Forecast errors in global population projections: implications for food

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1. Introduction

The demand for food in any given country or region depends on several factors, among which are income, cultural preferences and the number and age of its inhabitants. Thus population projections form a crucial input into models of future demand for food and other agricultural products. Fortunately, given this importance, population forecasts can be reasonably reliable. As Ron Lee puts it,

> "On average people live long lives, have a long lag between birth and childbearing, and experience demographic rates with highly regular age patterns. These patterns change quite slowly. For these reasons, population is reliably predictable over fairly long periods compared to economic performance or the weather. Nonetheless, demographic forecasting does involve a good deal of uncertainty." (Lee 1999, 156).

This paper investigates just how much uncertainty does attach to future population forecasts and considers the potential sources of error. After this introduction the paper begins with a discussion of how population projections are produced and notes the nature and scale of errors in past forecasts. After that the paper considers the methods that have been used to provide more rigorous statistical estimates of the degree of uncertainty in future estimates. The paper then outlines the method used by Lutz, Sanderson and Scherbov (2001) in a paper in *Nature* and discusses its advantages. The results presented in Section 4 are drawn from the work of this group of researchers. Finally, the conclusion offers a number of considerations for the incorporation of population forecasts into economic models of demand.

2. Understanding global population projections

Virtually all forecasts of future population are based on the methodology of cohort-component projection. The origins of this methodology lie in the 1930s (De Gans 1999), and after World War II it came to be the only method widely employed by governments and international organizations. In essence it is 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 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 given 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. Conventional forecasts have relied on the concept of “scenarios” to represent the range of possible future outcomes. Typically, these present a small number of alternative 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 always been paid to the medium forecast, on the reasonable basis that this is what the forecasters think is most likely. To quote Lee once more,

> “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 demographers 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 and published with the title *Beyond Six Billion: Forecasting the World’s Population* (NRC 2000). A paper by O’Neill et al in the online journal *Demographic Research* 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 a number of others. The NRC project involved assessing retrospectively and precisely 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 to these assessments are of considerable importance. The largest cause of errors in short-term forecasts (up to 5 or 10 years) is poor data. The baseline information for many countries, especially in the developing world, is limited and this can lead to substantial misestimates of population size. In the longer run (beyond 10 years) the main cause for 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 precise 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 at 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 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 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.

3. 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 modeling 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 in itself, 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 will be shown below, estimating future fertility is the key element of uncertainty in forecasting future population.

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 thing 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 (as discussed above), the nature of these errors is now well understood, and 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. I am extremely grateful to the scholars who produced these forecasts (Wolfgang Lutz, Sergei Scherbov and Warren Sanderson) for generously sharing their unpublished results with me.

4. Results

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 (LA) and 1.9 (NA). 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 models of demand, it is possibly more significant to know about the predictability of 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; this measure is below 1.3 today in Italy, Spain, and a number of other European countries, for example.

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, with the 60 percent range 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 was over 60 is something that might give pension fund managers and others concerned with old-age support pause for thought.

5. Conclusion

This paper has given a brief overview of the nature of past errors and future uncertainties in population forecasts. The newly developed probabilistic approach to forecasting offers opportunities for substantially more sophisticated demographic projections. These can serve as valuable input into dynamic models of demand for food and other agricultural produce. It is to be hoped that economists exploit this opportunity.

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