Global Population Projections:

Is the UN Getting it Wrong?*

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Executive Summary

The most momentus changes have taken place in the world's population over the past 50 years. The so-called "demographic transition" in the developing countries led to the most rapid growth ever recorded in global population numbers. Many extravagant extrapolations of this period of rapid population growth were made with little appreciation of why it was occurring. There are now other dramatic changes in population growth and structure underway and there appears to be even less awareness and understanding of what is happening and what is likely to happen to population growth and structure over the next 20 to 30 years. The world's population has entered a phase of rapidly slowing growth and eventual population decline in many countries because of the extension of the below replacement fertility rates being experienced in developed countries to developing countries.

The changes of the past 50 years have at times been poorly forecast by demographers, including the United Nations' Population Division, which has responsibility for global projections. While they have understood some of the changes taking place, they have not performed well in guessing the magnitude of the changes. The changes in the most important factor of all—the fertility rate—are hardly understood and have been very poorly forecast. If demographers had anticipated the changes much better, maybe we could have been spared some of the more outrageous claims by proponents of population control and, more recently, by those concerned about environmental issues.

Understanding demographic change is very important for long-term policy making. There has recently been a wider grasp of the fact that the populations of many countries are aging rapidly. This has implications for all kinds of public policy: health and education facilities, pension plans, housing, food production, research and development, and so on. However, the rapidity of the reversal in population growth in some countries and the decline in population that is in prospect has received almost no public attention.

This paper traces the major changes in the global population over the past half-century and examines the reasons for the very rapid growth, particularly in the poorer countries. It discusses why the projections of population growth by the body with responsibility for such projections have at times been misleading. The paper also discusses current projections, looking at recent trends in fertility rates and life expectancies and what these are likely to mean for global population growth and growth in particular regions and major countries. Of particular concern is that the UN appears to be underestimating the future decline in fertility rates, despite all evidence to the contrary. As a result the latest long-run global population projections appear to be much too high.

The demographic transition—the shift from high to low mortality and fertility rates—in lower-income countries, as previously experienced in the now high-income countries, resulted largely from the provision of clean water and sanitation, pesticides, and vaccinations against major infectious diseases, as well as improved living standards. The improved health conditions led to sharp reductions in infant mortality. In turn, this meant that women did not have to bear as many children as previously to be assured that there would be sufficient offspring to look after their parents in their old age.

At the same time as infant mortality and fertility rates were declining, the health and life expectancy of the remainder of the population was improving as incomes were rising and food production was increasing. In spite of the Malthusian concerns, world food production outpaced population growth in this period of the most rapid population growth in the world's history.

The fastest population growth took place in those countries where the fertility rate did not fall as quickly as the mortality rate. The resulting rapid increase in cohorts of young people led to a longer-term increase in population ("population momentum") even though fertility rates continued to decline.

The demographic transition is now over for most developing countries. Most of these countries now have total fertility rates (TFRs) below 2.1 per cent, the replacement rate. However, their populations will continue to increase for some considerable time because of population momentum. But with life expectancies continuing to increase and fertility rates still declining, populations will age rapidly. Presently, the most dramatic cases of aging of the population are taking place in Italy, Japan and Spain. Japan's TFR has been below the replacement rate since the early 1970s and has continued to fall, reaching 1.3 per cent in 2000. The TFR in Italy and Spain has been below 1.2 per cent since the mid-1990s. The UN Population Division estimates that in 2002, 24 per cent of Japan's population were 60 years or older. It is estimated that by 2050 around 42 per cent of the population will be 60 years or older. Below-replacement fertility rates will eventually lead to population decline. Japan's population, for example, is expected to begin to decline from 2007.

Key questions for demographers and policy makers are whether the below-replacement fertility rates being experienced in all northern, southern and western European countries, and elsewhere, will continue their downward path, and whether developing countries face similar trends? As evidenced by the experience in Hong Kong, Singapore and South Korea, the decline in fertility rates in the present developing countries could be even faster than in the developed countries. For example, the TFR in Hong Kong in 2000 was 1.17 per cent—below that in Italy and Spain—while the TFR decline in South Korea has been faster than in Japan.

In its year 2000 "medium variant" projection to 2050, however, the UN Population Division has assumed that the TFR will stabilise around 2.1 per cent in most developing countries and move back towards the replacement rate in those higher income countries where the TFR is already well below the replacement rate. These assumptions mean a considerable increase in the TFRs in countries such as Hong Kong, Singapore and South Korea, for example. They also mean an increase in the TFR in China. The UN Population Division may be making serious mis-judgements in the most important assumption underlying its population projections.

A review of past UN population projections shows that there have been systematic biases in their assumptions about future trends in important factors. The most significant errors have been the consistent over-estimation of fertility rates in both developed and developing countries. The speed of the decline in fertility in the last one-third of the 20th Century consistently surprised the UN. The increase in life expectancy throughout the world has been almost as consistently under-estimated. However, the impact of under-estimating the increase in life expectancy has been not as important for population projections as the bias in the fertility assumption. Of the variables underlying population projections, the behaviour of the fertility rate is the least well understood. Therefore, until understanding improves, the greatest uncertainty will attach to the fertility rate assumption. This means that most of the uncertainty in the population projections is the uncertainty about how many young people there will be.

Looking back at UN population projections, there have been three periods since 1957 when UN medium variant projections have significantly under or over estimated population growth. The first was in the late 1950s when forecasters were underestimating growth up to 1990 but overestimating growth to 2000, partly as the result of underestimating both life expectancy and fertility rates. In the late 1960s, population forecasts for the years 1990 and 2000 were again over-forecast, largely as the result of underestimating the decline in fertility rates. UN assumptions about fertility rates did not catch up with the trends underway until the mid-1970s. It is likely that the over-forecasting of population growth of the late 1960s gave some support to the "population explosion" and "resource depletion" scare scenarios being propagated at the time.

In the late 1980s and early 1990s the projections for the year 2000 population again became too high because the fertility assumption was over-estimating the trend. And again in the 2000 projection there has been a marked shift in the projections, basically as the result of a change in the fertility assumption. Whereas in the 1998 UN population projections the medium variant global population projection for 2050 was 8.91 billion, in the year 2000 revision the projection for 2050 is 9.32 billion—an increase of almost 400 million.

The reason for this change in the 2000 projections is the revision of the fertility rates in developing countries—slowing the decline in the least developed countries, and in the "low fertility" developing countries increasing the fertility rates towards the replacement rate of 2.1 per cent. These revisions appear to be highly questionable. There is no sign of a turnaround in fertility rates in countries that have already reached very low levels. There is limited understanding of the reasons for the decline in fertility rates and for their persistence far below the replacement rate. Therefore, it appears heroic to assume an increase in the fertility rates rather than assuming rates will remain constant or continue to decline.

Given their population size, the future of fertility rates in China and India will have a large bearing on the global population. In the case of China, the UN has assumed an increase in the TFR from the present 1.8 per cent to 1.9 per cent in 2010-15 and thereafter. For Bangladesh and India the UN assumes that the TFR will continue to decline until 2025 and then hold at the replacement rate of 2.1 per cent.

The UN's 2000 medium variant projections show the global population increasing to 8.27 billion by 2030 and to 9.32 billion by 2050. Whereas their global population projection for year 2030 published over the period 1994 to 1998 was reduced by over 500 million, in the projections published in 2000 they increased this projection by 160 million and increased the projection for 2050 by almost 400 million. The fertility rate assumptions that are the basis for this reversal appear to be highly questionable.

As stated earlier, the estimations of the degree of uncertainty associated with the UN population projections largely reflect the degree of uncertainty associated with the fertility assumption. Estimations of the probabilities with the UN projections indicate that there is a high likelihood that the 2000 projection for 2030 could be 500 million too high or too low and that there is a low likelihood that the projection error could be as much as one billion too high or too low. Given the UN's past performance in population projections, it is likely that their projections will be too high rather than too low.

The rate of growth of the global population is slowing rapidly and the projections of the population level to be reached in this Century have been falling for some time. Indeed, declining populations are now being projected for several countries and more are likely to be added to this list. Moreover, country populations are aging—in some cases, very rapidly—with declining fertility and increasing life expectancy. These changes in the trends and structure of populations have important implications, not least for food production.

Introduction

The Malthusian spectre of the world's population outstripping its capacity for food production continues to influence thinking in some quarters. In more recent years, concern about rapid population growth has also been expressed in terms of the damage caused to global resources. Forecasts of the growth in population have sometimes been extraordinarily pessimistic (if you believe that population growth is bad). Around the time of the United

Nations Conference on Population in the mid-1990s, forecasts of the world's population reaching 10-12 billion within this Century were not unusual. No doubt, such forecasts are often made to serve particular interests.

In the many unwitting extrapolations of the rapid population growth of the past 50 years, there has been little appreciation of why this rapid growth has taken place. There appears to be even less understanding of what is likely to happen over the next 20-30 years. The most momentous changes have taken place in the world's population during the past half-century, and not just in the developing countries. The so-called demographic transition in the developing countries led to the most rapid growth ever in global population numbers. And now that this phase is largely over, we have entered a phase of very slow growth and eventual population decline because of the extension of the below-replacement fertility rates of developed countries to developing countries.

These changes of the past 50 years have at times been very poorly forecast by demographers, including the United Nations' Population Division, which has responsibility for global projections. While they have understood some of the changes that have been going on, they have not performed well in guessing the magnitude of the changes. The changes in the most important factor of all—fertility rates—are hardly understood and have been very poorly forecast. If demographers had anticipated the changes much better, maybe we could have been spared some of the more outrageous claims by proponents of population control and, more recently, by those concerned about environmental issues.

Understanding demographic change is very important for long-term policy making. There has recently been a wider grasp of the fact that the populations of many countries are aging rapidly. This has implications for all kinds of public policy: health and education facilities, pension plans, housing, food production, research and development, and so on. However, the rapidity of the reversal in population growth in some countries and the decline in population that is in prospect has received almost no public attention.

This paper traces the major changes in the global population over the past half-century and examines the reasons for the very rapid growth, particularly in the poorer countries. It discusses why the projections of population growth by the body with responsibility for such projections have at times been misleading. The paper also discusses current projections, looking at recent trends in fertility rates and life expectancies and what these are likely to mean for global population growth and growth in particular regions and major countries. Of particular concern is that the UN appears to be underestimating the future decline in fertility rates, despite all evidence to the contrary. As a result the latest long-run global population projections appear to be much too high.

Global population trends

The demographic transition

In 1900 the world's population was estimated to be around 1.65 billion. By mid-2000, global population was estimated at 6.1 billion (United Nations, 2001), i.e., world population almost quadrupled during the 20th Century, achieving faster growth than in any other such recorded period. By comparison, the growth rate for the 19th Century is estimated at 0.6 per cent, and the growth rate for the past millennium is estimated at 0.3 per cent. The rapid

global population growth of the early 1960s that led to the upsurge in Malthusian gloom-and-doom predictions by writers such as Ehrlich (1968) was 2.2 per cent. Although still unusually high, global population growth had fallen to 1.3 per cent by 2000. What are the factors responsible for these recent sharp changes in population growth?

The rapid population growth of the latter part of the 20th Century primarily occurred in the developing countries. In higher-income countries, population growth rates largely declined throughout this period. In Western Europe, the growth rate fell from 0.7 per cent in the period 1950-73 to 0.32 per cent in the 1973-98 period (Maddison, 2001, Table B-11). In the United States, the growth rate fell from 1.45 per cent in the period 1950-73 to 0.98 per cent in the 1973-98 period. In the former Soviet Union, the growth rate of the population fell from 1.43 per cent in the period 1950-73 to 0.61 per cent in the 1973-98 period. However, within the developing regions, population growth increased in Asia up to the 1965-70 period, when it reached a peak of 2.44 per cent; it peaked in 1960-65 in Latin America at 2.79 per cent; and in the Africa region it peaked at 3.02 per cent in the 1990-95 period (United Nations 2001).[1]

The rapid population growth that developing countries experienced during the latter half of the 20th Century is attributed to what is called the demographic transition—a shift from high to low mortality and fertility—and, in particular, to the manner in which the transition evolved. There is still debate over the underlying causes of the demographic transition; however, it is widely believed that to a large extent it was the result of a combination of improved health and improved economic conditions. But these factors do not appear to explain the transition in all cases.

The improved health conditions mainly resulted from the provision of clean water and sanitation and pesticides, and vaccinations against major infectious diseases, which led particularly to a marked reduction in deaths of infants. The provision of clean water and sanitation in many poor countries has been described as the greatest medical advance in the 20th Century, because it has saved many more lives than any medical discovery. The sharp reduction in infant mortality meant that women did not have to bear as many children as previously to be assured that there would be sufficient children alive to look after their parents in their old age. Poor countries do not have the necessary taxation base to be able to afford public social security such as aged pensions; the family carries this responsibility.

At the same time as infant mortality was declining, the health of the rest of the population was improving in those countries where incomes were rising and access to food was improving. In spite of the Malthusian concerns, world food production outpaced world population throughout this period of most rapid population growth, particularly in the large developing countries where food consumption necessarily relies primarily on domestic production (see Mitchell, Ingco and Duncan 1997). As a result, life expectancies increased significantly in poor countries. Life expectancy at birth for developing countries as a whole was just over 40 years in 1950 (United Nations 1991). By 1998, it is estimated that life

[1] Population growth rates differed greatly in the various developing country regions prior to 1950. In Latin America the population growth rate for the period 1913-50 was 1.97 per cent. In Asia (excluding Japan) it was 0.92 per cent. Maddison (2001) attributes the rapid growth rates in this and earlier periods to the decline in mortality rates. Over the period 1900 to 1950, Latin America's life expectancy rose from 35 years to 51 years. Asia's life expectancy rose from 24 years to 40 years.

expectancy at birth was 60 years for the low-income developing countries and 70 years for the middle-income developing countries (World Bank 2001).

The most rapid population growth has taken place in countries where the fertility rate has not fallen as quickly as the death rate. As a result, while more people are living longer, the number of children that survive increases rapidly and these cohorts form a bulge, much like the post-World War II "baby boom", which leads to a long-term increase in population (referred to as "population momentum"), even though fertility rates continue to decline. Fertility decline may be delayed because of cultural traditions; or because it may take time for families to be convinced of the permanence of the lower infant mortality rates; or because economic growth is poor and there are not the employment opportunities available for women to raise the opportunity cost of their having children.

Why didn't the present high-income countries experience rapid, sustained population growth during their demographic transition as recently experienced in the developing countries? In the present high-income countries, the advances in the control of pests and disease that developing countries have recently been able to take advantage of were developed over a long period of time and, therefore, mortality rates fell much more slowly than in developing countries that were able to piggyback on these medical advances. As a result, mortality and fertility rates declined at more similar rates in developed countries.

Below-replacement fertility

The demographic transition is over for most developing countries. Most of these countries have reached or fallen below the Total Fertility Rate (TFR) of 2.1 per cent, the replacement rate of population growth. However, their populations will continue to increase for some time because of population momentum. Still, the path of fertility rates in the future will have a huge impact on the structure of populations and their growth rate. With life expectancy continuing to increase and fertility rates falling, populations will age rapidly. The most dramatic cases of aging of the population are taking place in Italy, Japan and Spain. Japan's TFR has been below replacement rate since the early 1970s and has continued to fall throughout this period to reach 1.3 per cent in 2000. The TFR in Italy and Spain has been below 1.2 per cent since the mid-1990s. The UN Population Division (UN 2002) estimates that in 2002, 24 per cent of Japan's population was aged 60 years or older. It is estimated that by 2050 around 42 per cent of the population will be 60 years or older and 36 per cent will be 80 years or older. Of Italy's 2002 population, the UN estimates that 25 per cent was 60 years or older, while for Spain the figure was 22 per cent. By 2050, it is projected that the share of the population 80 years or older will be 33 per cent in Italy and 30 per cent in Spain.

Below-replacement fertility rates will ultimately lead to a decline in population. Japan's population, for example, is projected to decline from 2007. A major question for demographers is whether the below-replacement fertility rates now being experienced in all northern, western and southern European countries will continue their downward path (UN 2000), and whether developing countries face similar trends. There is the possibility that the decline in fertility rates could be even more rapid in the present developing countries than in the developed countries. As illustration, the fertility decline in Hong Kong (TFR of 1.17 per cent in 2000) and South Korea (TFR of 1.51 per cent in 2000) to below-replacement rates has been faster than it was in Japan (UN 2001).

The United Nations Population Division, which is responsible for population projections, in its "medium-variant" projection to 2050 has assumed that the TFR will stabilise around the replacement rate of 2.1 per cent in most developing countries and move back towards the replacement rate in those higher-income countries where the TFR is already well below the replacement rate. This assumption means a considerable increase in the TFR in Hong Kong, Singapore and South Korea, for example. It also means an increase in the TFR in China. In view of the persistence of below-replacement rates in the developed countries, these assumptions may mean that the UN Population Division is again making serious mis-judgements in the assumptions underlying its population projections.

Global population projections

Virtually all population projections are based on a simple accounting procedure. The number of births in a year is generated by multiplying the number of women in each child-bearing age group by the fertility rate they are assumed to experience. Once born, each cohort experiences fertility, mortality and migration according to the assumptions specified. The key to so simple a forecasting method does not lie in any statistical or mathematical sophistication, but in the underlying assumptions. Thus demographers have long shied away from terming their output "forecasts", preferring to call them "projections", i.e., the logical working out of the consequences of initial assumptions. Nevertheless, when such projections are made by official agencies they inevitably take on the role of *de facto* forecasts.

However, all demographers are aware that their projections come with a degree of uncertainty and the UN and others have relied on the concept of "scenarios" to represent a range of possible future outcomes. Typically, these scenarios present a small number of future paths for fertility, mortality and migration, generating a range of trajectories. It is common for three future tracks, based on high, medium and low fertility, to be presented. However, most attention has been paid to the medium projection, on the reasonable basis that this is what the forecasters think is most likely. To quote Lee:

> "These scenario-based indications of uncertainty are of some use, but they have certain serious problems: no probability is attached to their high-low ranges, and they are internally inconsistent in the sense they misrepresent the relative uncertainty in different measures such as population size, fertility and old-age dependency ratios." (Lee 1999, 156).

Although long aware of the problem of uncertainty, until recently demographers rarely addressed the issue directly. During the late 1990s they began to take the issue of uncertainty more seriously. The most systematic consideration of errors in global demographic forecasts has been carried out by the United States National Research Council (NRC) and published with the title *Beyond Six Billion: Forecasting the World's Population* (NRC 2000). A paper by O'Neill *et al* (2001) has also provided a helpful review of the methods and assumptions of the main international forecasters, with comparisons of the projections made by the United Nations, the US Census Bureau, the World Bank and others.

The NRC project involved assessing retrospectively the errors in forecasts made by the UN, based on the organization's later estimates that were able to draw on updated information. The conclusions from these assessments are of considerable importance. The largest cause

of errors in short-term forecasts (5 to 10 years ahead) was poor data. The baseline information for many countries, especially in the developing world, is limited and this can lead to substantial mis-estimates of population size. In the longer run (beyond 10 years) the main cause of error in past forecasts was poor assumptions about future trends in fertility, mortality and migration. The NRC report also showed that errors were much larger for individual countries than for large regions or the world as a whole. A further clear conclusion of the report was that the future size of some age groups was harder to forecast than others. As Nico Keilman puts it, "forecasts of the youngest and oldest age groups show most uncertainty, because fertility and mortality are hard to predict" (Keilman 2001, 491).

In addition to estimates of the scale of errors in past forecasts, it is also possible to examine systematic biases in their assumptions about future trends. Some examples of these biases in past UN forecasts are presented in Figures 1 to 6, extracted from O'Neill *et al* (2001, Figures 13 and 14). The most significant error in global projections has been a consistent over-estimation of fertility. Birth rates declined substantially in almost every country of the world during the last third of the 20th century, and the speed of decline consistently surprised forecasters. Figure 1 shows the trend in the total fertility rate (in effect, the number of children born per woman over a lifetime) from the late 1960s to the late 1990s for the world as a whole. The thick line represents the UN's 1998 estimate of what actually happened over that period, with the thinner lines plotting out the assumptions built into forecasts of various dates. The tendency to overstate fertility is immediately obvious. Figures 2 and 3 show that this error was common in the UN forecasts of both developed and developing regions, with large discrepancies of similar form apparent in the graphs for both Latin America and Europe.

The extent of fertility decline in the developing world is not always appreciated. In a recent review of global demographic convergence, Wilson (2001, 165) suggests that: "Given the extent to which fertility has been declining in almost all countries, it is highly likely that by 2010 a majority of the world's people will live in places where fertility is below the level of long-run replacement, quite possibly by as early as 2005."

While the underestimate of the speed of fertility decline demonstrated in Figures 1-3 is the largest element of error in past assumptions, the scale of mortality improvement has also been somewhat underestimated. Figure 4 presents estimates and forecasts of global life expectancy at birth on the same basis. The tendency towards pessimism is apparent, though the discrepancy is less consistent than the bias in fertility and works out as having less impact on population size and structure. As with fertility, the errors in past projections affect both developed and developing regions. Figure 5 provides striking evidence of excessive caution in predicting improvements in health in North America. However, as Figure 6 shows, in one region recent mortality trends have been worse than expected—Africa. The spread of HIV/AIDS, especially in Eastern and Southern Africa, has produced a considerable reduction in life expectancy in those parts of the continent, leading to stagnation in mortality for Africa as a whole.

In sum, systematic consideration of past projections has reinforced the need to consider the issue of uncertainty more explicitly. This has led to the development and application of forecasting methods that can, in principle, quantify uncertainty. These are considered in the next section.

Probabilistic demographic forecasting

In the search for greater statistical rigour in handling the uncertainty of their projections, demographers have taken three main approaches: extrapolation of error levels in earlier forecasts, time series modelling and judgemental methods. Some work, including the results presented later in this paper, employs combinations of the three.

In *Beyond Six Billion* the US National Research Council team used the errors of previous projections to provide confidence intervals around their estimates of population size and structure (NRC 2000). This *ex post* approach does not produce forecasts, but provides a means to attach probability intervals to separately generated projections. The approach has considerable statistical appeal, but also certain drawbacks. One significant problem is that the period during which fully documented forecasts have been made is relatively short compared with the length of the period being forecasted. A further issue is that estimates of past errors from one source (e.g., the UN) do not necessarily apply to others (e.g., The World Bank). This is significant, as the UN has been making detailed global forecasts for longer than any other organization. Nevertheless, as the NRC report makes clear, this approach can provide valuable probabilistic estimates of future population trends.

Time series methods rely on statistical models that are fitted to historical data and have a number of theoretical advantages (Alho 1990). However, although appealing for short-term forecasts, such methods have problems when applied over long periods for which they often give excessively wide prediction intervals (Keilman 2001). Moreover, some of the methods used require detailed input data on recent trends that are not available worldwide. Sophisticated time series models have been developed to model future trends in mortality in developed countries (Lee and Carter 1992, Tuljapurkar et al 2000), but application of similar methods to fertility and to countries with less extensive and reliable data remains more problematic. In fact, as shown below, estimating future fertility is the key element of uncertainty in forecasting future populations.

Judgemental or "expert" methods can be used to constrain very broad prediction intervals, but bring their own problems. In this style of forecasting, a group of experts is asked to indicate the probability that a given parameter (e.g., the total fertility rate or life expectancy at birth) will fall within a certain range at a given date. A weakness of this method, indicated by research in other fields, is that experts are generally too confident and suggest inaccurately-narrow estimates of uncertainty (Armstrong 1985).

In short, no standardized method of probabilistic population projection has emerged. The community of expert forecasters is relatively small, with just a few active groups of researchers and considerable interchange and collaboration. However, there remain significant differences over how best to proceed. Possibly the only point that all scholars in this field agree upon is that conventional scenario-based methods are to be avoided.

The results presented below are taken from projections made by a group of researchers based at institutions in Austria, the Netherlands and the United States. The approach is a combination of the three basic methods outlined above and some results were reported in a paper in *Nature* dealing with the end of global population growth that received considerable attention in the general media (Lutz *et al* 2001). Much of the information presented below, however, has not previously been published. A fuller specification of the methods and assumptions is given in the paper in *Nature*.

For present purposes the method can be summarized as follows. Using estimates of uncertainty taken from the NRC report *Beyond Six Billion* and from a panel of experts, the authors estimate uncertainty distributions around fertility, mortality and migration trends. This information is used to make 2,000 simulations of future populations by single year of age for 13 world regions starting in 2000. These simulations create a large database of information that can then be interrogated to estimate the median and uncertainty intervals for variables of interest, such as the proportion of the population under age 20 or over 60. Assumptions with regard to mortality and fertility for the period to 2030 are based on the United Nations 1998-based projections. Although earlier UN forecasts have been shown to contain systematic biases, the nature of these errors is now well understood, and this understanding provides a clear basis for interpreting the current results. In terms of predictability, the results reported here show a somewhat greater range of uncertainty than the NRC report. (We are extremely grateful to the scholars who produced these forecasts (Wolfgang Lutz, Sergei Scherbov and Warren Sanderson) for generously sharing their unpublished results with us.)

Error distributions for demographic projections

The results are presented in a series of graphs. Figure 7 gives a striking demonstration of the enormous potential of fertility for influencing future population size and age structure. It gives the age-sex pyramid for one region (Central Asia) in 2030. In addition to the median predicted age structure, the graph shows the confidence intervals for each age at various levels of uncertainty. The narrowest band around the median indicates a 10% band on either side (i.e. 40% to 60%). The next band shows a further 20% range either side of the median (20% to 80%) and the widest band corresponds to the 95% range (2.5% to 97.5%). These same levels of uncertainty are used in all graphs in this section of the paper. As is immediately obvious from Figure 7, it is much harder to forecast fertility than mortality and migration. For anyone alive in 2000, forecasting their chances of still being so 30 years later is a relatively secure exercise. In contrast, knowing how many babies will be born in any of the next 30 years is a much more difficult task. Although Figure 7 refers to just one region, its implications are general. The greatest uncertainty in forecasting the future population lies in estimating fertility. Thus, over a time horizon of 30 years, the main uncertainty is the size of the age group under 30 years of age. In short, it is at the bottom of the age pyramid that the action is to be found in terms of forecast uncertainty.

Figure 7 is a snap-shot of the situation in 2030. The remaining nine figures look at trends over the 30 years up to that date in leaps of five years at a time. Figures 8-10 deal with total population, Figures 11-13 with the proportion of the population under age 20, and Figures 14-16 with the proportion over 60. All nine figures plot lines representing the value of the relevant measure at the same levels of uncertainty used in Figure 7: 2.5, 20, 40, 50, 60, 80, and 97.5. Each group of three figures presents the picture for the world as a whole, along with one developing and one developed region.

Figure 8 plots total global population over the next three decades. By 2030 the extent of uncertainty is quite large, with the 95 percent range extending from 6.9 to 9.3 billion. Even a more compact central 60 percent range (from 20 to 80) is more than a billion wide (7.6 to 8.6 billion). The figures for North and Latin America show similar trends. At first blush this might be thought surprising, given the fact that large economic differences remain between the two. However, the demography of the two regions is already fairly similar. For

example, life expectancy is almost 70 in Latin America against 77 in North America, while the total fertility rate is 2.6 in Latin America and 1.9 in North America. The similarity of Figures 9 and 10 serves to underline the extent to which the developing world is close to passing through the demographic transition. For a more detailed discussion of global demographic convergence, see Wilson (2001).

While trends in total population are interesting, from the point of view of input into research and policy analysis, it is possibly more significant to know about the predictability of the age structure. Figures 11 to 13 give a striking impression of how much uncertainty attaches to estimates of the proportion of the population under age 20. By 2030 the values for the world as a whole (Figure 11) reach a 95 percent confidence range extending from 23 to 37 percent. The 60 percent range runs from 28 to 34 percent. In short, the large majority of the uncertainty over total population is in fact uncertainty over how many young people there will be. Figure 12 indicates an even greater range for South Asia, the 95 percent range in 2030 running from 23 to 41 percent. The 95 percent range for Western Europe in 2030 is relatively speaking even greater, 12 to 25 percent. Even the 60 percent range for Western Europe (18 to 23 percent) can be seen to embrace situations that can be termed demographically unsustainable. If any population reaches the point of having only 12 percent of its numbers under age 20, it is almost certainly heading for effective extinction. And one with 18 percent is probably heading that way too. While corresponding to the tail of the distribution of predictions, the levels of fertility that generate this rapid decline are not much lower than those seen today in many parts of Southern and Eastern Europe. The 95 percent range of total fertility that underlies these projections is 1.0 to 2.4 in 2030; total fertility is below 1.3 today in Italy, Spain, and a number of other European countries.

Finally, Figures 14 to 16 examine forecasts for the population of retirement age (broadly defined to be 60 plus). In addition to the world values, trends are plotted for the Pacific OECD (Japan, Australia and New Zealand) and Australia's immediate neighbours in South East Asia and the Pacific. As is to be expected on theoretical grounds, these proportions are more predictable than those for the under-20 age group. Moreover, much of the variance in the proportion of the total population over 60 is attributable to uncertainty at the youngest ages; the variance of the absolute numbers 60 plus is less than in the proportions plotted here. Nevertheless, there is still a good deal of uncertainty to be seen even at older ages. For the world as whole, the 95 percent range runs from 14 to 20 percent in 2030, with the central 60 percent range from 15 to 18 percent. For the Pacific OECD, however, the proportion is both higher and less predictable, with the 95 percent interval extending from 28 to 40 percent, and the 60 percent range from 31 to 36 percent. As with the comments on Western Europe above, even a small chance of reaching a situation in which 40 percent of the population is over 60 (as expected for Japan by 2050) is something that might give pension fund managers and others concerned with old-age support pause for thought.

UN Population Projections

As can be seen from Table 1, there have been three periods since 1957 when UN medium variant population projections have significantly over- or under-estimated population growth. The first was in the late 1950s when forecasters were underestimating population growth up to 1990. It is likely that they underestimated the decline in infant mortality and the improvements in life expectancy (see Figure 4). However, in the case of the 1957 forecast of the 2000 population, which over-estimated the actual level, it is likely that they

underestimated the decline in fertility rates. Next, as can be seen from Figures 1, 2, and 3, in the late 1960s the future fertility rates assumed were much higher than the actual rates, which was probably responsible for the overestimation of the population levels for 1990 and 2000. UN assumptions about fertility rates did not catch up with the trends underway until the mid-1970s. It is likely that the over-forecasting of the late 1960s gave some support to the panic that was being generated at the time through publication of "population explosion" and "resource depletion" scenarios.

With respect to the UN's projection for year 2000, there was movement back to more accurate projections from the mid-1970s to the mid-1980s, but in the late 1980s and early 1990s the 2000 projections again became too high. As can be seen from Figure 1, this was because the fertility assumption was still overestimating the trend. Subsequent projections over the period to 1998 obviously picked up on this and year 2000 projections move closer and closer to the actual level.

However, we can see from the projections for years 2010, 2020, 2025, 2030 and 2050 made over the period 1990-2000 that in the UN's 2000 projection there is again a marked shift from earlier projections. Whereas, population projections for these years had been declining, the projections published in 2000 move back up again. This is especially noticeable for the year 2050 projection. Whereas in the 1998 revision the medium variant projection gave a global population of 8.91 billion, in the year 2000 revision the projection is 9.32 billion—an increase of almost 400 million.

The reasons for this change are that in its 2000 revision the UN assumed that fertility rates in what they describe as the "high fertility" developing countries (a group of 16 least developed countries, mostly in Africa) will not decline as fast as they had assumed previously. Also, for three populous countries (Bangladesh, India and Nigeria), fertility rates are not assumed to decline as quickly as in previous projections. The change in the fertility assumption for the least developed countries led to an increase of 243 million in the 2050 projection, while the changed fertility assumption for the three

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populous countries led to an increase of 131 million in the 2050 projection. As well as these changes
in the fertility assumptions, fertility rates in the "low fertility" countries (i.e., those developed and developing countries with fertility rates below replacement rates) are not expected to continue declining but at various points move back towards the replacement fertility rate. Some of these assumptions about future fertility rates and the resulting population projections appear to be highly questionable.

There is no sign of a turnaround in fertility rates in those countries that have already reached very low levels. Indeed, as a conference held by the UN itself on fertility in below-replacement fertility countries showed (UN 2000), the only high-income country in which the fertility rate has turned around is Sweden; but this reversal was temporary and its fertility rate has begun to decline again. Presenters at that UN conference put forward numerous social, cultural and economic reasons for the decline in fertility in countries such as France, Japan and Italy, but none of them anticipated that the situation would be reversed. It is obvious that there is limited understanding of the reasons for the decline in fertility rates and especially for the persistence of rates far below the replacement level. Therefore, it appears

heroic to assume an increase in fertility rates rather than assuming that rates will remain constant at present levels or continue on a declining trend.

As noted above, some of the countries of Asia that have experienced rapid economic growth have fertility rates below replacement level. The UN has assumed that these trends will also be reversed. For example, the Total Fertility Rate for South Korea is assumed to remain at its present level of around 1.5 per cent for the next five-year period and then increase to 2.1 per cent by 2050. The Total Fertility Rate in Japan is also expected to reverse its downward trend and move from its present level of 1.33 per cent back to 1.75 per cent by 2050. It is difficult to see why these countries should not follow the declining fertility path of the Western European countries, as they have up until now.

Given their population size, what happens to fertility rates in China and India will have a large impact on the global population. In the case of China, the UN has assumed an increase in the Total Fertility Rate from the present 1.8 per cent to 1.9 per cent in 2010-15 and thereafter. Jiang (2001) of China's State Planning Commission, says that China has no intention of relaxing its family planning policies, and their own projections to 2050 assume a continuing decline in the birth rate. The UN assumes that the Total Fertility Rate in Bangladesh and India will continue to decline until 2025 and then hold at the replacement rate of 2.1 per cent. Again, there is no basis in the experience of other countries to support such an assumption.

In the case of the least developed "high fertility" countries, the UN says that so far there is no evidence of a fertility reduction to justify an assumption of declining fertility rates for these countries. Given the little that is known about fertility rates, it is difficult to argue with this conclusion. However, the UN acknowledges the problem of HIV/AIDS in many of these countries. The impact that this pandemic has had on mortality rates can be seen in Figure 6. The rising mortality rates may well offset the absence of any decline in the high fertility rates. On the other hand, a successful challenge of HIV/AIDS may be accompanied by better economic circumstances and the possibility of falling fertility rates.

The UN's 2000 projections shown in Table 1 have global population increasing to 8.27 billion by 2030 and to 9.32 billion by 2050. Whereas the UN projections of the global population made over the period from 1994 to 1998 were reduced by over 500 million for year 2030 and by almost one billion for 2050, in the 2000 projections they have been increased by 160 million for 2030 and by almost 400 million for 2050. The fertility assumptions that are the basis for this reversal appear to be highly questionable. Given the calculations underlying Figure 9, it can be seen that the range of uncertainty of the projection for 2030 is quite large, with a 95 per cent range of 2.4 billion and a 60 percent range around one billion. This wide range reflects the uncertainty about the assumptions, particularly the fertility rate assumption. Hence, there is a reasonably high likelihood that the projection for 2030 could be 500 million too low or too high (i.e., 7.8 billion to 8.8 billion) and a low likelihood that the projection error could be more than one billion too high or too low (i.e., within the range 7.1 billion to 9.5 billion). Based upon the UN's past performance, it is likely that their projections will be too high rather than too low.

Conclusions

The world's population grew very rapidly during the latter half of the 20th Century because of the demographic transition experienced by most developing countries. The sharp decline in both mortality and fertility rates led to rates of population growth never before experienced, even by the present developed countries when they underwent their demographic transition in earlier times. The rapid population growth gave rise to extravagant projections of global population based on a lack of understanding of what was taking place. While the population momentum built up from the earlier high population growth rates will lead to relatively high global population growth for some considerable time, the population growth rate is falling rapidly and, moreover, populations are aging rapidly. If fertility rates continue on their present path, population levels will begin to decline in more and more countries. Indeed, the fertility rates in some countries in Southern Europe have reached levels from which it will be very difficult to prevent continuous decline.

The United Nations Population Division, which has responsibility for global population projections, has understood the changes taking place reasonably well and has generally made projections that have turned out to be fairly close to the mark. However, there have been a few periods when the key assumptions made by the UN, particularly the fertility rate, have been off track, leading to significant errors. There have been persistent biases in the form of underestimation of the improvement in life expectancy and the decline in fertility rates. Forecasting the fertility rate remains the most problematical aspect of the projections exercise.

The latest population projections by the UN have revised upwards the global population projections on the basis on some questionable assumptions about future fertility rates. Fertility rates in the least developed "high fertility" countries are projected not to decline and fertility rates in the low-fertility, high-income countries are assumed not to decline any further. Given the limited understanding of the factors underlying changes in fertility rates, these assumptions have little or no justification. Even more suspect is the assumption that the decline in the fertility rates of developing countries experiencing robust economic growth will be reversed. There is no justification for this assumption in the experience of other developing countries further along the fertility-decline path, nor in the experience of the high-income countries.

Given the error bounds that have been estimated for UN population projections and the tendency of the UN to underestimate the decline in fertility rates, there is a strong likelihood that the medium variant projection for 2030 is a considerable over-estimate. A figure below 8 billion could be closer to the mark than the 2000 projection of 8.27 billion. Moreover, there is a good chance that the projection of 9.32 billion for 2050 could be over-estimated by 500 million or more.

Table 1: United Nations Medium Variant Population Projections, 1957 to 2000 (billions)

Year	Actual	1957	1963	1968	1973	1978
1950	2.52					
1960	3.02	2.91				
1970	3.70	3.48	3.59	3.63		
1980	4.44	4.22	4.33	4.46	4.37	4.42
1990	5.27	5.14	5.14	**5.44**	5.28	5.28
2000	6.06	**6.28**	**6.28**	**6.49**	**6.25**	**6.20**

Source: United Nations, World Population Prospects (various issues), Population Division, Department of Economic and Social Affairs, New York.

Table 1 (cont'd): United Nations Medium Variant Population Projections, 1957 to 2000 (billions)

Year	Act.	1982	1984	1988	'90	1992	1994	1996	1998	'00
1990	5.27	5.24	5.25	5.29						
2000	6.06	6.13	6.12	**6.25**	**6.26**	**6.23**	6.16	6.09	6.06	
2010		6.99	6.99	7.19	7.20	7.15	7.03	6.89	6.80	6.83
2020		7.81	7.82	8.06	8.09	8.05	7.89	7.67	7.50	7.58
2025		8.18	8.21	**8.47**	**8.50**	**8.47**	8.29	8.04	7.82	7.94
2030							8.67	8.37	8.11	8.27
2050							9.83	9.37	8.91	**9.32**

Source: United Nations, World Population Prospects (various issues), Population Division, Department of Economic and Social Affairs, New York.

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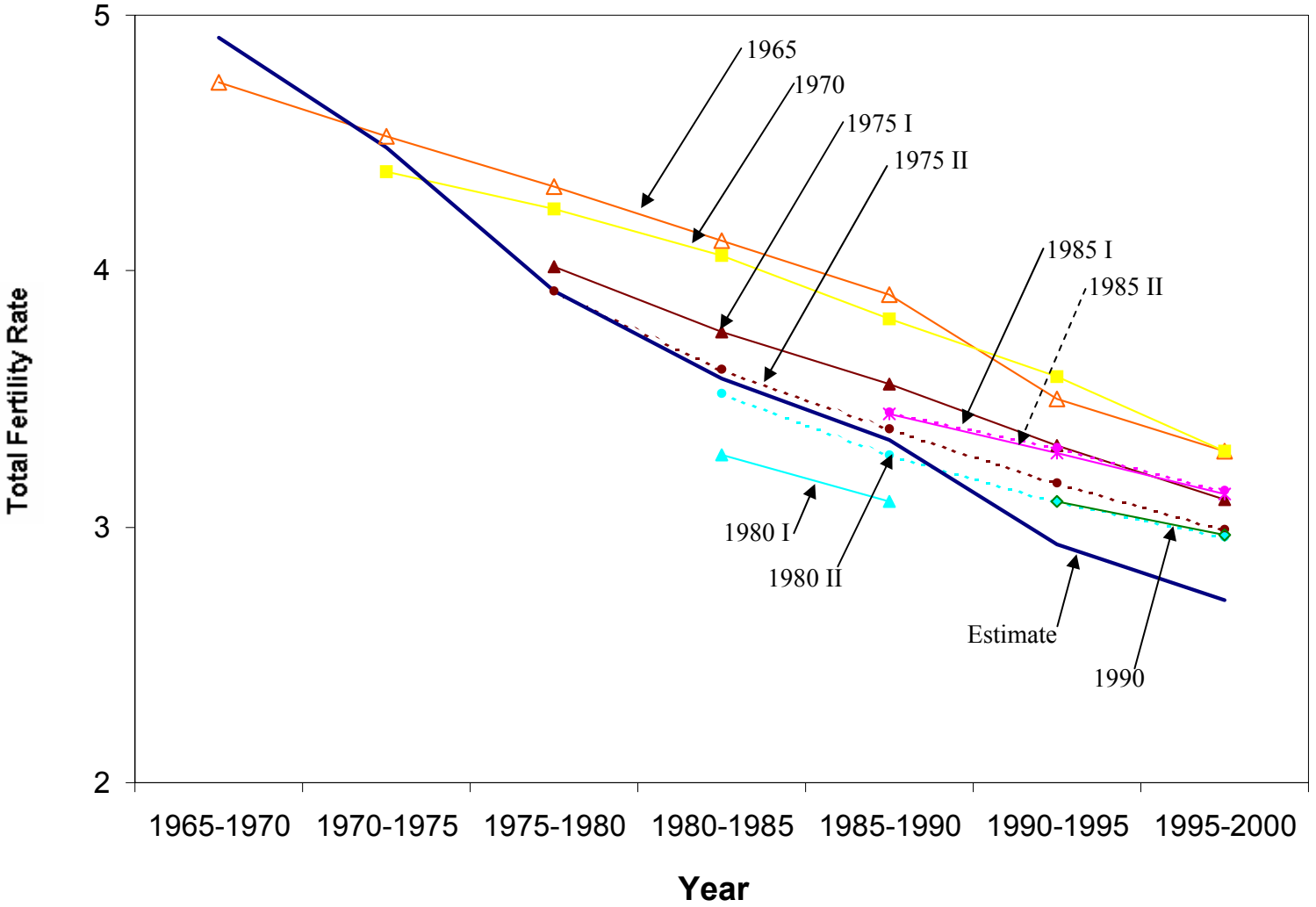
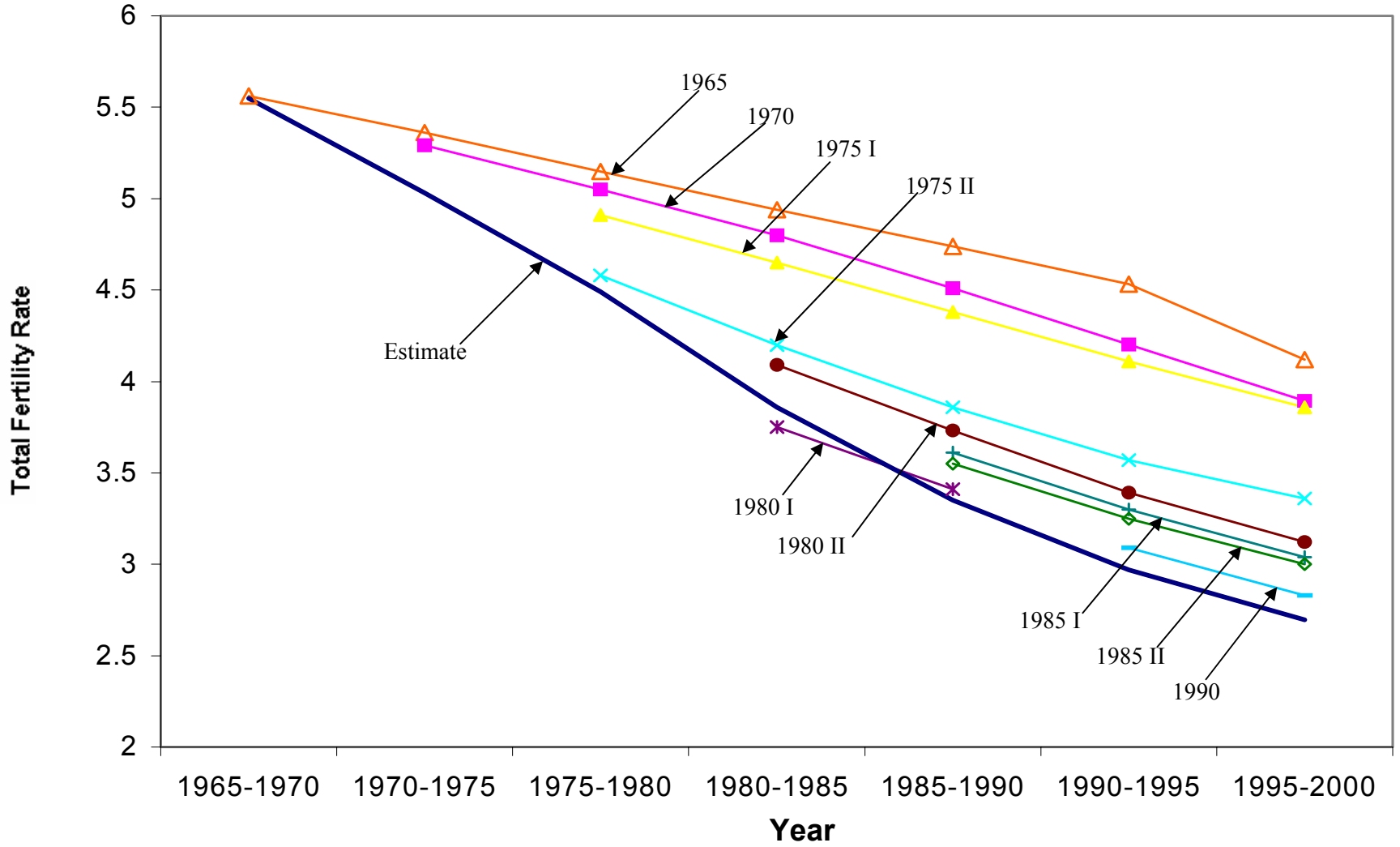
Figure 1: World Total Fertility Rate



Source: O'Neill et al 2001

Figure 2: Latin America Total Fertility Rate



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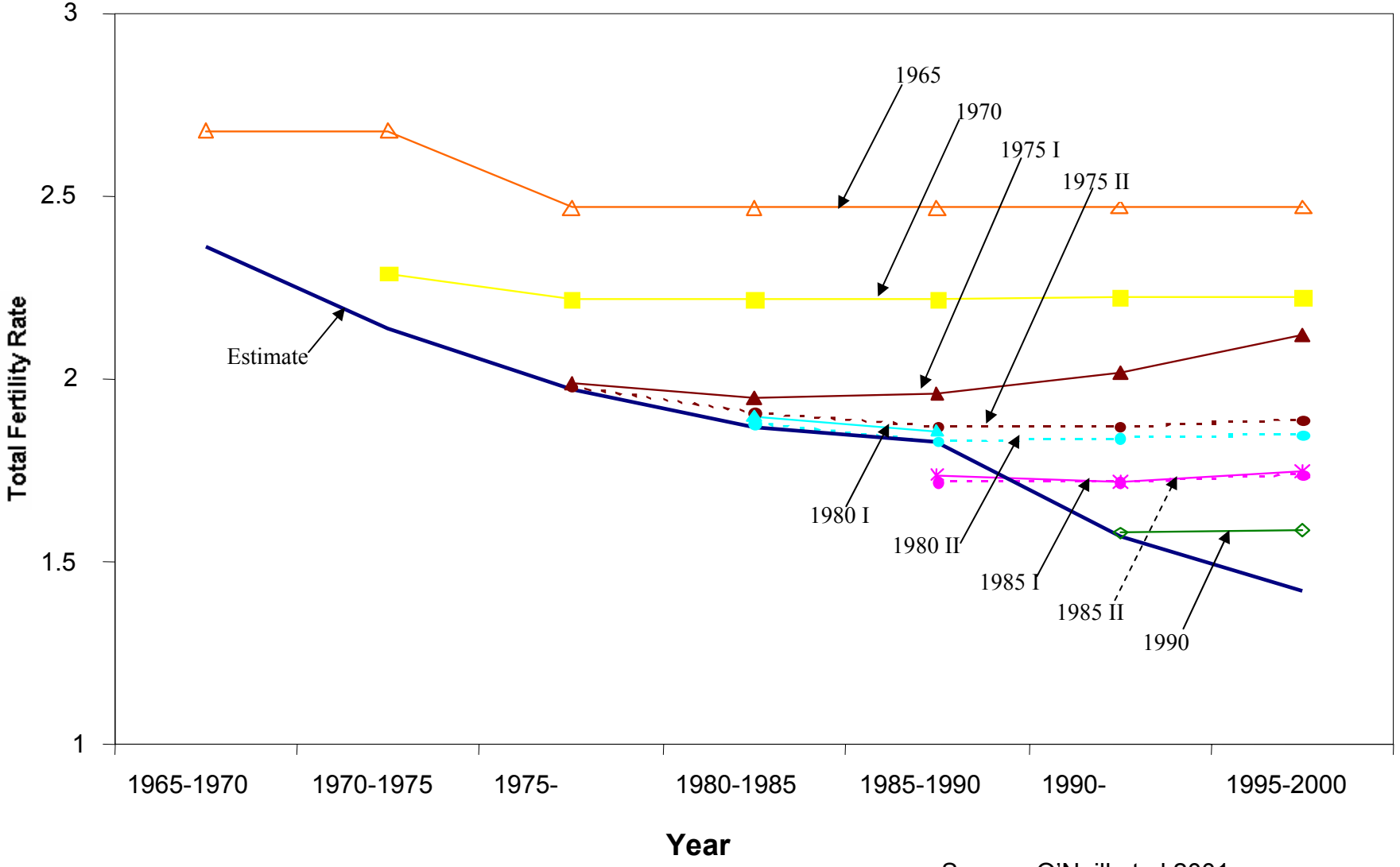
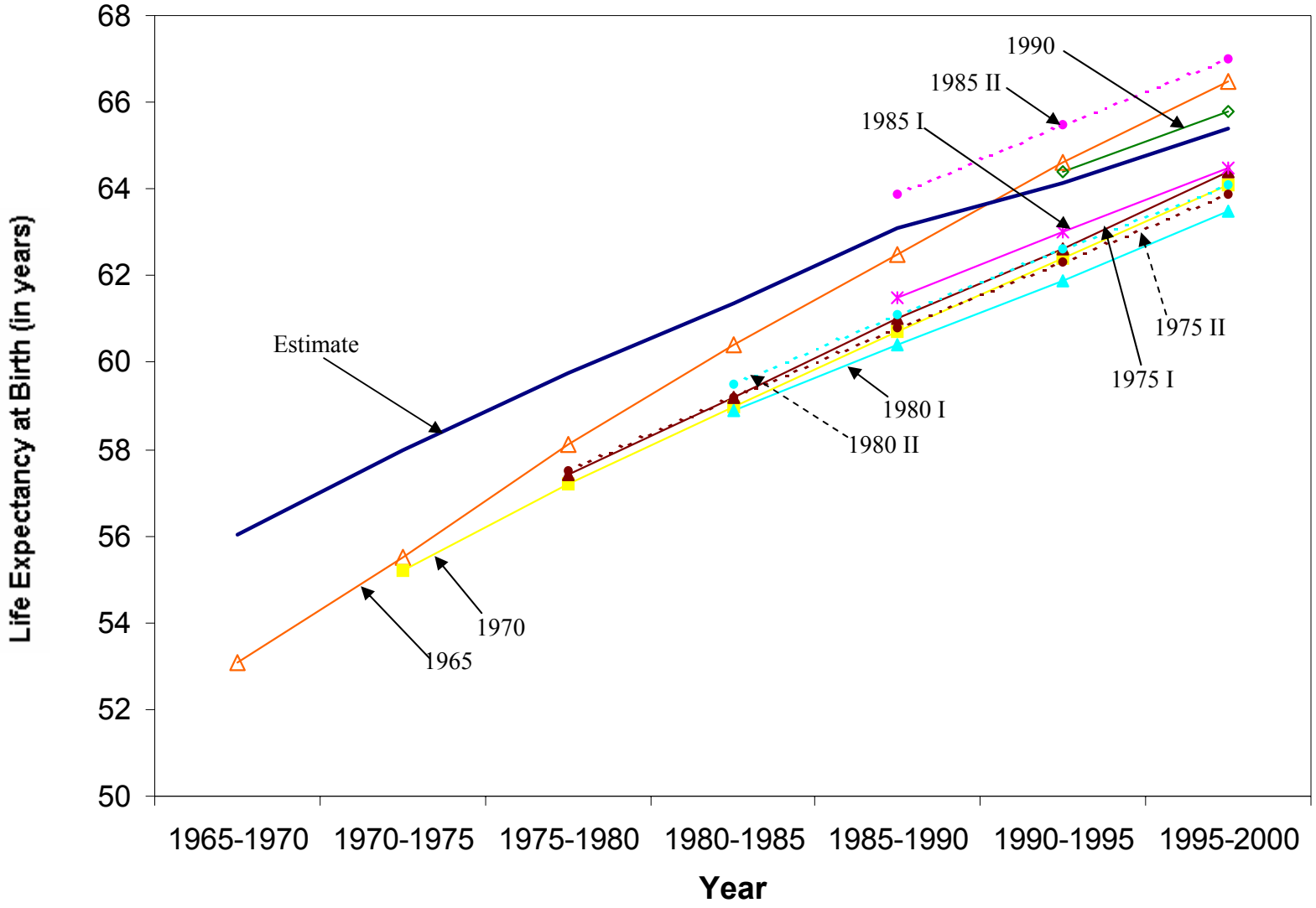
Source: O'Neill et al 2001

Figure 3: Europe Total Fertility Rate



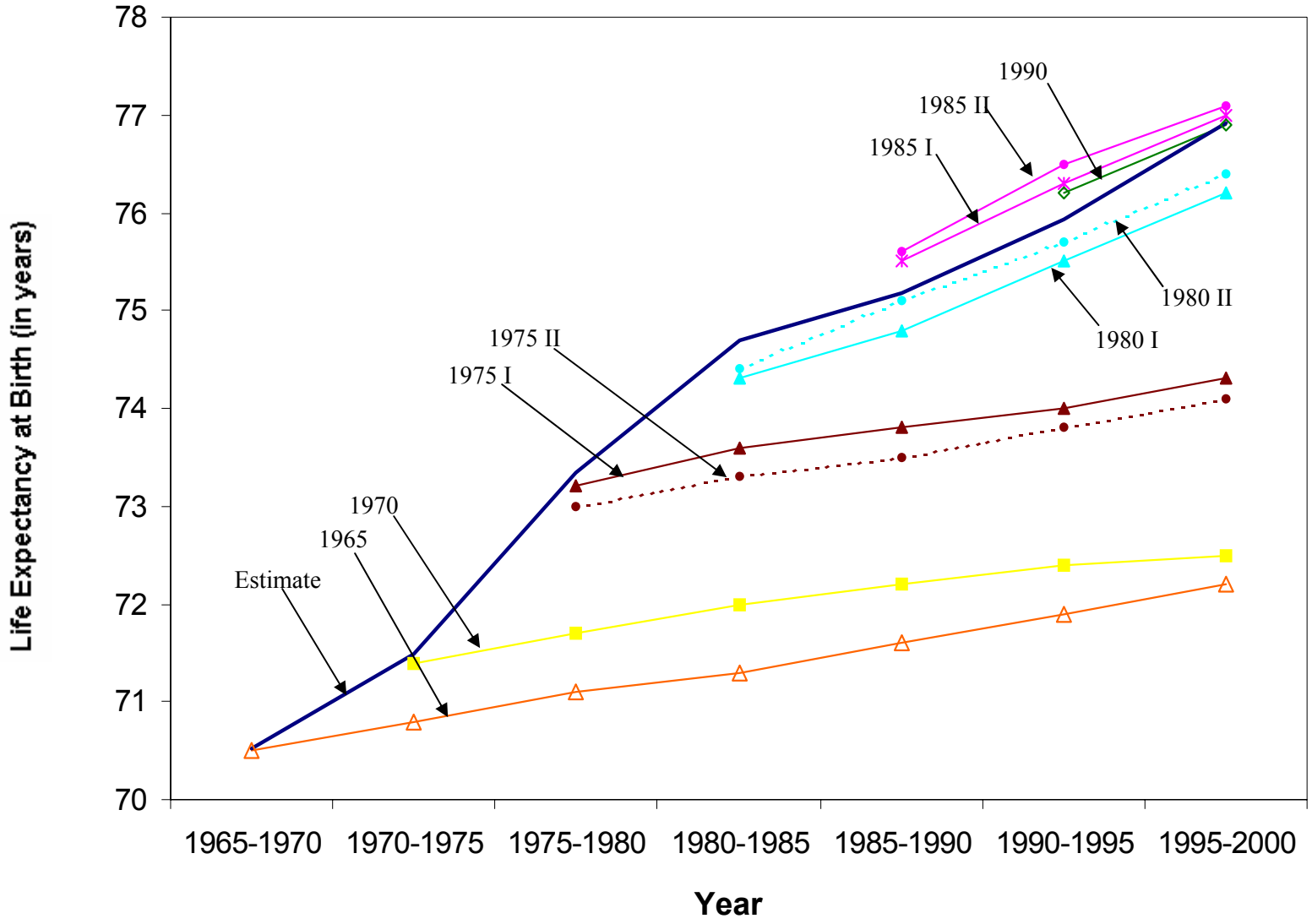
Source: O'Neill et al 2001

Figure 4: World Life Expectancy at Birth



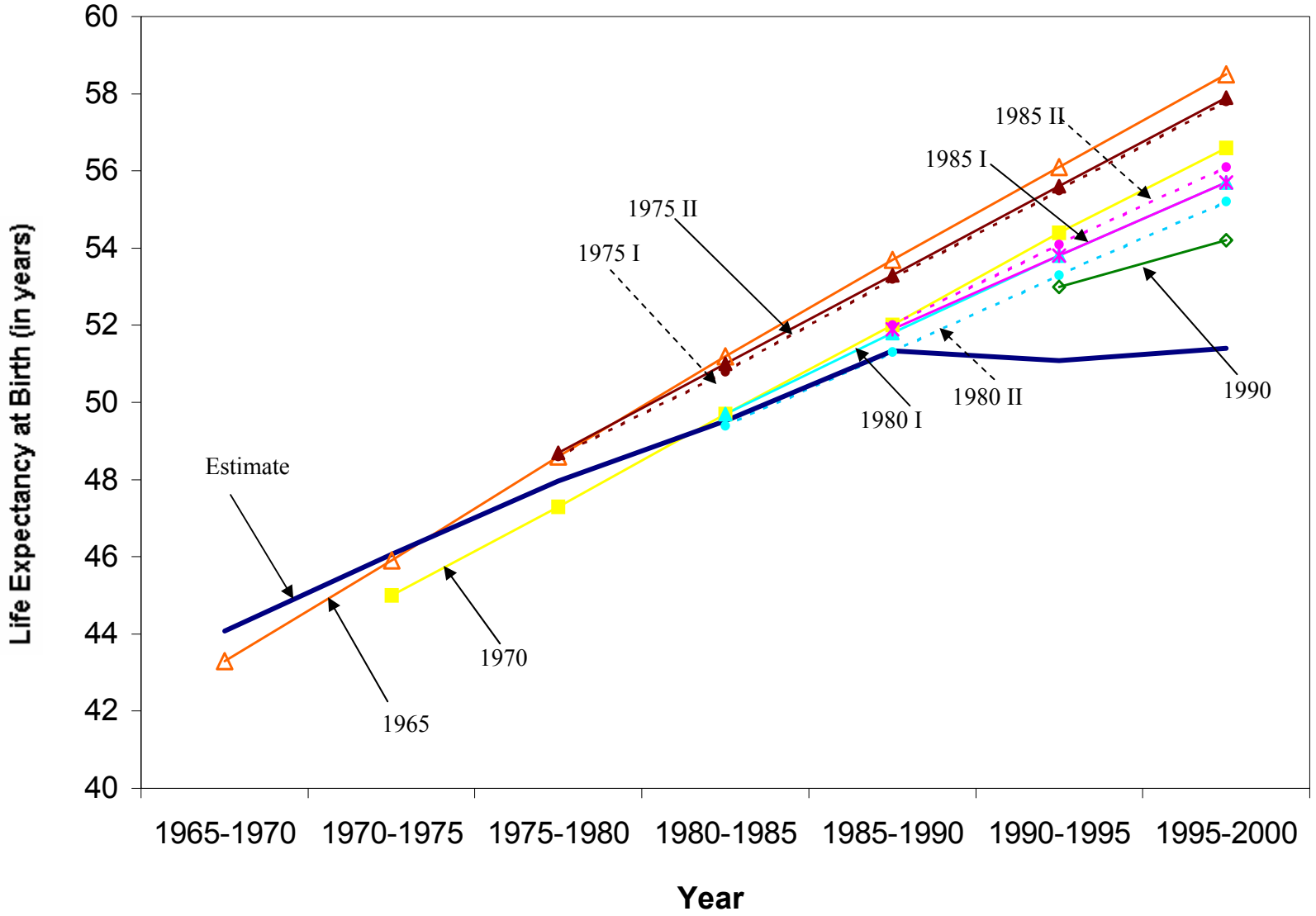
Source: O'Neill et al 2001

Figure 5: North America Life Expectancy at Birth



Source: O'Neill et al 2001

Figure 6: Africa Life Expectancy at Birth



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Source: O'Neill et al 2001

Figure 7: Central Asia, 2030

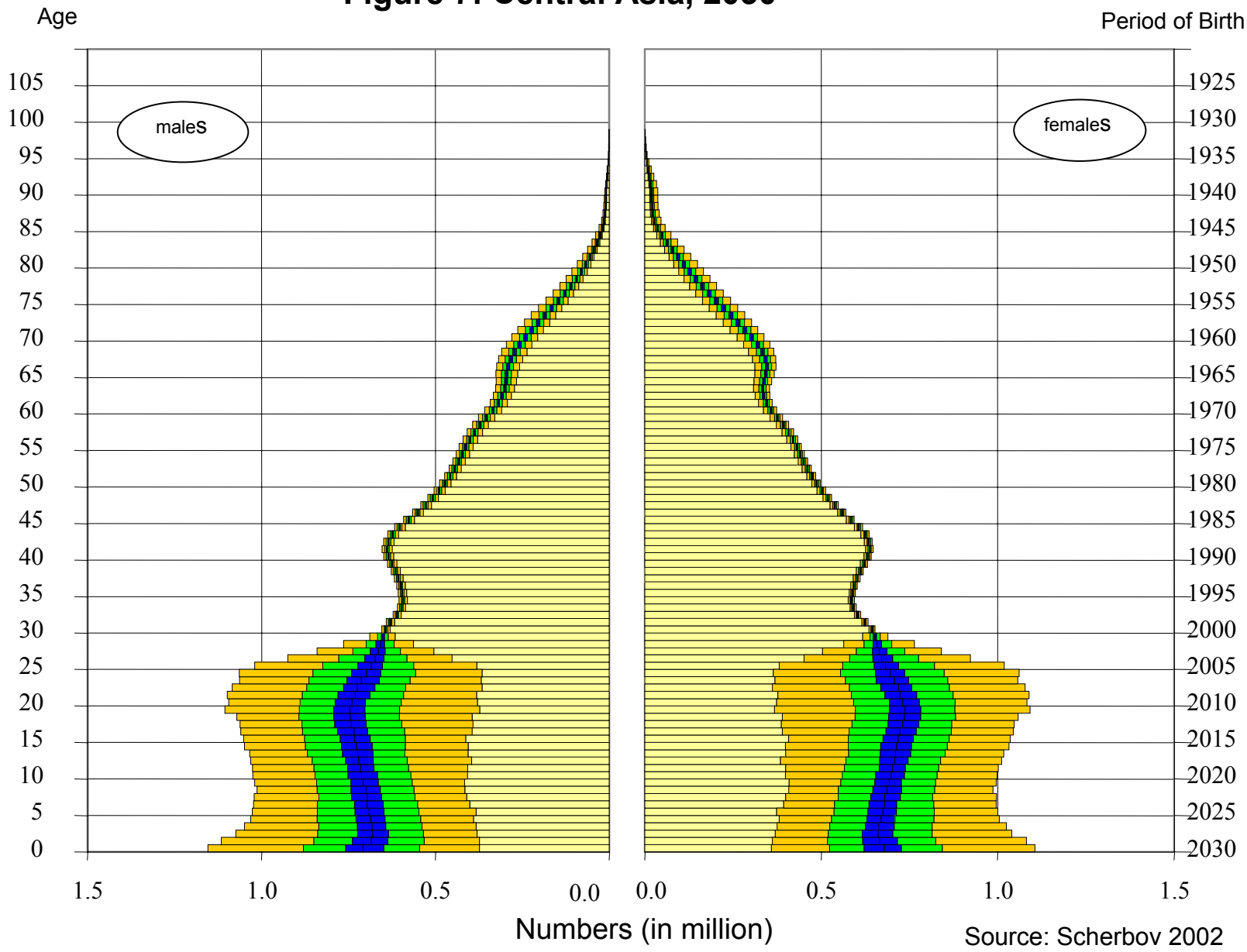
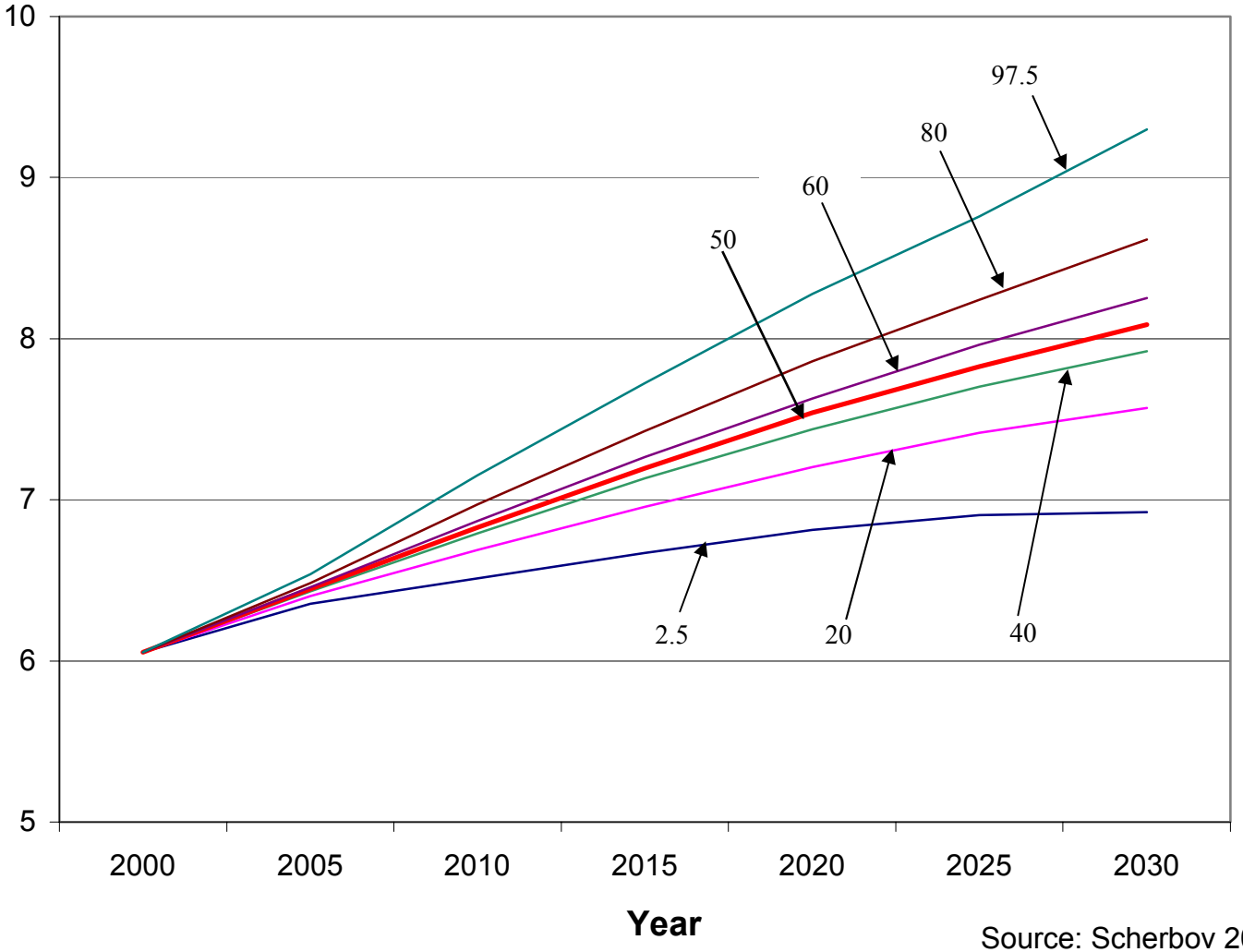
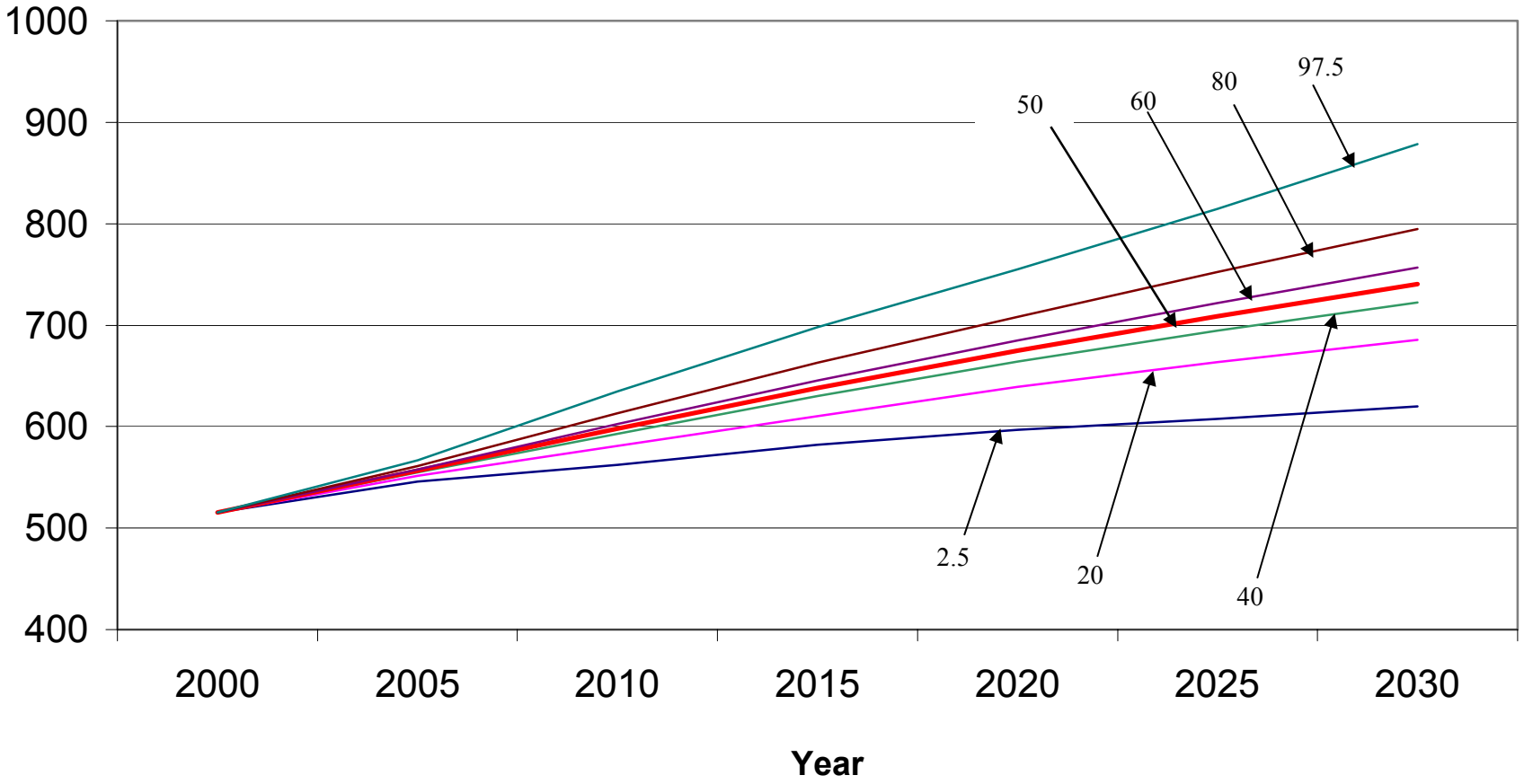


Figure 8: Confidence intervals for total population - World (billions)



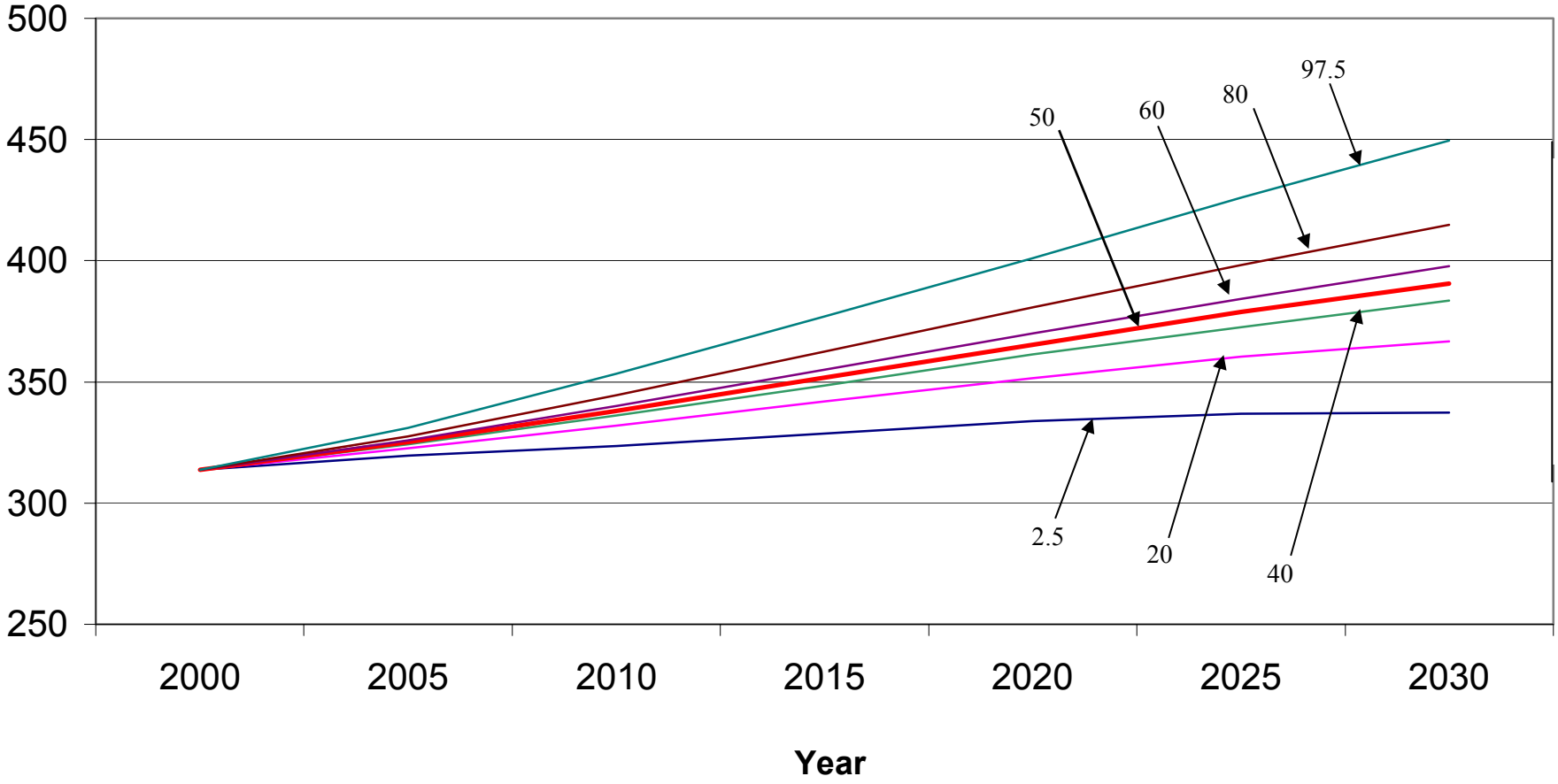
Source: Scherbov 2002

Figure 9: Confidence intervals for total population - Latin America (millions)



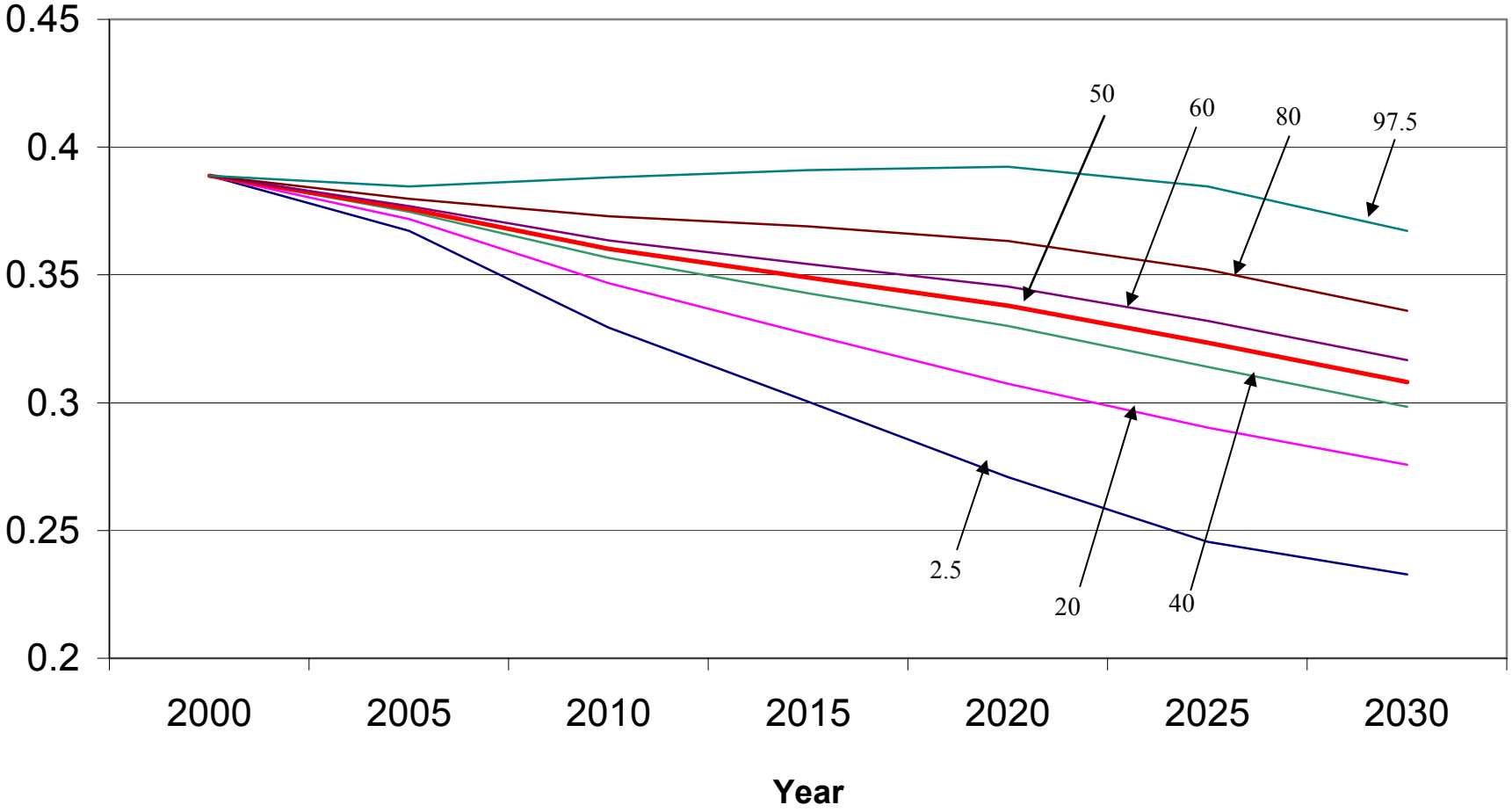
Source: Scherbov 2002

Figure 10: Confidence intervals for total population - North America (millions)



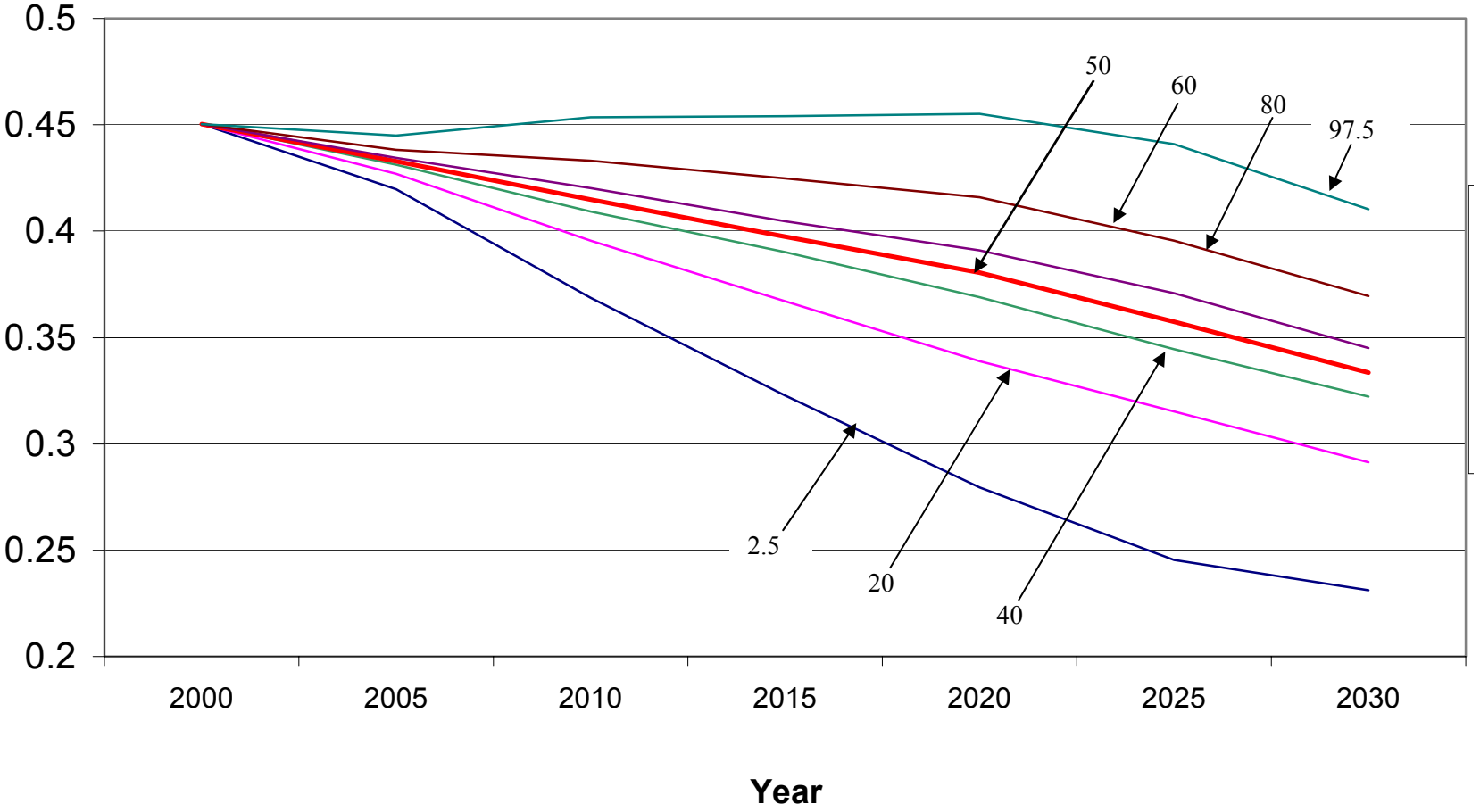
Source: Scherbov 2002

Figure 11: Confidence intervals for proportion of population < 20 - World



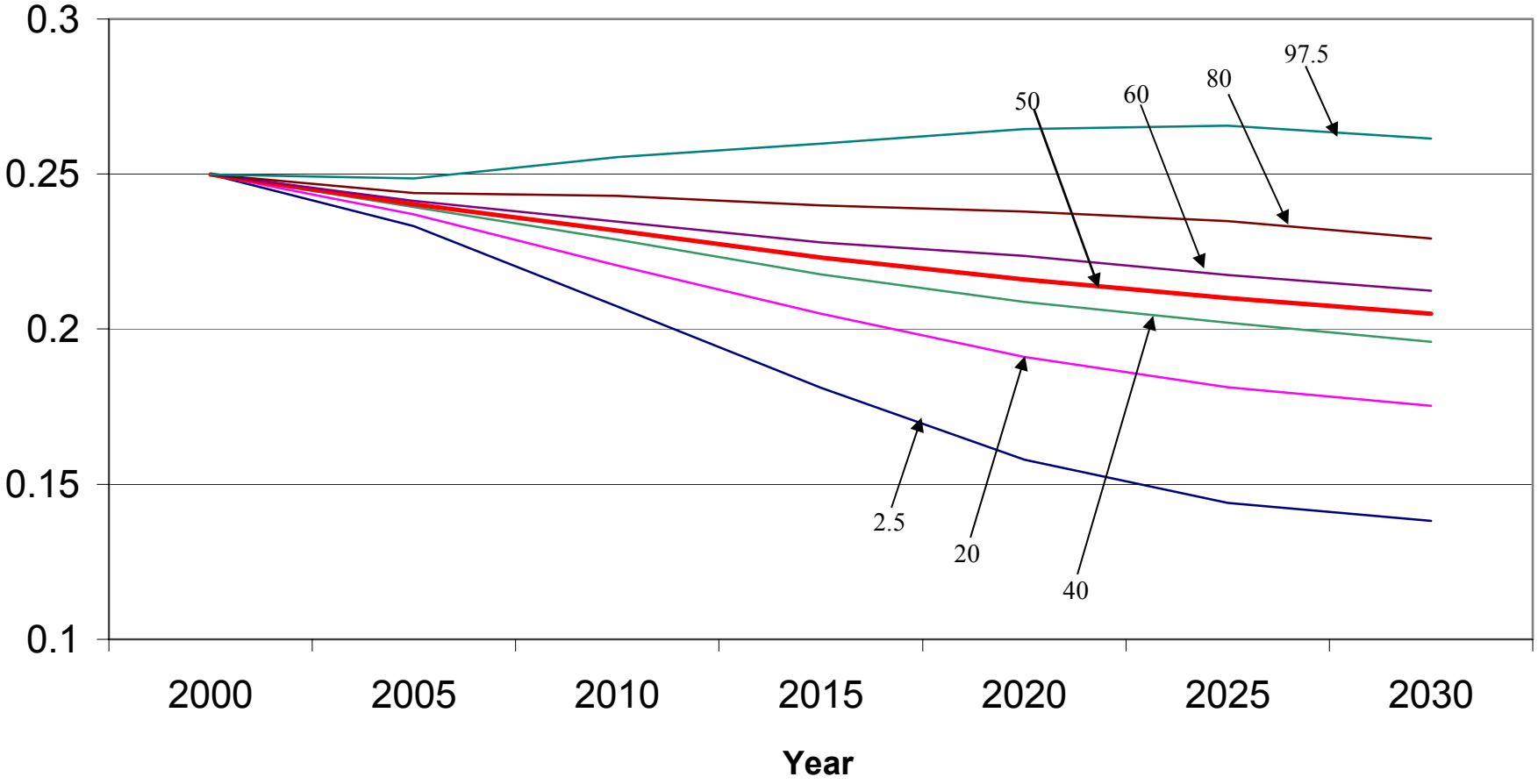
Source: Scherbov 2002

Figure 12: Confidence intervals for proportion of population < 20 - South Asia



Source: Scherbov 2002

Figure 13: Confidence intervals for proportion of population < 20 Western Europe



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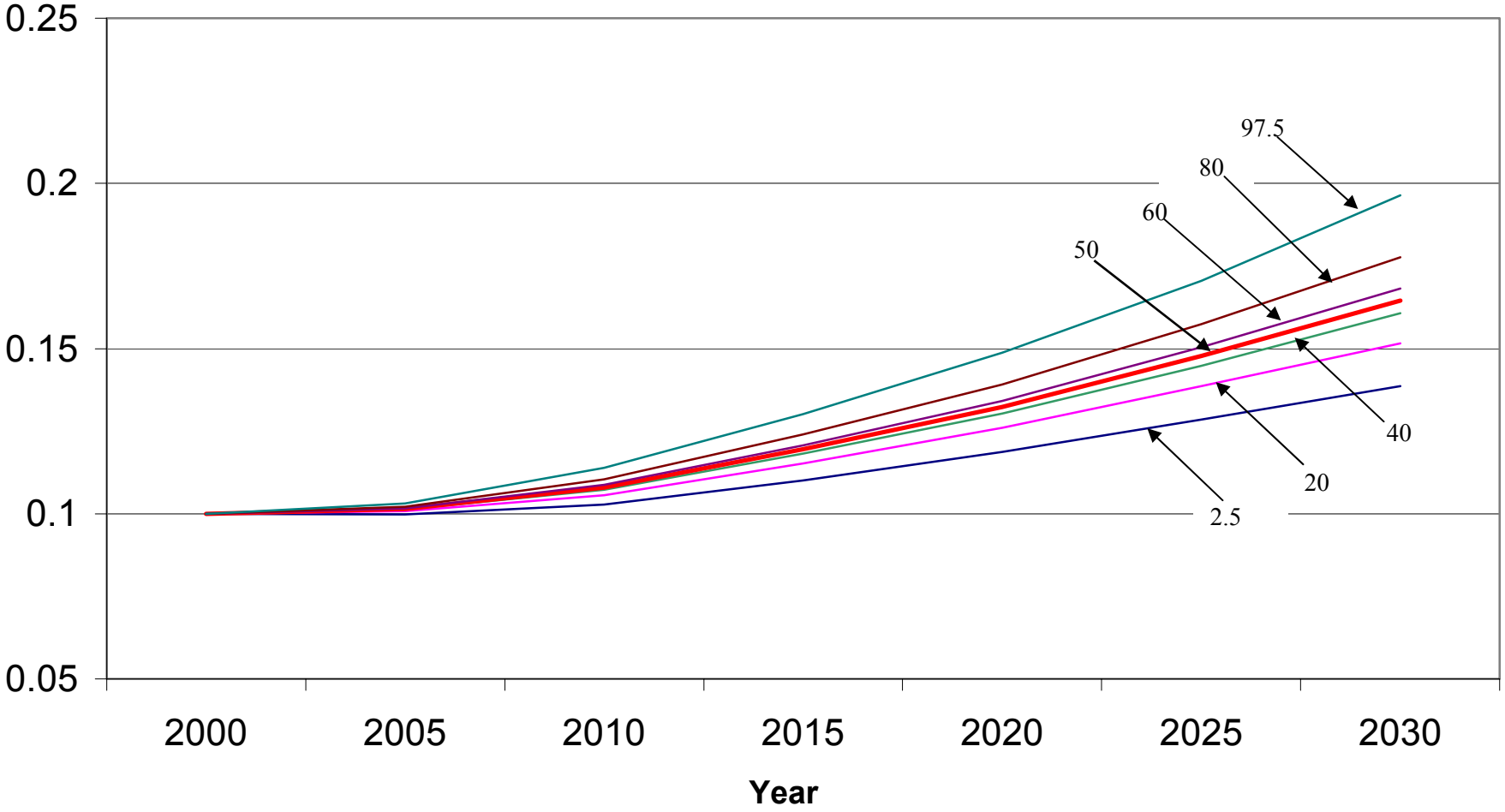
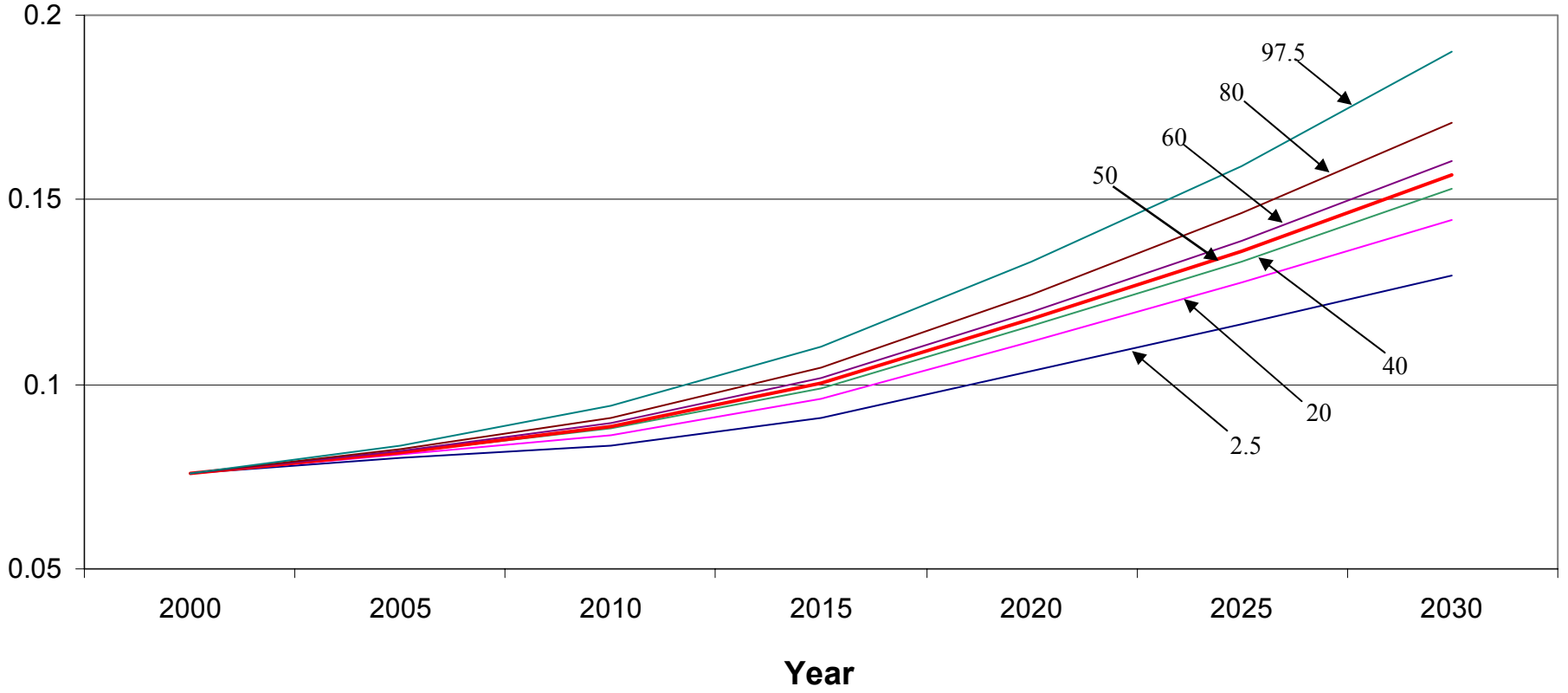
Source: Scherbov 2002

Figure 14: Confidence intervals for proportion of population 60 plus - World



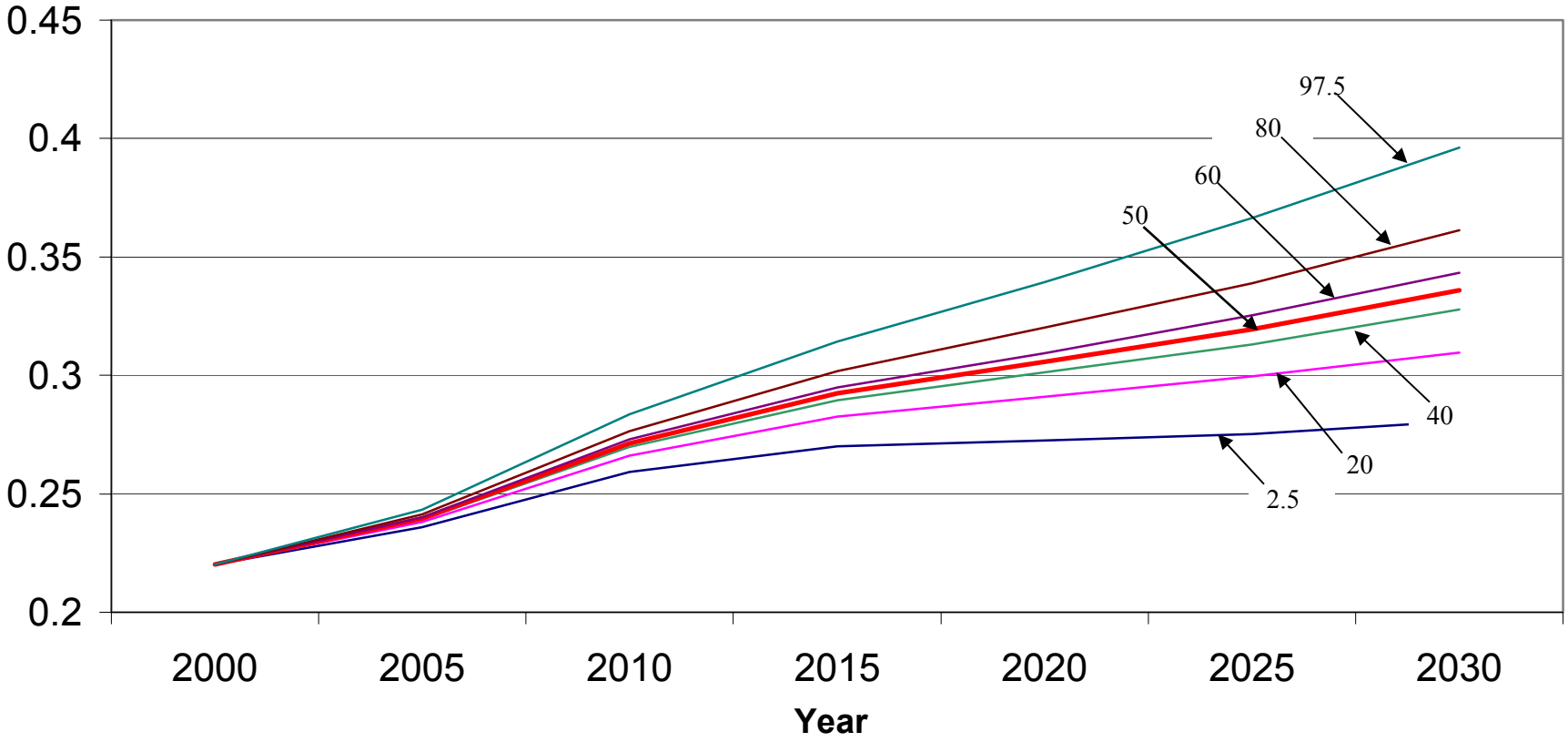
Source: Scherbov 2002

Figure 15: Confidence intervals for proportion of population 60 plus - SE Asia and Developing Pacific



Source: Scherbov 2002

Figure 16: Confidence intervals for proportion of population 60 plus - Pacific OECD



Source: Scherbov 2002