.5 billions,

or about the same as the disaggregated version with rate of increase r(t) falling in a straight line to 2050. Recent demographic transitions have taken place more rapidly than early ones, and if this continues to be true 30 years is an upper bound for the future.

The Principle of Momentum

The above has taken little account of age. Despite experimenting that showed that projections without age came equally close to the true number that emerged 10 or 15 years later, one ought nonetheless to examine the effect of momentum due to age distributions being favorable to births following a long period of high fertility. If a country drops to zero fertility at a moment when its birth rate is b, its expectation of life $\mathring{e}_0$, its rate of increase r, and its mean age of childbearing μ, then the ratio of its ultimate stationary population to that at the moment of fall is

$$\frac{b\mathring{e}_0}{r_\mu} \frac{R_0 - 1}{R_0} \doteq \frac{b\mathring{e}_0}{\sqrt{R_0}} ,$$

or if $b = 0.040$, $\mathring{e}_0 = 60$, $R_0 = 2.5$, we have the ratio 1.52.

If the less developed countries increase for an average of 20 years at an average rate of 2.4 percent, then drop to bare replacement, their population will be

$$(2.9)(1.024)^{20}(1.52) = 7.1.$$

Adding 1.4 for the developed countries gives 7.1 + 1.4 = 8.5 billions.

Stationarity

The number of births in the United States has been just over 3 million during this decade despite a very large cohort of women of childbearing age, themselves the outcome of cohorts of over 4 million during the 1950s. As the number of childbearing couples begins to taper off in the 1980s we can expect some fall in the number of births. But this may not occur; it is possible that the falling off in the number of persons of childbearing age will be offset in some degree by an increased average family size, though no one can be sure. On the other hand there are still some unwanted births, and these are certain to be reduced both through better contraceptive methods (a once-a-month pill for women and a pill for men would help) and through better dissemination of existing methods. If 3 million turns out to be the level of births in the United States, and if the expectation of life for the average of both sexes climbs to 75 years, then the long-run stationary population of the United States will be exactly the product of these two, or 225 million.

Similar calculation can be made for other countries whose birth levels have fallen nearly to stationarity, which is to say, in the long run just offsetting deaths. In F.R.G. and in Austria the current births are fewer than current deaths. If the births in the F.R.G. rise to 700,000 and continue at that level, and are associated with an expectation of life of 75 years, the resulting stationary population would be 52.5 million, or 10 million fewer than are now present.

For Europe and the Soviet Union as a whole the corresponding level for births may well be on the order of 12 million per year. This would correspond to a total population of 12 × 75 = 800 millions, against the 728 millions shown for 1975 by the U.S. Bureau of the Census.

Adding the 3 million births of the United States, 2 million for Japan, 12 million for Europe and the U.S.S.R., 1 million for Canada, Australia, etc., gives 18 million births per year for the developed countries. The ultimate stationary population to which these point is 1,350 million. This compares with 1,132 million estimated for the same developed countries for mid-1975 by the U.S. Bureau of the Census. It says they have less than 20 percent more to climb before they reach their permanent high. That some such relatively low ultimate total seems likely is argued in detail below. Calculations of this kind, that can be done on the back of an envelope, have the advantage of being immediately understandable and therefore subject to critical judgment.

HOW ACCURATELY CAN THE FUTURE BE KNOWN?

Serious projections provide a range for any future date, and the succession of ranges fans out as one goes forward in time. The fan or horn takes its characteristic shape from the fact that survivorship among the living population has, at least in the past, followed a clear trend, while births are subject to such large fluctuations that the trend is hard to separate out. As the projection goes forward in time the births subsequent to the jumping-off point make up a larger and larger part of the population. By the year 2000 more than one half of the world population will have been born since 1975, by the year 2025 nearly 80 percent. It is on the number of these births that the main effort of the forecast must be centered.

As an example of the fan estimated long enough ago that we can now form some judgment as to where the performance will lie within it, consider Table 4, showing United Nations estimates made in 1968. The gradually widening range ends with a low of just under 6 billion and a high of just over 7 billion for the year 2000. It now appears that the low figure is closer to the mark. Births in both developed and less developed countries fell faster than was anticipated by extrapolation of pre-1968 trends. The 1963 assessment was probably more accurate than that of 1968--its low was 5,449 million and its high 6,994 million. Besides being more accurate in having the wider range stretching much further on the low side, the 1963 estimate was more modest in allowing a wider range, which is to say, a wider allowance for ignorance.

The range--somewhat over 1.1 billion between low and high or 10 percent each way from the mean in 1968, and 1.5 billion or 12 percent in 1963--reflects correctly the accuracy with which such estimates can be made, if one wishes to have a one-half to two-thirds chance of straddling the true figure.

In recent years the United Nations has stressed the medium variant of its estimates, tending to neglect the high and low variants. This is what many of its customers want--the best guess than can be made on each future year, so that they can use the figure without thinking too much about it. Yet the

Table 4. The fan of uncertainty as assessed by the United Nations in 1968 (millions of persons).

	High variant			Medium variant			Low variant		
Date	Less developed countries	Developed countries	Total	Less developed countries	Developed countries	Total	Less developed countries	Developed countries	Total
1965	2252			2252	1037	3289	2252		
1970	2564			2542	1090	3632	2523		
1980	3379		4589	3247	1210	4457	3137		4347
1990	4425		5761	4102	1336	5438	3820		5156
2000	5650		7104	5040	1454	6494	4523		5977

Table 5. Estimates of 1980 world population (millions of persons); from United Nations, various dates.

Date	Low	Medium	High
1951	2976		3636
1954	3295		3990
1957	3850	4220	4280
1963	4147	4330	4550
1968	4347	4457	4589
1973		4374	

Table 6. United Nations medium variant of population in the year 2000 as assessed at various dates (millions).

Assessed in	World	More developed	Less developed
1963	6130	1441	4688
1968	6494	1454	5040
1973	6254	1360	4894

range is a way of informing the customer as to how much he can rely on the medium variant, and its partial abandonment must be reckoned as a step backward.

Table 5 shows the 1980 population as estimated at various times from 1951 to 1973. The first estimates were much too low, and successive estimates kept rising to a peak, reached in 1968, when 1980 was estimated at 4,457 million persons. Since then the United Nations revision has been downwards. It is more than possible that the lower 1973 figure will also prove high. It is understandable that forecasters should change their numbers as new data keep appearing, and that they should be influenced by such facts as the trend towards acceptance of contraception in developing countries.

As a rough way of describing the uncertainty fan, the high estimate of Table 4 supposes an average 2.7 percent per year increase for the less developed countries, and the low estimate 2.0 percent. This range could well prove too narrow to have a two-thirds probability of straddling the number that will be counted in 1980. The U.S. Bureau of the Census, estimating the year 2000 in 1974, shows an average annual increase of 1.17 percent for the high variant and 0.55 percent for the low. This also could prove too narrow.

The forecaster is in a dilemma. He wants to be useful to his client, yet he is aware that forecasting is difficult. If he gives a realistic range for 2/3 confidence the client would scorn his numbers, even though no better numbers are to be had.

Table 7. Estimates of world population to the year 2050 from three publications (millions of persons).

Source		1975	2000	2025	2050
United Nations, with data up to					
1968	High		7104		
	Medium		6494		
	Low		5977		
1973	High				
	Medium	3968	6254		
	Low				
World Bank (1972)					
Projection A		4019	5916		8,136
Projection B		4042	6690		13,444
Frejka (1973)					
Bare replacement by					
2000-2005		4007	5922		8,172
2020-2025		4022	6422		10,473
2040-2045		4030	6670		13,024

One can obtain some impression of the degree to which further data influence the forecast by studying successive revisions, for example as these affect developed and less developed countries in Table 6.

EXISTING FORECASTS BY REGION

Few serious published estimates are available for the 21st century, even for the world as a whole, and fewer yet are to be had by regions. Some of these are shown in Table 7.

The United Nations estimates stop at the year 2000. The World Bank (1972) goes much farther. Its work is based on an early version of the Frejka (1973) projections, the main contribution of the Bank being selection of two of the Frejka projections that may be considered realistic. The low estimate, called A, supposes that the average of fertility in the world will drop linearly to bare replacement by 2000-2005, and the high estimate B supposes that this condition will not be reached until 2040-45.

The World Bank Projection A gives population in the year 2000 as 5,916 million and in 2050 as 8,136 million. It will later be argued that this is a reasonable medium figure. The Bank contrasts it with Projection B, that gives the 2000

Table 8. Groups of countries as assembled for projection, with mid-1975 population as estimated by the U.S. Bureau of the Census (thousands of persons).

United States and countries of British settlement	
United States	213,631
Canada	22,811
South Africa	25,087
Australia	13,520
New Zealand	3,096
Total	278,145
Socialist countries of eastern Europe, including the U.S.S.R.	
Albania	2,411
Bulgaria	8,741
Czechoslovakia	14,804
German Democratic Republic	16,885
Hungary	10,541
Poland	34,022
Romania	21,245
U.S.S.R.	254,300
Yugoslavia	21,346
Total	384,295
Petroleum exporters	
Algeria	15,684
Ecuador	7,041
Gabon	519
Indonesia	139,421
Iran	34,903
Iraq	11,060
Kuwait	1,007
Libya	2,437
Nigeria	63,022
Saudi Arabia	6,231
Venezuela	12,821
Total	294,146
Developing countries--incomes of more than $400 GNP per capita in 1972	
Argentina	25,911
Barbados	232
Brazil	106,976
Chile	10,585
Republic of China	16,076
Colombia	25,185
Costa Rica	1,967
Cuba	9,252
Dominican Republic	4,907
Fiji	575
Guatemala	6,047
Guyana	786
Hong Kong	4,339
Israel	3,437
Jamaica	2,065
Lebanon	2,656
Malaysia	12,368
Mexico	59,238
Nicaragua	2,260
Panama	1,674
Peru	15,486
Singapore	2,251
Trinidad	974
Uruguay	3,059
Total	321,000

population as 6,690 million and the 2050 as 13,444 million. The ultimate stationary world population, reached about 2100, is nearly double on Projection B what it is on Projection A: 15,815 million against 8,386 million, but this is beyond our scope.

The 2050 figure designated A increases from 1975 at an average rate of 0.95 percent per year, while B increases at 1.62 percent per year.

For our purposes it is convenient to recognize six groups of countries. These are shown in Table 8, and may be summarized as

Table 9. Summary of categories of countries recognized for purposes of the present projection, from U.S. Bureau of the Census (millions of persons).

World	3996
United States and countries of British settlement	278
Western Europe and Japan	463
Socialist countries of eastern Europe, including the U.S.S.R.	384
Oil exporters	294
Developing countries of more than $400 GNP per capita in 1972	321
Less developed countries of less than $400 GNP per capita in 1972	2249

All of these groups but the last, which is residual, are listed in some detail in Table 8.

in Table 9 with 1975 totals in millions as given by the U.S. Bureau of the Census.

THE DEVELOPED COUNTRIES

In traditional societies, for example those of Africa on which John Caldwell (1976) has generalized, the flow of wealth was from young to old as long as the old lived; only at the moment of death did the accumulated wealth revert to the young. With modernization the flow of wealth is reversed; the young are raised and educated by the old and have no obligations after maturity. This is functional for dynamic societies, in which the independence of the young fits well--inheritance is unimportant for them. But combined with the loss by the family of its productive activities, this reversal of the flow of wealth removes ancient incentives to have any children. It acts in the same direction as the weakening of family solidarity, evidenced by a high frequency of divorce.

Divorce has increased especially during the past decade. In the United States divorces numbered 264,000 in 1940, rose gently and somewhat irregularly to 479,000 by 1965, then jumped to 708,000 in 1970 and to 970,000 by 1974. At first it seemed that the war and its aftermath were causing the increase, but apparently the cause is more basic.

At one time the family, at least in the middle and upper classes, was held together by the property that it shared. In all classes it was held together by men having so great an advantage in the labor market that a woman was better off sharing a man's income than having the whole of any income she could independently earn. Mores and laws made divorce difficult; divorced persons were regarded as somewhat tainted. And as an aspect of the circularity that prevails in such matters, the family was held together by the many children that it had. All of these things have changed during the past generation, and they seem to have changed especially rapidly between the 1960s and 1970s.

The prominence of divorce as a possibility in the minds of couples acts as a brake on childbearing. If there is even a chance that the couple will break up, they do not want children. Having custody of a child is a handicap to either partner equally for work and for remarriage.

Women now derive their identity in large part from their jobs, just as men have always done. The fraction of married women in the labor force rose from 22.0 percent in 1948 to 40.8 percent in 1970; among those with children under 6 years of age the rise was even steeper--from 10.8 percent to 30.3. Over the longer term numbers are provided by the censuses; of women 25-44 years of age only 15.1 percent participated in the labor force in 1890, and 47.5 percent by 1970.

Effective equality for women is an aspiration rather then an achievement. Average wages for men in 1974 were $204 per week, and for women $124, taking full-time workers in all industries and occupations together. Whatever the breakdown, it seems that men earn about 50 percent more than women, a ratio that changes very little as one goes back through time to the 1920s, when average earnings for men were $0.55 per hour, and for women $0.36. The statistics show either that women are doing different and less skilled work than men or that they are paid less for the same work; probably both are true. When jobs like bank teller, once sex-typed as male and now in considerable part performed by women, make the changeover they change their character and, one suspects, relative pay goes down. Sex-typing is universal; there are not many kinds of work that are indifferently performed by men and by women. What is defined as women's work varies over place as well as over time. In the U.S.S.R. women can become physicians, and the majority of physicians are indeed women, which seemingly favors equality, except that physicians are paid a small fraction of what they receive in America. But whether equal *de facto* or not, that women seek equality, and seek careers such as men have, it clearly associated with small families. It might be that the disinclination to have children is what makes women seek jobs, or the interest in jobs causes them to refrain from having children; but whatever the direction of association, the correlation is high. There seems little distinction on this between socialist and capitalist societies.

It is worth repeating that the decline in childbearing depends on the aspiration of women to equality rather than the achievement of equality. When a couple breaks up remarriage is far more difficult for the women, partly for the demographic reason that male mortality is higher. In the United States primary individuals, defined as household heads living alone or with non-relatives only, included in 1970 7,882,000 women and only 4,063,000 men. While age differences between parties to first marriages are small, on their second marriage men tend to find younger women, and in a society in which youth is desirable this is in itself a sign of male dominance.

We are dealing here with a complex of apparently inseparable factors. The acceptability of divorce is associated with increased equality for women in the labor market; the labor market activities of women are associated with their wish to have fewer children; their having fewer children makes it easier for couples to break up. That complex by which women aspire to be like men, in that they attain their identity through a job or career rather than through their position in the family, causes them to value their time in monetary terms, and so children become expensive. This contrasts with earlier times when children were a primary value and going out to work, even if opportunity offered, would have seemed too costly in terms of the children who would have to be sacrificed for it.

All this is superimposed on, and carries to an extreme, those characteristics of the family that are congruent with industrial society. On the one hand it has given up the production of most commodities and even services to outside agencies, so that the education, clothing, even feeding of the children is a cost in the family's external balance of payments, and on the other hand it does not have any way of putting its children to work in producinq anything usuful to itself or salable to child while young, not to mention the fact that he could not be put to work before the age of about 20 for lack of skills.

The operative question for prediction of fertility is the durability of the social trends above described. Some judgment is required on whether divorce, women's liberation, easy contraception and abortion, and other present conditions conducing to low fertility are permanent or transient. Much of what has been said above, after all, is rationalization after the fact of a falling birth rate. If a rise in the birth rate were to occur it would be explained as due to the reassertion of the durable values of the family against the materialism and immorality of the early 1970s. Most writers, however, find it difficult to imagine such a reversal.

Distinguishing Fluctuations from Trends

In developed countries fertility has come to be subject to the business cycle, and fluctuates with employment and earnings prospects. Such fluctuations make very tenuous any conclusions drawn from single months. U.S. births for August 1976 at 277,000 are distinctly down from births in August 1975, which were 288,000. Comparing the 8 months ended in August we have 2,067,000 in 1976 against 2,099,000 in 1975, again a drop.

Comparing the year ended August we find for 1976 3,117,000 against 3,206,000 for 1975. As a ratio to population the fall is proportionally greater, since the population had been increasing somewhat over the time:

1973	15.2 per thousand
1974	14.8 per thousand
1975	15.1 per thousand
1976	14.5 per thousand

all for the 12 months ended August.

Note that these rates are much below the low of the 1930s, which came in 1933 with 18.4 births per thousand population.

Taking account of age distribution would make recent figures stand out even more. Now is when the baby boom babies are at the height of their reproduction. The peak of postwar births having come in 1961, we can expect the number of potential mothers to start declining soon.

A question more important numerically for the future of world population is the extent to which the same causes of fertility reduction will occur in less industrialized societies. We cannot expect quite the same pattern, and it appears indeed that some very different forces are operating. To these we now turn.

THE LESS DEVELOPED COUNTRIES

What speed of decline of the crude rate of natural increase can poor countries realistically expect? This above all will determine the world population in the 21st century. What kind of evidence will permit a forecast of the decline?

Costa Rica has been cited as a horror story of rapid increase, and still is by writers who have not looked at the numbers recently. Despite prosperity, its rate of increase was over 3.5 percent per year into the 1960s. But then its birth rate fell from 44.9 to 37.3 per thousand population in 1960-65; at the same time its death rate fell from 9.2 to 7.3. The net outcome was a fall in the rate of natural increase from 35.6 to 30.0, or somewhat more than 1 per thousand per year. By 1974 its rate of increase was down to 24 per thousand, with births at 28 and deaths at 5. If births were to fall at 1 per thousand per year it would take only about 15 years to reach stationarity, for its crude death rate would rise as its rate of increase slowed.

Costa Rica's fall in the 1960s was not by any means a record. In the 20 years from 1954 to 1974 Singapore's rate of increase dropped from 4.5 percent to 1.4, Hong Kong's from 3.0 percent to 1.1 in the decade of the 1960s.

But for each such case there is more than one in which the birth rate is either stubbornly high or else its fall is matched by that of the death rate. India's births fell from 44 to 40 per thousand during the 1960s, but its deaths fell from 20 to 16, and about the same seems to be true of Indonesia. Since it is the large countries that mostly determine the totals for the less developed world, and the increase of these is gently rising to a (forecast) peak in 1975-80, followed by a gentle decline to the end of the century of little more than 1 point per thousand in each 5 years, according to the United Nations, it could take 75 years for the poor countries as a whole to reach stationarity.

Relation of Mortality and Fertility

As among continents and countries, those in which the birth rate is high tend to be those with high death rates. Rates per thousand for 1970-75, as estimated by the United Nations, are

	Births	Deaths	Natural increase
Africa	46.3	19.8	26.5
Latin America	36.9	9.2	27.7
South Asia	41.9	16.7	25.2
Western South Asia	42.8	14.3	28.6
Less developed regions	37.5	14.3	23.2

These areas are at very different stages of economic and sanitary progress, yet their rates of increase are similar. Africa's death rates at 10 per thousand higher than Latin America's, and so are its birth rates. For how long into the future can birth and death rates fall together, so that population growth continues at its present rapid pace?

The expectation of life for Africa was estimated at 36.1 years for 1950-55, and it seems to have risen almost 1/2 a year per year until 1970-75, when it is estimated at 45.0 years. While this may seem low in present American terms, it is well to note that at the beginning of the 20th century the United States expectation of life was 47.3 years. South Asia shows 48.5, a level attained in the United States after 1900. Latin America at 61.0 is doing better than the United States until the early 1930s.

Yet parallel trends of birth and death rates cannot continue, and even if they did the rate of increase would slow down. The rate of increase of expectation seems to press against a ceiling at about 75 years for females. With or without such a ceiling, the fraction of children that pass reproductive age comes to exceed 0.9 as $\mathring{e}_0$ for females passes 70, and so cannot rise much

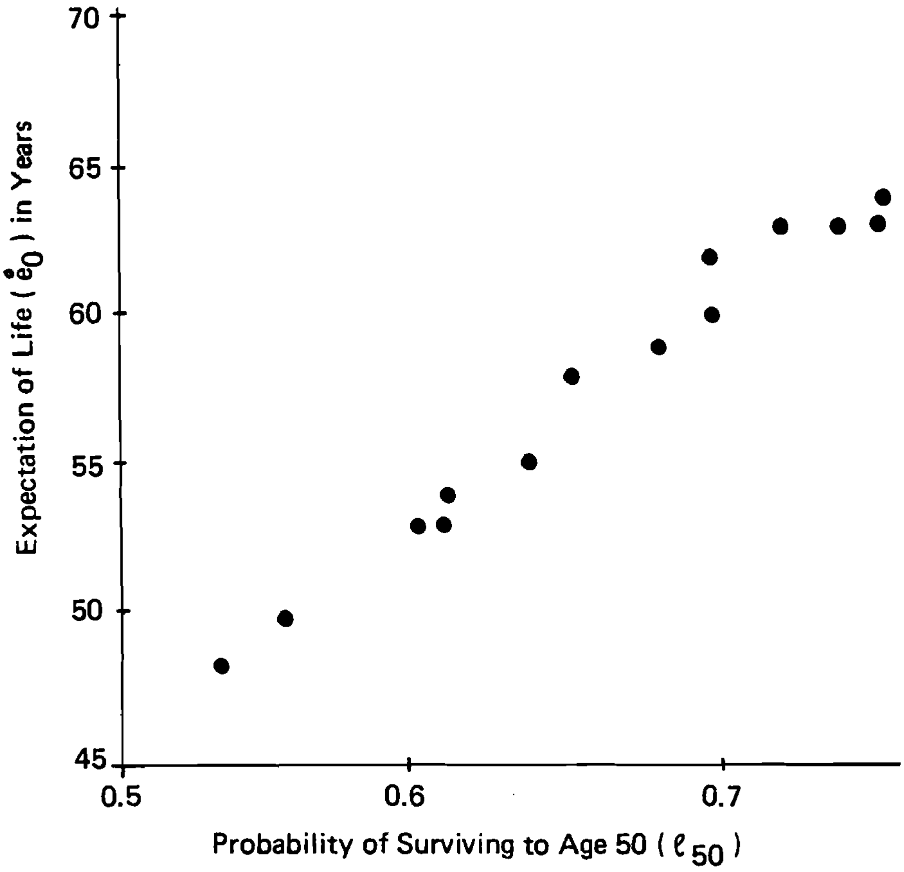

Figure 3. Probability of surviving to age 50 against expectation of life, females, countries of Europe, Asia and Latin America.

more even if expectation of life continues upward. Figure 3 shows that ℓ_{50} , the chance of surviving to age 50, goes up more or less in a straight line with $\mathring{e}_0$, and then is forced to bend sharply.

Empirical Evidence on Fertility

Since complete statistics are not to be had, we must depend on fragmentary items of evidence now coming to light to judge what the birth rate in the Third World is doing. Some of these items suggest that it has started a precipitous decline.

Under the World Fertility Survey Thailand has carried out a retrospective survey, so far not released by the government. Confidential figures from that survey show for the total fertility rate (approximately the number of children that would be born to surviving women if the current birth rates continued)

1960	6.6
1968	6.1
1972	5.3
1973-4	4.3

The rapid fall in the 1970s contrasts with the slow decline of the 1960s.

In Indonesia a United Nations-supported vital registration experiment used a dual record system in 10 areas, spread widely through Bali and East Java, though not a proper random sample. The result was a total fertility rate of 3.3, while Central Java showed 3.7; meanwhile Sumatra, where no birth control has been promoted and where the rates have always been higher, showed over 6. As among the 10 places a reassuring correlation appears between family planning activities and the fall of the birth rate.

In the Philippines Father Madigan of Xavier University has carried out surveys in a rural part of Mindanao during 1971-75 He found that the birth rate, as high as 45 per thousand in 1972, had fallen to 30 in 1975. Also in the Philippines, 7 provinces are being studied by a team that includes Father Madigan, Mercedes Concepcion of the University of the Philippines in Manila, and Father Wilhelm Flieger at San Carlos University in Cebu. Their preliminary figures show a significant downtrend during the 1970s.

In Colombia the 1973 census had a question on date of birth of the youngest child, and if the child was born in the preceding 12 months questions were asked to ensure complete returns. The outcome seems to be a crude birth rate of about 33 per thousand, which is about 10 per thousand lower than was found in the 1960s.

The Demographic Transition

The demographic transition is the process by which high death rates and high birth rates give way to low rates. In Paul Demeny's (1968) lapidary expression: "In traditional societies, fertility and mortality are high. In modern societies, fertility and mortality are low. In between, there is demographic transition." Taking for granted that the transition either has gone to completion or will do so in every country, the important question is by how many years the fall in births will follow the fall in deaths. If it is 10 years the population will typically increase by about one third; if it is 100 years the increase will be 20-fold. Thus our objective of narrowing the range of possibilities for the 21st century is not helped by the general concept of a demographic transition; it would be greatly helped by any evidence on the time interval between the fall in deaths and that in births.

Several items of evidence do bear on the matter. As mentioned earlier the more recent the transition the more quickly it takes place. The slopes of the lines representing birth and death rates are more sharply downward, and the birth curve seems to lag less behind the death curve. The matter has been studied by Father Wilhelm Flieger (1967). In Sweden births fell long after those in Britain, and in the years 1900-30 fell by 13.68 per thousand population; births in England and Wales dropped by

8.13 per thousand in 1870-1900 and by 10.35 in 1900-30. The evidence is not altogether unambiguous, but on the whole the numbers encourage us to think that future transitions will take place more quickly.

This would follow if the transition is closely tied to the rate of economic expansion, for this takes place more rapidly now than it did in the past. Rates of economic advance of 6 and 8 percent per year, recently exceeded by Japan and Brazil, are common today, whereas 2 or 3 percent per year was doing well in the 19th century.

The attitudes of elites and publics to birth control are changing quickly. During the 1960s the attitudes in many poor countries were reminiscent of that of France in the early 20th century when she was in military-demographic competition with Germany. Latin American newspapers, reported on by Joseph Stycos, saw contraception as against religion and harmful to the future of their country. They surpassed themselves in rhetoric concerning Unites States assistance in birth control, contending that American imperialists were envious of their demographic vigor and were attempting genocide through the pill and the IUD. Such rhetorical overkill was heard on all continents.

Echeverria became president of Mexico in 1970 on a pronatalist platform. He promised to populate the country, to fill its empty spaces. But within three years of assuming power he removed pre-existing bans on birth control and gave up all reference to empty spaces. In Mexico as elsewhere in the 1970s the notion of population as a weapon has been quietly interred and birth control is being actively disseminated. India is proceeding to compulsory sterilization. Americans and Swedes on family-planning missions find doors open to them nearly everywhere. Why has the old policy been reversed?

The first reason is urbanization. As rural areas have filled and climbed up on their food supplies, movement to the cities has accelerated. The growth of cities in the poor countries not only dominates the statistics, but is the dominant impression of every visitor to countries from Indonesia to Egypt to Brazil. Peasants who could be hungry in a distant countryside without causing a ripple now become a genuine problem to their elites, for overpopulation no longer takes the form of the sharing of poverty and patient malnutrition, but threatens political action in the capital itself. Echeverria observed that the increments of population do not go out to pioneer in the jungle, undertake homesteading, or build with their own hands irrigation projects in the dry areas, but prefer rather to come to Mexico City and make themselves the problem of their government. He suddenly realized that he had overpopulation on his hands, a realization duplicated by governments around the world.

The abruptness of the move into the cities is increased by a feature of the drop in mortality, which fell suddenly in many countries in the early 1950s. The effect was similar to that of a baby boom as far as survivors into their twenties about the present time are concerned. The effect is particularly striking

Table 10. Age distribution of Eastern South Asia for 1975, United Nations (1976).

Age	Population in thousands	Difference
0-4	4988	
		791
5-9	4197	
		614
10-14	3583	
		509
15-19	3074	
		417
20-24	2657	
		590
25-29	2067	
		131
30-34	1936	
		103
35-39	1833	
		189
40-44	1644	

in Eastern South Asia, whose ages are given for both sexes together in 1975 in Table 10. The drop in first differences after age 25 needs no underlining. This matter is complicated by United Nations regional numbers are based, and the effect does not appear clearly in either Africa or Latin America. But where it does appear it must have political consequences: large youth cohorts, better educated than their parents, of an age and disposition to migrate to cities, are bound to exert pressures that will not accord with the policies of their seniors in power.

Some urbanization was occurring in the 1960s and did not cause changes of policy in the direction of birth control. The population problem was present all along, but in some aspects was effectively concealed by concessionary sales of United States grain. By an unspoken coincidence of objectives between the U.S. Congress and the elites of poor countries, surplus grain was shipped and received abroad, often paid for in rupees and rupiahs with the promise that the payee would never spend the paper money. Such transactions were equivalent to gifts, and their amounts were substantial.

In the mid-1960s India received United States grain at a rate of over 10 million metric tons of grain per year--at 440 pounds per person it was enough to provide for 50 million people, principally in the port cities. This local availability of grain, along with an internal pricing policy that lowered prices at the farm, accelerated rural-urban migration. It seemed impossible to administer the imported grain to help the people already in the cities without drawing more people.

This process concealed the population problem at the same time that it aggravated it. But the concealment ended sharply in 1973 with the exhaustion of U.S. surpluses. Henceforth grain had to be paid for, and because the same process of population increase was occurring in Burma, Thailand, and other former exporting countries, the number of suppliers on the world market sharply declined. Grain prices rose to $250 per ton and higher.

The population problem became visible as it was directly translated into cash terms. If a shortage occurred, so that the last 10 percent of the population had to be provided for by purchases on the world market, then India would have to lay out something like $2.5 billion. To see the magnitude of this in Indian terms, one has only to note that total exports in 1973 were $2.9 billion. Since exports are a gross figure, including the re-export of some imports, one can say that, in default of local production, the marginal 10 percent of population would require all of India's import capacity.

Exports of the F.R.G. in the same year 1973 were valued at $69 billion; she could have fed her population luxuriously on imported foodstuffs without seriously interfering with her other imports. This aspect of the population problem need be of no concern to developed countries, but nonetheless an undercurrent of worry ran through British economics, even when British industry was ahead of all others, about whether it would always be possible to trade coal and steel for grain. What, some economists persisted in asking, if countries that supplied Britain with its food, especially the United States, themselves industrialized? How then would Britain be able to feed its 30 million people?

The main point is that urbanization, with its political and economic consequences, now reveals to governments throughout the Third World the nature of the population problem, and they are taking action. Since reproduction is an intimate matter, no one knows how effective their action will be. France, trying in the opposite direction, did not have much success in raising her birth rate. But governments are not powerless to make what is dear to the country come to seem dear to the individual family. They have a wide range of positive and negative incentives. One must suppose that their new realization of the problem will show in an accelerated fall of birth rates.

These somewhat general considerations will now be translated into specific projections.

A GENERAL METHOD AND COMPUTER PROGRAM

Projecting the Components

To determine future mortality we work from the fact that some countries have a gain of almost one year in $\overset{\circ}{e}_0$ for each calendar year that goes by. This does not mean that their citizens will live forever, since most of the increase is due to improvements at the youngest ages, which will have to stop somewhere before mortality zero is reached.

To begin with the percentage decrease of ${}_5M_x$, the age-specific death rate, we recognize that such decrease cannot possibly be as great at the older ages as at the younger ones, and at the very oldest ages it seems to fall to zero. For the youngest ages a 15 percent fall per 5 years seems a reasonable average over a variety of times and places; suppose for age x we call the fall $0.15(1 - \frac{x}{100})$ as a fraction of ${}_5M_x$.

But we need to adjust for the fact that the higher the expectation of life the smaller the rate of fall. Thus the historical record suggests that the decline of mortality under present medical conditions may be approaching zero when we are up to age 75, and be three times as rapid at $\overset{\circ}{e}_0 = 45$ as at $\overset{\circ}{e}_0 = 65$. This would be allowed for by applying the factor $(75 - e_0)/20$ to the preceding.

Finally, the rate of fall is more rapid the more recently it occurs. Europe's fall in the 19th century was slower than today's, if for no other reason than the introduction of antibiotics. A rough way of allowing for this is to apply the factor (t - 1800/100, where t is the calendar year.

Putting all this together gives for the fractional decrease in the age-specific ${}_nM_x$ at last birthday the quantity

$$\delta = \left(\frac{t - 1800}{100}\right)\left(\frac{75 - \overset{\circ}{e}_0}{20}\right) 0.15\left(1 - \frac{x}{100}\right) ,$$

where the initial projection is from the calendar year t - 5 to t, and the expectation of life at calendar year t - 5 is $\overset{\circ}{e}_0$. Thus if the projection from time t - 5 to t was by a life table based on ${}_nM_x$, that from time t to time t + 5 would be based on ${}_nM_x(1 - \delta)$.

One could implement this by recalculating the life table in each cycle of projection, or else approximately by modifying ${}_5L_{x+5}/{}_5L_x$, taking it to the power $1 - \delta$:

$$\left.\frac{{}_5L_{x+5}}{{}_5L_x}\right|_t = \left(\left.\frac{{}_5L_{x+5}}{{}_5L_x}\right|_{t-5}\right)^{1-\delta} .$$

In fact no universal formula such as the above can be found that will provide a good fit to all times and places. The most that can be said for it is that it takes account of some main variables, that it is suited to computation with no need for the operator to make *ad hoc* adjustments, and most important, that it is an explicit set of assumptions that are subject to criticism and improvement. The commodity may not be very good, but at least the consumer can know exactly what he is getting.

For fertility the difficulties are even greater, and variations in the assumptions make even more difference to the result. But suppose we assume that all populations will be down to bare replacement by the end of the century, and that they will drop in a straight line. If the last period for which data are to be had is 1970-75, this means that we must arrange five drops in fertility, to the final condition in which the Net Reproduction Rate R_0 is unity. This last is arranged by setting the rates at each age equal to F_x/R_0 and the intermediate age-specific rates at $F_x(\frac{4}{5} + \frac{1}{5R_0})$, $F_x(\frac{3}{5} + \frac{2}{5R_0})$, etc.

But we know that the fall is greater at the oldest ages. A factor that allows for this is x/30, which can be applied to each age, at the cost of requiring iteration if the point of replacement is to be exactly the interval 1995-2000. It would be better to have the rates drop slowly at first, then more rapidly, then slowly again.

Migration is a relatively small fraction for the large populations of Asia. Europe has had some in-migration, but it is offset by out-migration to the United States and elsewhere. The one area where migration makes an appreciable net difference is Northern America and Oceania, where its total has reached as high as a million per year.

Program for Life Table and Population Projection

The program that follows in Table 12, written in FORTRAN IV, provides an estimate of future population, for males and females separately, in five-year intervals, for 100 years. The age intervals can be condensed; males and females added; the period of projection lengthened or shortened. (For Table 12, see page 31.)

Table 11. Less Developed Countries projected to 2050 by sex, assuming declining mortality and fertility down to bare replacement by 1995 (Low estimate) and by 2015 (High estimate), millions of persons.

	Oil exporters	Other LDCs > $400 income per head*	Other LDCs > $400 income per head	Total LDCs
		Low estimate		
1975				
Male	143.6	162.5	1134.1	1440.2
Female	144.7	161.9	1089.4	1396.0
Total	288.3	324.4	2223.5	2836.2
2000				
Male	208.2	229.5	1613.3	2051.0
Female	215.4	232.5	1584.7	2032.6
Total	423.6	462.0	3198.0	4083.6
2025				
Male	248.4	272.9	1909.3	2430.6
Female	262.2	281.2	1916.6	2460.0
Total	510.6	554.1	3825.9	4890.6
2050				
Male	256.4	280.9	1976.7	2514.0
Female	275.5	292.9	2017.1	2585.5
Total	531.9	573.8	3993.8	5099.5
		High estimate		
1975				
Male	143.6	162.5	1134.1	1440.2
Female	144.7	161.9	1089.4	1396.0
Total	288.3	324.4	2223.5	2836.2
2000				
Male	246.0	250.0	1909.3	2405.3
Female	252.7	252.3	1874.9	2379.9
Total	498.7	502.3	3784.2	4785.2
2025				
Male	330.2	316.7	2526.3	3173.2
Female	341.8	322.2	2525.6	3189.6
Total	672.0	638.9	5051.9	6362.8
2050				
Male	371.1	342.6	2839.6	3553.3
Female	389.5	351.6	2890.1	3631.2
Total	760.6	694.2	5729.7	7184.5

*24 countries listed in report of November 26, 1976.

The changes in mortality and fertility that are assumed follow simple rules, the same for all populations. For mortality the fall takes place at a pace that is more rapid the lower the initial expectation of life, the later the calendar year, and the younger the age. For fertility the fall is taken to be proportional at all ages, and to drop to bare replacement in 20, 30, and 40 years, these giving low, medium, and high variants of the future population. (Details in the memorandum of November 26, 1976, Population of the World and Its Regions, 1975-2050.) The program is applicable without modification to any population, and preliminary experimenting shows it to fit reasonably well to the changes in mortality and fertility that have occurred in the past.

Input to the program consists of the population, deaths, and births of the jumping-off time, in our first application mid-1975. Five-year age groups, with 0 and 1-4 at last birthday shown separately and 85 and over as a single item, are the input categories. In this case the deaths are for 1970-4. Births are for both sexes together, in five-year intervals of age of mother.

The input cards are divided into 8-column fields, and are as follows:

Card 1 Females, population 0, 1-5, 5-9, ..., 40-44, in columns 1-8, 9-16, 17-24, etc.

Card 2 Females, population 45-49, 50-54, ..., 85+, in columns 1-8, 1-18, ..., and total of all ages in columns 73-80

Cards 3 and 4 Same for deaths

Cards 5 and 6 Description of data set

Card 7 Jumping-off year, in columns 1-4

Card 8 Number of 5-year periods of projection required columns 1-2

Card 9 Sex ratio at birth, typically 1.05, in columns 1-4

Cards 10 and 11 Number of births to women of each age, using same fields as for population and deaths, i.i., ages 15-19 ..., in columns 33-40, etc.

Cards 12-20 Same for males, except without birth cards

Preceding all these data cards is a single card giving the number of 5-year cycles to replacement, punched in column 8.

Population, Deaths, and Births by Age

The United Nations compilations of current data are the best available, and we used them for population, deaths, and births. These gave five-year age intervals up to age 80, and we wanted 0 and 1-4 at last birthday, as well as 80-84 and 85 and over, at least for making the life table, though not for the projection. To make a rough allowance for the trend of births, the 0 was calculated by first finding the ratio of the 5-9 to the 0-4; then taking the fifth root of this, say λ, then calculating $(1 - \lambda)/(1 - \lambda^5)$ as the fraction of the under 5 to call under 1. To split the 80 and over $({}_{\infty}P_{80})$, we took ${}_5P_{70}$, ${}_5P_{70}$, ${}_5P_{75}$, P_{80} , and calculated

$$ {}_5P_{80} \doteq {}_{\infty}P_{80}/(1 + {}_5P_{75}/{}_5P_{70}) \quad . $$

Having exposed population of these ages for males and females separately we then took the expectation of life for the given sex and population group as provided by the United Nations, and used the age-specific death rates of the corresponding model life table of the Coale and Demeny (1966) West set. These were multiplied by the population to estimate the number of deaths.

Table 12. FORTRAN program for projection, programmed by Gary Littman.

```
FORTRAN IV G1  RELEASE 2.0            MAIN             DATE = 76365          14/09/25
0001               DIMENSION P(19),AM(19),AL(19),CPL(19),CPLS(19,11,2),E(19),Q(19),
                  1A(3),N(3),D(19),DEL(19),B(19),F(19,11),PP(18,21),FEM(21,11)
                  2,PPS(4,21,3)
0002               INTEGER START,Z
          C        NUM IS THE NUMBER OF FIVE YEAR PERIODS UNTIL REPLACEMENT
          C          FERTILITY IS REACHED PLUS ONE
0003               READ (5,315) NUM
0004           315 FORMAT (I8)
0005               DO 1000 LCOUNT =1,9
0006               DO 310 MF=1,2
0007               DO 300 KOUNT=1,NUM
0008               CALL LIFE (P,AL,CPL,KOUNT,DEL,AM,F)
0009               T=175+5*KOUNT
0010               T=T/150.
0011               TMF=MF
0012               T=T*((75.+5.*(2.-TMF))-E(1))/20.
0013               IF (T.LT.0.)) T=0.
0014               DO 300 I=1,19
0015               CPLS(I,KOUNT,MF)=CPL(I)
0016               IF (I-2) 301,302,303
0017           301 J=0
0018               GO TO 304
0019           302 J=1
0020               GO TO 304
0021           303 J=5*(I-2)
0022           304 CONTINUE
0023           300 DEL(I)=T*.15*(1.-.01*FLOAT(J))
0024           310 CALL PROJ (P,AL,CPLS,FEM,MF,NUM,START,Z,S,PPS)
0025          1000 CONTINUE
0026               STOP
0027               END
```

FORTRAN IV G1 RELEASE 2.0 LIFE DATE = 76365 14/09/25

```
              SUBROUTINE LIFE (P,AL,CPL,KOUNT,DEL,AM,E)
               DIMENSION P(19),AM(19),AL(19),CPL(19),E(19),Q(19)
             1,A(3),N(3),D(19),DEL(19)
              REAL*8 TABLE(3)
              REAL*8 TITLE(4)
C             TABLE AND TITLE HAVE BEEN DESIGNED TO ALLOW THE USER
C             SOME CHOICE IN LABELLING THE LIFE TABLE.  MY INTENTION
C             IS THAT TABLE BE USED AS AN INITIAL TITLE LIKE 'LIFE
C             TABLE FOR:', AND TITLE BE USED TO INDICATE THE NATURE
C             OF THE DATA.
              INTEGER D,P
              IF (KOUNT.GT.1) GO TO 4
              READ (5,11) (P(I),I=1,10)
              READ (5,11) (P(I),I=11,19)
              READ (5,11) (D(I),I=1,10)
              READ (5,11) (D(I),I=11,19)
           11 FORMAT (10I8)
              DO 1 I=1,19
               P(I) = P(I)* 1000
              DEL(I)=0.
    1         AM(I)=FLOAT(D(I))/FLOAT(P(I))
            4 DO 25 I=1,19
           25 AM(I)=AM(I)*(1.-DEL(I))
              AL(1)=100000.
              A(1)=.07+1.7*AM(1)
              A(2)=1.5
              A(3)=2.5
              N(1)=1
              N(2)=4
              N(3)=5
              DO 7 I=1,3
              AL(I+1)=AL(I)*(1-A(I)*AM(I))/(1+(N(I)-A(I))*AM(I))
    7         CPL(I)=(AL(I)-AL(I+1))/AM(I)
              DO 2 I=4,17
    2         AL(I+1)=AL(I)*EXP(-5*AM(I)+5*(P(I+1)-P(I-1))*(AM(I+1)
             1-AM(I-1))/(48*P(I)))
              AL(19)=AL(18)*EXP(-5*AM(18)+5*(P(16)-4*P(17)+3*P(18))
             1*(AM(16)-4*AM(17)+3*AM(18))/(48*P(18)))
              DO 3 I=4,18
    3         CPL(I)=5*(AL(I)-AL(I+1))*(1+5*(AM(I+1)-AM(I-1))/24)/
             1ALOG(AL(I)/AL(I+1))
              CPL(19)=AL(19)/AM(19)
              TOT=0.0
              DO 8 I=1,19
    8         TOT=TOT+CPL(I)
              E(1)=TOT/AL(1)
              DO 9 I=2,19
              Q(I-1)=1-AL(I)/AL(I-1)
              TOT=TOT-CPL(I-1)
    9         E(I)=TOT/AL(I)
              Q(19)=1.
              IF (KOUNT.GT.1) GO TO 24
              READ(5,20) TABLE
   20          FORMAT(3A8)
               WRITE(6,21) TABLE
   21          FORMAT('1',//////////' ',45X,3A8)
               READ(5,22) TITLE
   22          FORMAT(4A8)
               WRITE(6,23) TITLE
   23          FORMAT(' ',45X,4A8)
               WRITE(6,15)
   15          FORMAT(//' ',32X,'X',5X,'P',8X,'D',9X,'Q',9X,'L(X)',8X,
             1'L',12X,'E'//)
           24 CONTINUE
               DO 5 I=1,I
               IF(I-2)12,13,14
   12          J=0
               GO TO 5
   13          J=1
               GO TO 5
   14          J=5*(I-2)
    5          WRITE(6,6) J,P(I),D(I),Q(I),AL(I),CPL(I),E(I)
            6 FORMAT (' ',33X,I3,I11,I8,F11.6,2F11.3,F12.3)
               RETURN
               END
```

FORTRAN IV G1 RELEASE 2.0 PROJ DATE = 76365 14/09/25

```
      SUBROUTINE PROJ (P,AL,CPLS,FEM,MF,NUM,START,Z,S,PPS)
      DIMENSION P(19),AL(19),CPLS(19,11,2),B(19),F(19,11),
     1PP(18,21),FEM(21,11),SUMM(11),PPP(21)
     2,NTEMP(19),NYF(21),PPS(4,21,3)
      REAL S
      INTEGER B,Z,ZZ,P,START,FIN,MF
C     START IS THE YEAR AT WHICH THE PROJECTION BEGINS
       READ (5,1131)  START
 1131  FORMAT (I4)
       READ (5,1121)     Z
 1121  FORMAT (I2)
C     Z IS THE NUMBER OF FIVE YEAR PROJECTIONS TO BE MADE
  100 FORMAT (10I8)
C     S IS THE SEX RATIO
      READ(5,410) S
  410 FORMAT(F8.6)
      IF (MF.EQ.2) GO TO 350
      READ (5,100) (B(I),I=1,10)
      READ (5,100) (B(I),I=11,19)
      DO 101 I=1,19
       B(I) = B(I) * 1000
      F(I,1)=FLOAT(B(I))/FLOAT(P(I))
  101 F(I,1)=F(I,1)/(1.+S)
      R0=0.
      R1=0.
      DO 20 I=4,14
      XI=5*(I-2)
      XI=XI+2.5
      R0=R0+CPLS(I,NUM,MF)*F(I,1)
   20 R1=R1+XI*CPLS(I,NUM,MF)*F(I,1)
      R0=R0/100000.
      R1=R1/100000.
      XNUM=5*(NUM-1)
      XM=(30./XNUM)*(1.-R0)/R1
      DO 25 J=2,NUM
      DO 25 I=1,19
      XI=5*(I-2)
      XI=XI+2.5
      XT=5*(J-1)
   25 F(I,J)=(1.+XM*XI*XT/30.)*F(I,1)
      DO 210 I=1,NUM
  210 SUMM(I)=0.
      DO 215 J=1,NUM
      DO 215 I=4,14
      XI=5*(I-2)
  215 SUMM(J)=SUMM(J)+.00001*CPLS(I,J,MF)*F(I,J)
      DO 700 J=1,NUM
      DO 705 I=1,19
      IF (F(I,J).GE.0.0) GO TO 705
      TMP=0.
      DO 706 K=1,19
      IF (F(K,J).GE.0.0) GO TO 706
      WRITE (6,710) K,J,F(K,J)

  710 FORMAT (2X,13HADJUST F(K,J),5X,2I5,F12.6,//)
      TMP=TMP+.00001*CPLS(K,J,MF)*F(K,J)
  706 CONTINUE
      DO 707 K=1,19
  707 F(K,J)=F(K,J)*SUMM(J)/(SUMM(J)-TMP)
      DO 708 K=1,19
      IF (F(K,J).GE.0.0) GO TO 708
      F(K,J)=0.
  708 CONTINUE
      SUMM(J)=0.
      DO 709 K=1,19
  709 SUMM(J)=SUMM(J)+.00001*CPLS(K,J,MF)*F(K,J)
      GO TO 700
  705 CONTINUE
  700 CONTINUE
  350 CONTINUE
      PP(1,1)=P(1)+P(2)
      DO 102 I=2,18
  102 PP(I,1)=P(I+1)
      ZZ=Z+1
      DO 103 J=2,ZZ
C     IF JJ=J-1, THE OBSERVED FERTILITY AND LIFE TABLE ARE USED
C       FOR THE FIRST CYCLE OF PROJECTION
C
C     IF JJ=J, THEY ARE NOT
      JJ=J
      IF (JJ.GT.NUM) JJ=NUM
```

```
FORTRAN IV G1  RELEASE 2.0             PROJ                 DATE = 76365            14/09/25
            PP(2,J)=PP(1,J-1)*CPLS(3,JJ,MF)/(CPLS(2,JJ,MF)+CPLS(1,JJ,MF))
            DO 104 I=3,18
        104 PP(I,J)=PP(I-1,J-1)*CPLS(I+1,JJ,MF)/CPLS(I,JJ,MF)
            IF (MF.EQ.2) GO TO 400
            SUM=0.0
            DO 105 I=3,14
        105 SUM=SUM+(PP(I-1,J-1)*(F(I,JJ)+
           1((CPLS(I+1,JJ,MF)/CPLS(I,JJ,MF))*F(I+1,JJ))))
            PP(1,J)=0.5*(CPLS(1,JJ,MF)+CPLS(2,JJ,MF))*SUM/ALT(1)
            GO TO 103
        400 CONTINUE
            PP(1,J)=S*(CPLS(1,JJ,MF)+CPLS(2,JJ,MF))*FEM(J,JJ)/FEM(1,JJ)
        103 CONTINUE
            FIN=START+(Z*5)
            IF (MF.EQ.2) GO TO 111
            WRITE(6,110) START,FIN
        110 FORMAT ('1',////' ','FEMALE POPULATION PROJECTION FROM',I5,' TO'
           1,I5)
            GO TO 112
        111 WRITE (6,113) START,FIN
        113 FORMAT ('1',////' ','MALE POPULATION PROJECTION FROM',I5,' TO'
           1,I5)
        112 CONTINUE
            DO 120 J=1,ZZ
        120 PPP(J)=0.
            DO 125 J=1,ZZ
            DO 125 I=1,18
        125 PPP(J)=PPP(J)+PP(I,J)
            DO 600 I=1,18
        600 NTEMP(I)=5*(I-1)
            NYR(1)=START
            DO 605 I=2,ZZ
            II=I-1
        605 NYR(I)=NYR(II)+5
            DO 130 J=1,ZZ
            PPS(1,J,MF)=0.
            DO 135 I=1,3
        135 PPS(1,J,MF)=PPS(1,J,MF)+PP(I,J)
            PPS(2,J,MF)=0.
            DO 136 I=4,13
        136 PPS(2,J,MF)=PPS(2,J,MF)+PP(I,J)
            PPS(3,J,MF)=0.
            DO 137 I=14,18
        137 PPS(3,J,MF)=PPS(3,J,MF)+PP(I,J)
        130 PPS(4,J,MF)=PPS(1,J,MF)+PPS(2,J,MF)+PPS(3,J,MF)
            IF (MF.EQ.1) GO TO 138
            DO 139 J=1,ZZ
            DO 139 I=1,4
        139 PPS(I,J,3)=PPS(I,J,1)+PPS(I,J,2)
            WRITE (6,140) START,FIN
        140 FORMAT ('1',/' ','POPULATION PROJECTION FROM',I5,' TO',I5)
            WRITE (6,141)
        141 FORMAT (///,21X,'0-14',28X,'15-64',28X,'65+',28X,'TOTAL',/,16X,
           1'F         T         M',19X,'F         T         M',19X,'F         T         M',
           219X,'F         T         M',//)
            DO 142 I=1,ZZ
        142 WRITE (6,143) NYR(I),(PPS(1,I,MF),MF=1,2),(PPS(2,I,MF),MF=1,2),
           1(PPS(3,I,MF),MF=1,2),(PPS(4,I,MF),MF=1,2),(PPS(K,I,3),K=1,4)
        143 FORMAT (/,2X,I4,5X,2F12.0,8X,2F12.0,8X,2F12.0,8X,2F12.0,/,18X,
           1F12.0,21X,F12.0,21X,F12.0,21X,F12.0)
        138 CONTINUE
            IF (MF.EQ.2) GO TO 310
            DO 300 I=1,NUM
            FEM(1,I)=CPLS(1,I,MF)+CPLS(2,I,MF)
            DO 300 J=2,ZZ
            FEM(J,I)=PP(1,J)
        300 CONTINUE
        310 CONTINUE
            RETURN
            END
```

For births the Coale and Trussell (1974) model tables were taken, using different mean age of childbearing (MEAN) and standard deviation (STDEV) for developed and less developed regions. Those considered appropriate to the groups of countries are as follows:

	MEAN	STDEV	R1
DCs	26.0	5.5	0.2732
LDCs	28.0	6.5	0.3196

Once the deaths and births for the three subgroups of LDCs were obtained, the total of the LDCs was found by addition, and similarly for the DCs. The world as a whole was the sum of the DCs and LDCs.

OTHER ESTIMATES

As among existing calculations those of the United Nations are most often quoted. These come in three variants, of which only the middle variant is published in detail. However, recent evidence shows that it is on the high side. In particular a number of countries have shown birth statistics that are lower than expected since the UN work was done in 1973. The UN low variant is not published in any detail, but I have been able to obtain from the United Nations the breakdown into more and less developed regions, and these are shown in Table 13. I would interpret these as an upper limit on what the population will be. That means that for the mid-21st century one can count on a world total under 9 billions.

Lester Brown has attracted wide attention in recent months with his report on world population (1976). He argues that the United Nations estimates are much too high. As evidence of this he cites the apparent rapid decline in the birth rate in China, the unanticipated fall to negative population growth in four European countries by 1975, and energetic population control measures in Mexico, Egypt, and many other countries of the Third World. He accepts that the world rate of population increase, as high as 1.90 percent in 1970, had fallen by 1975 to 1.64 percent.

It is not alone through the fall in the birth rate that Brown anticipates a further rapid drop in the rate of increase. Some recent upturns in national death rates, partly due to malnutrition, seem likely to continue. Overgrazing, deforestation, and overploughing are to be found on all continents, and apparently the world fish catch has passed its peak. Rising world food prices are bound to translate into rising death rates in the poorest countries.

Demographers have by and large given up the search for mathematical functions that will fit a past population and predict the future, but such may incidentally complement the work

Table 13. United Nations low estimate for the years 1975 to 2100, showing more and less developed regions; (millions of persons).

Year	More developed regions (MDR)	Less developed regions (LDR)	World
1975	1132	2836	3968
2000	1314	4685	5999
2025	1405	6368	7773
2050	1410	7588	8998
2075	1410	8052	9461
2100	1410	8139	9548

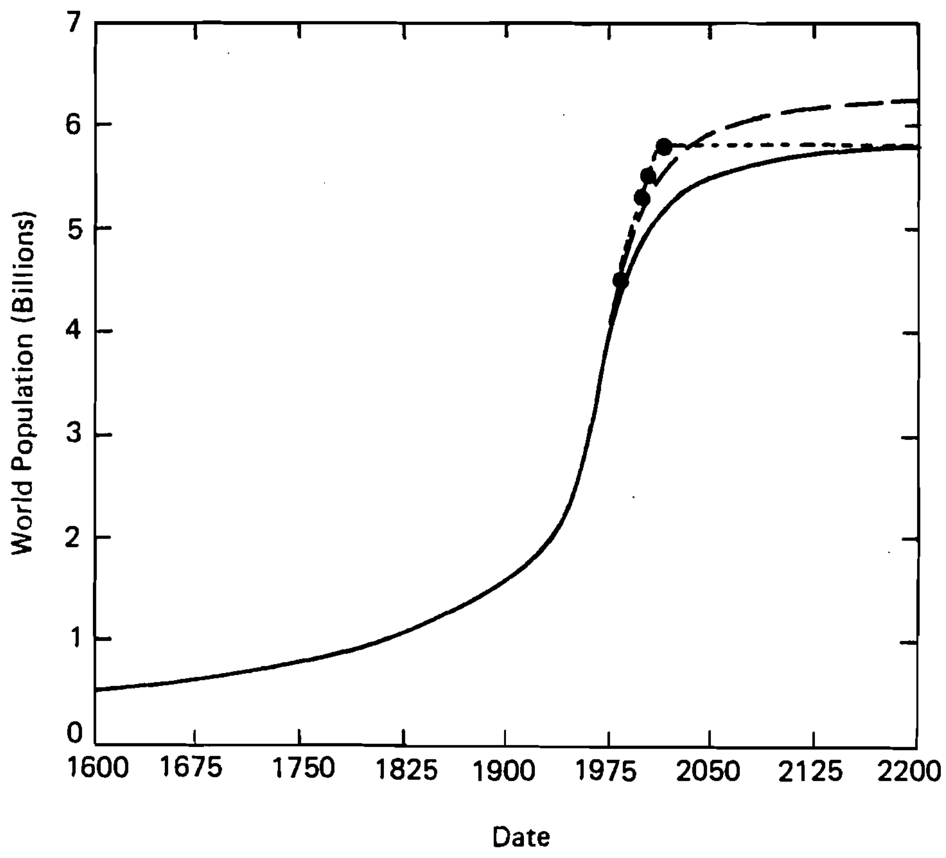

Figure 4. World population estimated by logistic, from Roper (1976).

here using the components method. Roper (1976) provides a generalization of the logistic or inverse hyperbolic tangent. His fitted world population goes to an asymtote of about 6 billion (Figure 4).

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