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SUPPLEMENTARY MATERIALS

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WORLD POPULATION

World population stabilization unlikely this century

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The United Nations (UN) recently released population projections based on data until 2012 and a Bayesian probabilistic methodology. Analysis of these data reveals that, contrary to previous literature, the world population is unlikely to stop growing this century. There is an 80% probability that world population, now 7.2 billion people, will increase to between 9.6 billion and 12.3 billion in 2100. This uncertainty is much smaller than the range from the traditional UN high and low variants. Much of the increase is expected to happen in Africa, in part due to higher fertility rates and a recent slowdown in the pace of fertility decline. Also, the ratio of working-age people to older people is likely to decline substantially in all countries, even those that currently have young populations.

The United Nations (UN) is the leading agency that projects world population into the future on a regular basis (*1*). Every 2 years the UN publishes revised data of the populations of all countries by age and sex—as well as fertility, mortality, and migration rates—in a biennial publication called the *World Population Prospects* (*2*). In July 2014, probabilistic projections were released for individual countries to 2100. Unlike previous projections, these estimates allow us to quantify our confidence in projected future trends using established methods of statistical inference. These projections are based on recent data, including the results of the 2010 round of censuses and recent surveys until 2012, as well as the most recent data on incidence, prevalence, and treatment for the countries most affected by the HIV/AIDS epidemic (*3*), which had not been included previously.

Our analysis of these data shows that world population can be expected to increase from the current 7.2 billion people to 9.6 billion in 2050 and 10.9 billion in 2100 (Fig. 1A). These projections indicate that there is little prospect of an end to world population growth this century without unprecedented fertility declines in most parts of sub-Saharan Africa still experiencing fast population growth.

Traditionally, the UN has also provided high- and low-projection scenarios (shown in Fig. 1A), obtained by adding or subtracting half a child from the total fertility rate [(TFR) in children per woman] on which the main (or medium) projection is based, for each country and all future time periods. These scenarios have been criticized as having no probabilistic basis and leading to inconsistencies (*4*, *5*). For example, though it is plausible that fertility could exceed the main projection by half a child in a given country and year, it is unlikely that this would be the case for all countries and all years in the future, as assumed in the high projection.

In a methodological innovation aimed at overcoming this limitation, we derived new probabilistic projections based on probabilistic Bayesian hierarchical models for major components of demographic change—namely, fertility (*6*–*8*) and life expectancy (*9*, *10*). These models incorporated available data and take advantage of data from other countries when making projections for a given country. They also incorporated external information through Bayesian prior distributions, including an upper bound of 1.3 years per decade on the asymptotic rate of increase of life expectancy, based on historic data on life expectancy in leading countries (*11*) and on changes in the maximum age at death (*12*). The models included the assumption that the TFR for a country will ultimately fluctuate around a country-specific long-term average that is estimated from the data; these long-term averages are between 1.5 and 2 children per woman for most countries with high probability (*7*).

Probabilistic population projections were then obtained by inputting the output from the statistical models to the standard cohort component projection method (*4*, *13*). Aggregates were based on individual country projections and take into account the correlations between countries' fertility future trajectories (*8*). The models yielded probabilistic projections and, thus, probabilistic limits for future quantities of interest, responding to calls for probabilistic population forecasting (*5*). (See the supplementary materials and http://esa.un.org/unpd/ppp/ for summary tables, plots, assumptions, and methodology.) Here we summarize the overall trends and discuss their implications for world population in the future. The probabilistic projections of world population (Fig. 1A) provide a general statement of the confidence we can have in the projections. For example, there is a 95%

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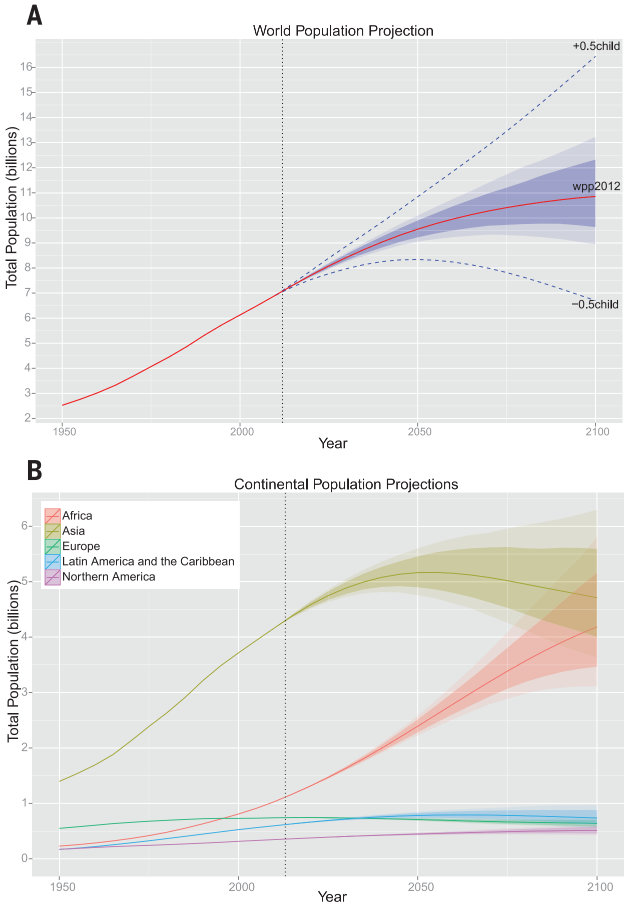

Fig. 1. World and continental population projections. (**A**) UN 2012 world population projection (solid red line), with 80% PI (dark shaded area), 95% PI (light shaded area), and the traditional UN high and low variants (dashed blue lines). (**B**) UN 2012 population projections by continent. In both panels, the vertical dashed line denotes 2012.

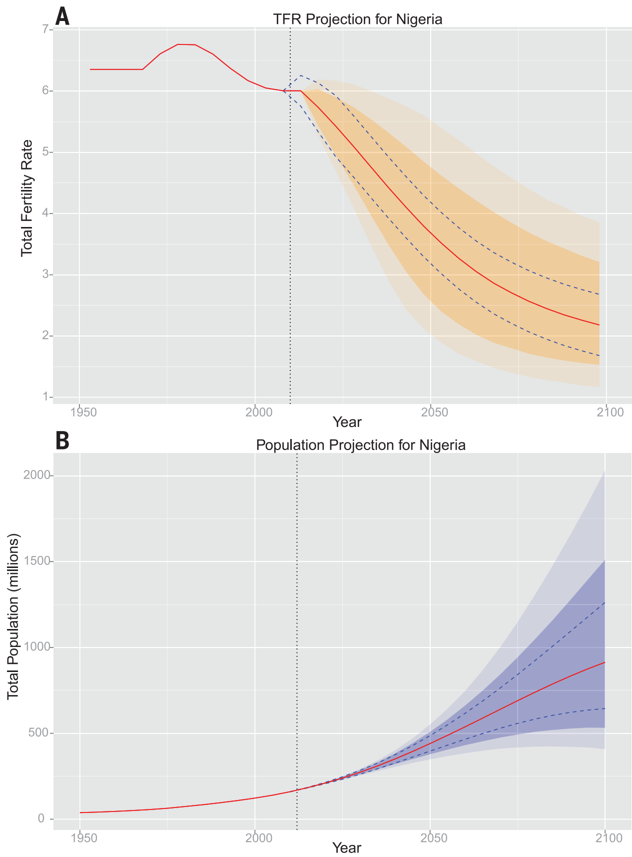

Fig. 2. TFR and population projections for Nigeria. UN 2012 projection of (**A**) TFR and (**B**) total population for Nigeria (solid red lines), with 80% PI (dark shaded areas), 95% PI (light shaded areas), and traditional UN high and low variants (dashed blue lines). In both panels, the vertical dashed line denotes 2012.

probability that world population in 2100 will be between 9.0 and 13.2 billion people. The projections also provide updated answers to long-standing questions about population change. Lutz *et al.* (*14*) gave an 85% probability that world population growth would end in the 21st century, but our probabilistic projection indicates that this probability is much lower, at only 30%. Lutz *et al.* (*15*) considered a doubling of world population from 1997 to 2100 to be unlikely, with a probability of one-third. We found a similar but slightly lower probability of 25%. The probabilistic intervals were much narrower than those between the traditional high and low scenarios, which seem to overstate uncertainty about future world population.

Figure 1B shows the projections of total population for each continent to the end of the century. Asia will probably remain the most populous continent, although its population is likely to peak around the middle of the century and then decline. The main reason for the increase in the projection of the world population is an increase in the projected population of Africa. The continent's current population of about 1 billion people is projected to rise to between 3.1 and 5.7 billion with probability 95% by the end of the century, with a median projection of 4.2 billion. Although this estimate is large, it does not imply unprecedented population density: Under this projection, Africa's population density would be roughly equal to that of China today.

The increase in the projected population of Africa is due to persistent high levels of fertility and the recent slowdown in the rate of fertility decline (*16*). Three-quarters of this anticipated growth is attributable to fertility levels above the replacement level, and the remaining quarter is due to mortality reduction and current youthful age structure (*17*). Since 1950, fertility has declined rapidly in Asia and Latin America and has also started to decline in Africa. Demographers had projected that fertility in African countries would decline at a rate similar to what has been observed in Asia and Latin America.

However, although fertility has been declining in Africa over the past decade, it has been doing so at only about one-quarter of the rate at which it declined in Asia and Latin America in the 1970s, when these regions were at a comparable stage of the fertility transition (*16*). Indeed, in some African countries, the decline seems to have stalled (*18*).

Bongaarts and Casterline (*16*) suggest two reasons for the slower fertility decline in sub-Saharan Africa. First, they note that despite declines in fertility desires in Africa, the most recent levels of ideal family size are still high, with a median of 4.6 children per woman. This is in line with prevailing family norms (*19*) and the fact that the TFR before fertility started to decline was higher in Africa (6.5) than in the other regions (5.8) (*20*, *21*). Second, the unmet need for contraception (the difference between the demand for contraception and its use) has remained substantial at ~25%, with no systematic decline over the past 20 years (*22*).

A stall in the decline in the past decade is apparent from the past and projected levels of TFR

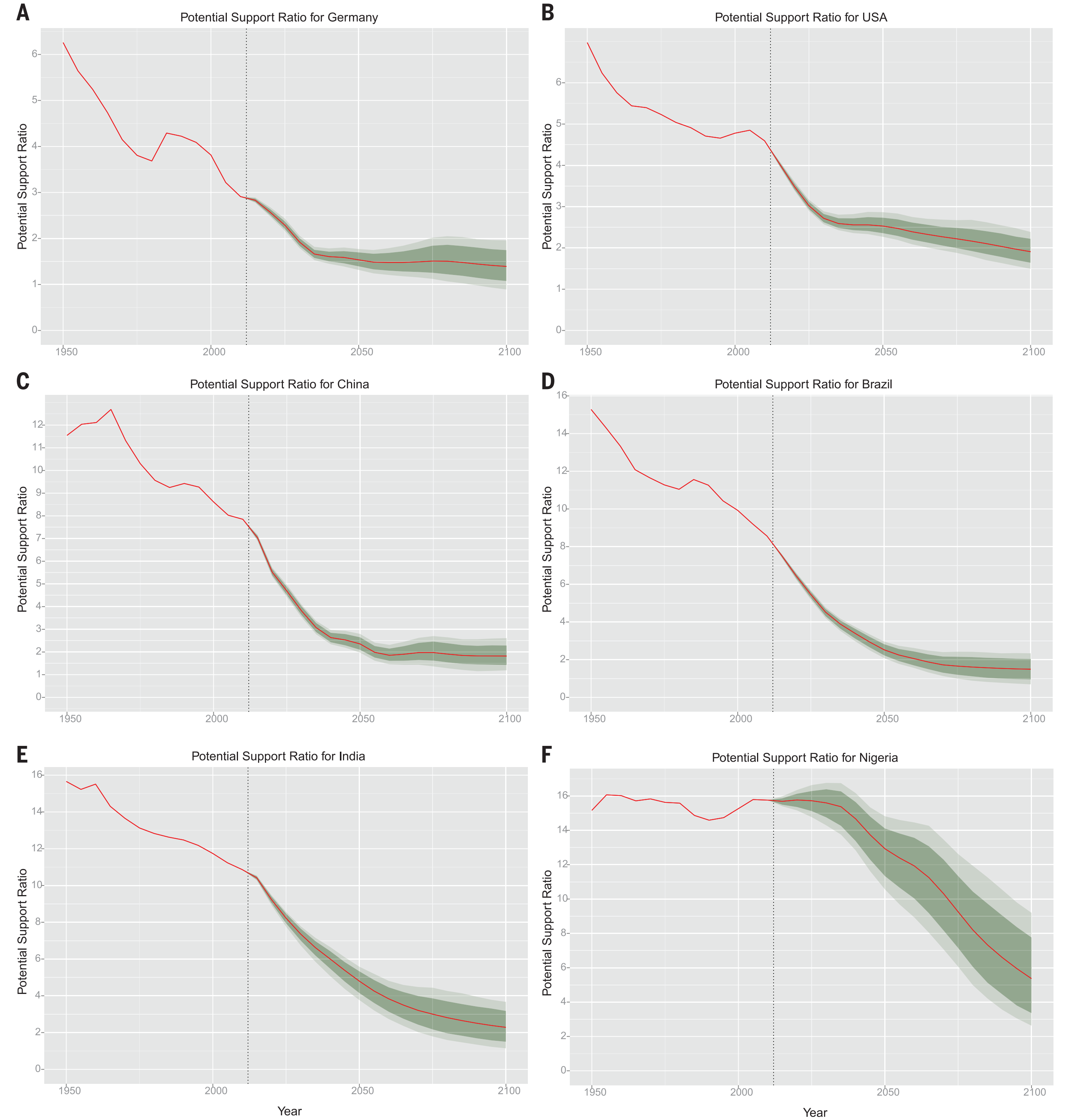

Fig. 3. PSR by country. (**A** to **F**) UN projections of PSRs, equal to the number of people aged 20 to 64 divided by the number of people aged 65 or over (solid red lines), with 80% PI (dark shaded areas) and 95% PI (light shaded areas) shown. In all panels, the vertical dashed line denotes 2012.

for Nigeria, the most populous country in Africa (Fig. 2A). The UN's projection continues to forecast a decline, but the uncertainty bands are wide, indicating that the stall could continue for a considerable time. This continued high fertility would result in a projected increase in total population of more than fivefold by 2100, from the current 174 to 914 million (Fig. 2B). There is considerable uncertainty about this projection, but there is still a 90% probability that Nigeria's population in 2100 will exceed 532 million, a more-than-threefold increase.

We also indicate the likely level of population aging in different countries. One measure of this is the potential support ratio (PSR), which is equal to the number of people aged 20 to 64 divided by the number of people 65 and over (Fig. 3). This can be viewed very roughly as reflecting the number of workers per retiree. Currently, the country with the lowest PSR is Japan, with 2.6.

Germany's PSR is currently 2.9 and is projected to decline rapidly at first, to 1.7 in 2035 and then to 1.4 by the end of the century. Although there is uncertainty about the level at the end of the century, with an 80% prediction interval (PI) of 1.1 to 1.7, it is likely that the German PSR will be well below the current Japanese ratio. The current

PSR in the United States is 4.6, and this is projected to decline to 1.9 by 2100 (80% PI: 1.6 to 2.2).

Whereas the population aging issues of developed countries have been widely discussed (*23*), the likely patterns in developing populations that currently have young populations are less well known. China's PSR is projected to decline to 1.8 (80% PI: 1.4 to 2.3) from the current high level of 7.8. Brazil's PSR is currently 8.6 and is projected to decline to 1.5 (80% PI: 1.0 to 2.0), which is well below the current Japanese level. India has a PSR of 10.9, but this is projected to decline to 2.3 (80% PI: 1.5 to 3.2) by the end of the century. The only country in Fig. 3 that is projected to have a PSR above 3 by the end of the century is Nigeria, whose PSR is currently at the high level of 15.8 and is projected to decline to 5.4 (80% PI: 3.4 to 7.8).

These results suggest some important policy implications. Rapid population growth in high-fertility countries can create a range of challenges: environmental (depletion of natural resources, pollution), economic (unemployment, low wages, poverty), health (high maternal and child mortality), governmental (lagging investments in health, education, and infrastructure), and social (rising unrest and crime) (*24*).

Among the most robust empirical findings in the literature on fertility transitions are that higher rates of contraceptive use and female education are associated with faster fertility decline (*25*). These suggest that the projected rapid population growth could be moderated by greater investments in family planning programs to satisfy the unmet need for contraception (*26*, *27*), as well as investments in girls' education. It should be noted, however, that the UN projections are based on an implicit assumption of a continuation of existing policies and reform efforts, but an intensification of current investments would be required for faster changes to occur. It should also be noted that the projections do not take into account potential negative feedback from the environmental consequences of rapid population growth. The addition of several billion people in Africa could lead to severe resource shortages that, in turn, could affect population size through unexpected mortality, migration, or fertility effects.

The implications are not all negative, however. Rapid fertility decline brings with it the prospect of a potential long-lasting demographic dividend in countries that currently have high fertility, such as Nigeria (see Fig. 3). Figure 3 also suggests that developing countries with young populations but lower fertility (e.g., China, Brazil, and India) are likely to face the problems of aging societies before the end of the century. This prediction suggests that these countries need to invest some of the benefits from their demographic dividends in coming decades in provisions for future seniors, such as social security, pension, and senior health care funds.

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SUPPLEMENTARY MATERIALS

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References (*28*–*47*)

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ADULT NEUROGENESIS

A latent neurogenic program in astrocytes regulated by Notch signaling in the mouse

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Neurogenesis is restricted in the adult mammalian brain; most neurons are neither exchanged during normal life nor replaced in pathological situations. We report that stroke elicits a latent neurogenic program in striatal astrocytes in mice. Notch1 signaling is reduced in astrocytes after stroke, and attenuated Notch1 signaling is necessary for neurogenesis by striatal astrocytes. Blocking Notch signaling triggers astrocytes in the striatum and the medial cortex to enter a neurogenic program, even in the absence of stroke, resulting in 850 ± 210 (mean ± SEM) new neurons in a mouse striatum. Thus, under Notch signaling regulation, astrocytes in the adult mouse brain parenchyma carry a latent neurogenic program that may potentially be useful for neuronal replacement strategies.

Neurogenesis in the adult brain is largely restricted to the dentate gyrus and the subventricular zone lining the lateral ventricles. However, astrocytes close to a lesion can display neural stem cell properties when assayed in vitro (*1*–*3*), and astrocytes can be forced to either convert into (*4*, *5*) or produce neurons (*6*) when reprogrammed by ectopic expression of transcription factors in vivo.

To explore the in vivo neurogenic potential of astrocytes, we used Connexin-30–CreER (Cx30-CreER) transgenic mice (*7*) carrying a R26R–yellow

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