World Population Prospects – A Long View

Thomas Buettner*

Abstract – There is no need to justify interest in population dynamics. But there is a pertinent need for sufficient, detailed and consistent evidence. Today, there is ample information about demographic trends for countries small, exceptionally large, and in-between. This was not always the case. Since the late 1940s, the United Nations Population Division endeavored to collect (often sparse) evidence for an increasingly complete picture known as World Population Prospects. Its evolution, through 26 revisions, is the topic of this article. It starts with the historical context, followed by brief discussions of the demographic components of change: fertility, mortality and (net) migration. Based on a reconstruction of past trends (or estimates), the Populations Division projects the population of today 235 countries or areas; the world's population could reach between 9.4 to 12.7 billion people, with a median of 10.9 billion. The article closes with suggestions about further improvements.

JEL Classification: J1, J13, F22, I1
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*Board member German Fund for World Population, former Assistant Director United Nations Population Divisions (planetbuettner@gmail.com)
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Prologue

It was the worst of time. It was 1944, WWII still raged on and would continue for about another year. It was a time of measured hope, too. In August 1944 (19.8.1944), the French Resistance begins an uprising in Paris and by August 25, Paris is liberated. On September 3, French and American troops liberated Lyon,[1] *and the British liberated Brussels. The Red Army had reached Warsaw, the Pacific Theater saw heavy fighting in the battle of the Philippines.*

At this ominous time, the University of Chicago held the Twentieth Institute of the Norman Wait Harris Foundation (September 4-8, 1944), with the general theme "Food in International Relations." Frank Notestein, the director of the Office of Population Research at Princeton University, presented a paper entitled "Population – The Long View" that reviewed the global population trends of the past three centuries and laid out the contours of a conceptual framework for global population projections (Notestein, 1945). He identified the population growth of his time as transitional and distinguished three demographic types, or regimes, that represent different stages of that growth (incipient decline, transitional growth, and high growth potential). He also stated the demographic cause of the transitional growth – mortality decline followed by fertility decline later – and posited that (rapid) aging of populations is unavoidable. He concludes: "[…] it appears […] that sensible planning for the future should be based on the assumption that the world will have at least 3 billion people by the year 2000. […] Food production will have to increase much more rapidly than population, and equally swift developments must occur in the fields of industrial production, education, public health, and government. For it is only when rising levels of living, improved health, increasing education, and rising hope for the future give new value and dignity to the individual life that old customs break, and fertility comes under control. […] In the long run it remains true that the control of mortality without the control of fertility is impossible." (Notestein, 1945, p. 57). His "short" summary (just 21 pages!) provided a lasting foundation for social analysis beyond demography. Notestein's attempt in that article to estimate the world population in 2000, however, failed spectacularly. The world population in 2000 was not 3, but 6 billion.

On 24 October 1945, the United Nations was established. Less than a year later, its Economic and Social Council, on 3 October 1946, created the Population Commission[2] *to afford "advice and assistance on matters affecting or affected by population change". At the same time, the Population Division as the Commissions Secretariat was created, with Frank Notestein its first Director.*

The need for population projections was realized early. The second session of the Population Commission considered the need for population estimates and forecasts and decided to set priorities: "Noting that the requirements for such estimates and forecasts were extremely large, the Commission (E/571) adopted a scheme of priorities designed to make available as soon as possible the estimates and forecasts which were most essential for the work of the various organs of the United Nations. The Commission considered that the first object should be to compile current estimates of the total population, as of a uniform, recent date, for all countries of the world. Other data which it recommended should have a high priority were estimates of population by sex and age groups for recent dates, forecasts of total population and sex and age groups for dates in the near future (1948, 1949 and 1950), and longer-range forecasts." (Population Commission, 1947, p. 20; United Nations, 1948, p. 640).

The notion of world population is not an invention of the 20th century. But it was the 20th century that began to measure it in earnest and in detail, its historic evolution first (Biraben, 1979, 2006; Durand, 1974). From the scattered empirical records of historical population growth emerged evidence that human populations by no means were destined to grow in an exponential fashion (the geometric growth envisioned by Malthus). But then, what would the future hold? Some theoretical propositions came from a synthesis of the empirical past in some countries, called the demographic revolution (Landry, 1934) or, later, the demographic transition (Davis, 1945; Notestein, 1945). It formulated a concept of a universal process from high to low levels of fertility and mortality. It has guided the demographers at the Population Division well, most of the time.

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1. Leon Tabah, the fifth director of the United Nations Population Division (from 1972 to 1984), took part in the liberation of Lyon and was awarded the Médaille de la Résistance.

2. Renamed, in 1994, the Commission on Population and Development pursuant to A/RES/49/128, para. 24, of 19 December 1994.

The World Population Prospects (WPP) have been work in progress from its beginning. As new demographic and other related data became available, as methodological improvements were developed, and as computational tools became more powerful, existing estimates and projections were revised, updated, and expanded, and revised again. Formats and titles of the outputs also changed, as did geographic coverage, demographic detail, and projection horizons. In many respects, comparing current revision of WPP with earlier ones is meeting considerable challenges. One of the most significant changes are geographic and political settings. Countries were gaining independences, changed their names, some countries split, notably the Soviet Union into 15 successor states, others united or re-united.

The evolution of the estimates and projections over time – now at its 26 iteration or revision – is a testament to the commitment of the international community and the dedication of the staff of the Population Division to its original mandate dating back to the 1940s.

In its current form, the WPP is an impressive account of demographic change for all 235 countries[3] of the world for the past 70 years, from 1950 through 2020.[4] This account is not just a collection of relevant demographic indicators: it has evolved into a complete and internally consistent reconstruction of the world's demographic history. It contains demographic detail that must have seem impossible for the demographers that started the project. The more visible part of the project – the population projections – are now available up to the end of the century with equal detail. Recently, projections results are produced with prediction intervals, plus certain illustrative scenarios.

This paper is a brief review of the history of efforts, approaches, failures, and successes of the United Nations WPP. The evolution of projection methodology will here not receive the deserved attention due to space limitations.[5] Population projections are here primarily understood as a powerful instrument of analyzing and understanding current conditions (Keyfitz, 1972), including our current understanding of future trends in fertility, mortality and migration.[6] The reference to the current conditions and understanding necessarily imply that these projections are an ongoing process. Here, we take the 2019 Revision as the reference, assuming it provides the best summary of past demographic trends (1950-2020), and projections (2020-2100). Future revisions of WPP will certainly introduce more changes, both for past estimates and for the projections: WPP will continue be work in progress.

The story of the United Nations population projections[7] did not begin with projecting the future, but with the past. In 1949, the study *World Population Trends 1920-1947* was published, presenting "[…] estimates of population, birth and death rates, life expectancy and age structure of the population, for the world and its principal regions" (United Nations, 1949, p. iii).

When the demographers at the United Nations Population Division published their first projections for the world in 1951 (United Nations, 1951), they based it on partial times series up to 1950, defining that year as the base year. [8] From that time on, the year 1950 marked the start of WPP. Successive revisions kept the year 1950 as the beginning of the exercise but moved the base year forward to the calendar year (that was divisible by five) nearest to the year the revision was completed (see Online Appendix C2). When new data from censuses, vital statistics, surveys, and other sources became available, the projected population for the new base year from the previous revision had to be updated. Obviously, new and updated base year population estimates would impact the outcomes of the projection exercises. But updating the base population estimates did also have an impact on the past: if the demographic accounting identity was to be maintained for the whole projection exercise, past population estimates, and the associated demographic variables, had to be revised, too. In other words: not only future populations were a moving target, but past estimates, too.

The rich history of the WPP may be presented in many ways. The usual presentation is often focused on the population – its size, composition, and geographical distribution. The driving forces of demographic change – fertility, mortality, and migration – are often less prominently addressed. Here, they are presented first. Then we look at population estimates in Section 2.

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3. As is the usual practice of WPP, the term "country" as used in this text also refers, as appropriate, to territories or areas. A more detailed classification is listed in Online Appendix C1 to this article. Link to the Online Appendices at the end of the article.

4. The latest revision of the United Nations' World Population Prospects, released in 2019, chose the year 2020 as the base year of its projections. The data for the year 2020 is, of course, projections, based on data available through 2019.

5. Online Appendix C2 lists some of the changes to the projection methodology. For the latest version, see United Nations (2019a, 2019b).

6. Caswell stated: "Population projections reveal something about present conditions […], not about the future behavior of the population" (Caswell, 2001, p. 30).

7. For more detailed account of the history of the past 26 revisions of the WPP see Online Appendix C2.

8. Sometimes called jump-off year or launch year.

1. The Evolution of Estimates and Projections: Components

1.1. Fertility

The past 70 year have seen sustained, sometimes dramatic, reductions in fertility. On average, the number of children per woman fell from 5.0 to 2.5 children for the world between 1950 and 2020, or about 0.2 children per woman per quinquennium. Such an average does not show the vast differences between countries, regions, and subregions during that period. A comparison of regions (Table 1, Figure I) shows an onset of fertility decline later than 1950, or even a temporary increase (Northern America, Oceania). It was not before the decade of the 1960s that sustained decline of fertility in most of these large aggregates was manifesting itself. Africa, with the highest average fertility in 1950-1955 of 6.6 children per woman, entered the fertility transition, on average, not before the decade of the 1970s. In 2015-2020 (base period), Africa has still the highest total fertility of 4.4 children. All other regions have transitioned to low fertility around or even well below the replacement level (Asia, Europe, Latin America, Northern America).

Average fertility levels for large aggregates or the world mask the existing great variations for the 235 countries. Currently, that is 2015-2020, fertility ranges from 7.0 children per woman (Niger) to 1.1 children per woman (Republic of Korea).

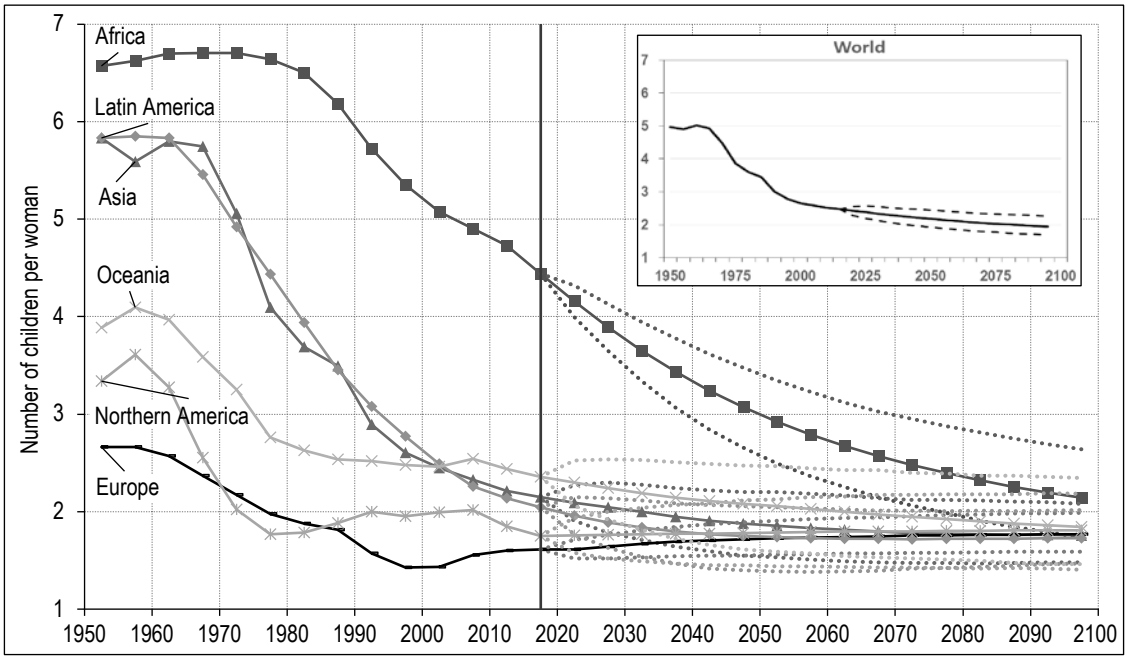
Remarkably, close to half (49%) of humankind lives already in countries with fertility at or below the replacement level of 2.1 children per woman (Table 2). Intermediate fertility, that is fertility between 2.1 and 5 children per woman, is estimated for another 46% of the world's

Table 1 – **Total fertility estimates and projections by regions, 1950-2100**

	Number of children per woman						Change (%)	
	1950-1955	1975-1980	1995-2000	2015-2020	2045-2050	2095-2100	1950-2020	2015-2100
World	5.0	3.9	2.8	2.5	2.2	1.9	-50	-22
Africa	6.6	6.6	5.4	4.4	3.1	2.1	-32	-52
Asia	5.8	4.1	2.6	2.2	1.9	1.8	-63	-18
Europe	2.7	2.0	1.4	1.6	1.7	1.8	-40	+10
Latin America	5.8	4.4	2.8	2.0	1.8	1.7	-65	-15
Northern America	3.3	1.8	2.0	1.8	1.8	1.8	-47	+3
Oceania	3.9	2.8	2.5	2.4	2.1	1.8	-39	-22

Sources: WPP 2019.

Figure I – **Total fertility estimates and projections by regions, 1950-2100**



Notes: Solid lines for the median of the prediction interval, dotted lines for the 95% prediction interval (upper, lower).
Sources: WPP 2019.

Table 2 – **Number of countries by fertility level and their share of world population, 1950-2020**

Births per woman	Number of countries			% of world population		
	1950-1955	1980-1985	2015-2020	1950	1980	2015
Below replacement (less than 2.1)	6	50	115	0.4	22.8	52.1
Intermediate (2.1 to 5)	68	94	109	34.1	60.1	43.0
High (more than 5)	161	91	11	65.5	17.1	4.9
Total	235	235	235	100	100	100

Sources: WPP 2019, author's calculations.

population. High fertility of 5 and more children is estimated to occur in about 5% of the world's population, that is in 11 countries. All these countries with high fertility level are found in Africa. The largest such countries are Nigeria, the Democratic Republic of Congo, the United Republic of Tanzania, and Uganda.

The assumptions regarding future fertility trends have the largest impact of population trends. Compared with mortality and migration, fertility is the main driver of population change and has been a major focus of policy interventions. It is also one of the items for which data from "statistically underdeveloped areas" have become available relatively soon and regularly.[9]

A detailed analysis of past fertility assumptions and their adjustments in subsequent revisions is outside the scope of this article (but would be interesting). Some demographers have criticized the United Nations for assuming for a long time an ultimate convergence of fertility to replacement fertility (2.1 children model) for low fertility countries. While the initial transition theory at least provided guidance about the direction of fertility to lower levels, the post transition situation does not profit from such guiding idea. The situation regarding the post-transition fertility is similar (but not equal) to the first demographic transition: the onset of fertility decline is the most uncertain factor in the first, and the level of completed fertility is the most uncertain in the second, if such level then exists. Once fertility decline started, the first demographic transition pointed to the direction of declining fertility and thus informed population projections relatively reliably. The second demographic transition, once (very) low fertility is reached, does not make strong arguments for an ultimate level of fertility, if any.

Vallin & Caselli noted that global population projections would become less reliable as most countries passed through the demographic transition: "In an era in which the great historical change, called the demographic transition, is coming to an end, the paradigm of the same name is of no assistance in predicting what will follow." (Vallin & Caselli, 2006, p. 231).

The introduction of a Bayesian hierarchical model to predict fertility levels based on past trends is an attempt to handle, inter alia, this conceptual uncertainty. It introduces an ultimate (low) fertility level that is no longer uniform at replacement level, but may be much lower, at different levels and arrived at in different times in the future. Once that stage is reached, fertility stays constant. But even this assumption of decrements that are approaching zero is accompanied by model-generated uncertainty bounds, or prediction intervals.

The 2019 Revision assumed a continued but varied fertility transition for countries with above replacement fertility (see Table 1). In terms of the aggregate level of regions, Africa, Asia, Latin America, and Oceania are expected to experience a long-term fertility reduction until 2100 (medium variant). Europe and Northern America could see a slight recovery of their low fertility level in the long run. By the end of the projection horizon all regions could be at or even below replacement level fertility.

At the end of the projection horizon in 2100 the number of countries with fertility levels above replacement levels is projected to shrink from 124 in 2015-2020 to only 21 at the end of the projection horizon in 2095-2100 (Table 3). All the remaining 21 countries would have rather moderate fertility levels, none higher than 2.5 children per woman.

1.2. Mortality

During the past 70 years the countries of the world and its regions have experienced a remarkable success in reducing mortality, by eliminating or controlling certain infectious diseases, stabilizing, and improving health care and improving overall

9. Starting in 1984, the Demographic and Health Surveys (DHS) have become an indispensable source of demographic information with more than 300 surveys in more than 90 developing countries. Methodologically similar and equally important, the Multiple Indicator Cluster Surveys (MICS), implemented by UNICEF, has collected a multitude of demographic and other data in 358 surveys in 118 countries.

Table 3 – **Number of countries by fertility level and their share of world population, 2015-2100**

Births per woman	Number of countries			% of world population		
	2015-2020	2045-2050	2095-2100	2015	2045	2095
Below replacement (less than 2.1)	121	164	214	52.1	71.1	79.5
Intermediate (2.1 to 5)	106	71	21	43.0	28.9	20.5
High (more than 5)	8	0	0	4.9	0.0	0.0
Total	235	235	235	100	100	100

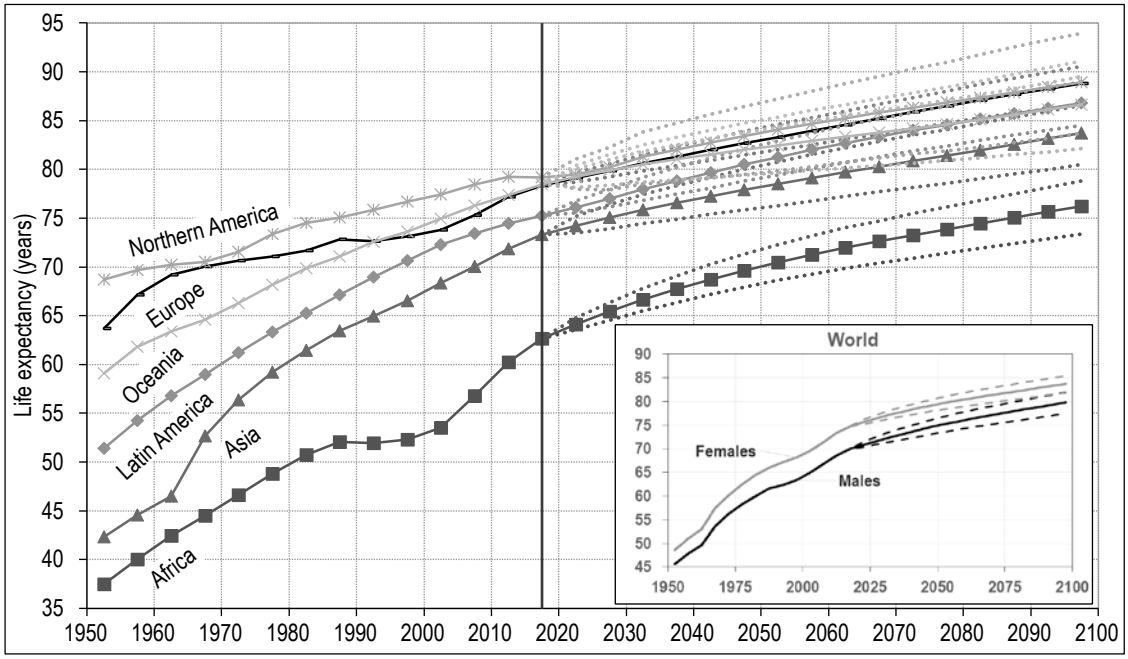
Sources: WPP 2019, author's calculations.

living conditions. This progress was not steady or without backslashes, but it happened. The 2019 Revision documents this transition to lower mortality (Figure II). Mortality declined for all countries and for almost all quinquennial periods for both males and females. There were some temporal exceptions to this global trend, caused, for some countries, by natural disasters, famine, civil strife, regional military conflicts and, notably, the HIV/AIDS pandemic. For the large aggregates of regions such temporary trend reversals are barely visible, except for Africa and Europe.[10]

Between 1950 and 2020, life expectancy for the world increased, on average and for both sexes combined, by about 25 years (Table 4).

10. The stall in life expectancy in Europe between 1985 and 2000 is mainly driven by increasing mortality in many successor states of the former Soviet Union as well as former Yugoslavia.

Figure II – **Life expectancy estimates for both sexes combined by regions, 1950-2100**



Notes: Solid lines for the median of the prediction interval, dotted lines for the 95% prediction interval (upper, lower).
Sources: WPP 2019.

Table 4 – **Life expectancy for both sexes combined by regions, 1950-2100**

	Life expectancy at birth (years)						Change (years)	
	1950-1955	1975-1980	1995-2000	2015-2020	2045-2050	2095-2100	1950-2020	2015-2100
World	47.0	60.3	65.6	72.3	76.8	81.7	25.3	9.4
Africa	37.5	48.8	52.3	62.7	69.6	76.2	25.2	13.6
Asia	42.3	59.2	66.6	73.3	77.9	83.7	31.0	10.5
Europe	63.7	71.1	73.1	78.3	82.7	88.8	14.6	10.5
Latin America	51.4	63.3	70.7	75.2	80.5	86.8	23.8	11.6
Northern America	68.7	73.3	76.7	79.2	83.4	88.9	10.4	9.8
Oceania	59.1	68.2	73.6	78.4	82.0	86.6	19.3	8.2

Sources: WPP 2019.

The largest absolute increase was observed for Asia, with 31 years over 70 years, followed by Africa gaining 25.2 years of lifetime per person on average. The smallest increase between 1950 and 2020 was estimated for Northern America (10.4 years), which had the highest level of life expectancy in 1950-1955. Most regions retained their relative position (except for a relatively minor crossover between Europe and Oceania). Clearly visible is also the levelling-off of life expectancy in Africa between 1985 and 2000, caused mostly by the HIV/AIDS epidemic (see below).

All countries participated in that impressive reduction in mortality, but at quite different times and with different paces. The number of countries with exceedingly high mortality (and corresponding low life expectancy) of less than 45 years dropped from 80 in 1950-1955 to just 10 thirty years later in 1980-1985, and by 2015-2020, no country was found at this level. At the same time, the number of countries with life expectancy above 75 years, increased to 133 in 2015-2020, while in 1950-1955, not one country was in that category (Table 5).

The remarkable reduction in overall mortality was caused to a large part by a dramatic decline in infant and child mortality. In 1950-1955, about one out of five newborn children did not reach its 5th birthday. Even in Europe, the under-five mortality rate was about one out of 10. In Africa and Asia, child mortality was exceedingly high: More than one in three children in Africa did not experience their 5th birthday; in Asia it was about one in four. That changed dramatically over the course of the 70 years that followed. Africa's under-five mortality rate was, in 2015-2020, where Europe stood during 1950-1955, Asia's under-five mortality rate resembles today that of Northern America in 1950-1955 (Table 6). The trend of significant reductions in child mortality is expected to continue over the projection horizon to very low levels. All estimated mortality data document a transition, still underway in many parts of the world, from early to late deaths. If low levels of child mortality subsist, early mortality has no major impact on the projections, except for Africa.

Progress is not destiny. One example of an unexpected severe reversal of mortality trends was the HIV/AIDS pandemic. Modeling the mortality impact of the HIV/AIDS epidemic started with the 1992 Revision and turned out to be a tremendous challenge. Limited empirical evidence had to be transformed into indicators of the epidemic (prevalence, incidence estimates) and further into age-specific mortality schedules for the affected populations. A competing risk model combined the mortality of the infected and the not infected population into a general dynamic mortality pattern. An example of the substantial uncertainty of the measurements

Table 5 – **Number of countries by mortality level and their share of world population, 1950-2020**

Life expectancy at birth, both sexes combined	Number of countries			% of world population		
	1950-1955	1980-1985	2015-2020	1950	1980	2015
<45	82	11	0	57	2	0
45-55	48	40	5	8	26	3
55-65	72	50	35	17	15	9
65-75	33	119	81	18	52	42
75+	0	15	114	0	5	46
Total	235	235	235	100	100	100

Sources: WPP 2019.

Table 6 – **Under-five mortality by regions, 1950-2100**

	Under-five mortality (deaths under age five per 1,000 live births)					
	1950-1955	1975-1980	1995-2000	2015-2020	2045-2050	2095-2100
World	213	124	82	40	22	12
Africa	311	200	151	71	36	18
Asia	234	127	73	31	15	6
Europe	93	26	12	5	2	1
Latin America	187	92	38	19	9	4
Northern America	36	17	9	7	4	2
Oceania	94	49	34	23	12	5

Sources: WPP 2019.

and models is seen in the comparison of life expectancy trends for Zimbabwe from the 1992[11] to the 2019 Revision of WPP (Figure III).

There was initially a clear underestimation, followed by an overestimation of the epidemic's mortality impact. Comparing the largest impact on life expectancy for Zimbabwe across several revisions, the 1992 Revision projected a life expectancy of 57.3 years, while the 2002 Revision came out with extreme low 33.1 years. The 2019 Revision, which relied on a much better empirical basis and revised epidemiological models, estimated life expectancy for 2000-2005 at 43.7 years for both sexes combined. The large variability of life expectancy estimates and projections, which has affected other countries with a significant burden of the epidemic as well, is clearly due to extremely limited empirical evidence initially about the dynamics of HIV/AIDS incidence and prevalence. All revisions, though, assumed and expected the Epidemic to be a temporary phenomenon, which is manifested by the ultimate rise of life expectancy for all revisions since 1992. This was in the beginning a matter of (institutional) optimism but was later confirmed after increasingly effective drugs became available, plus better testing und information.

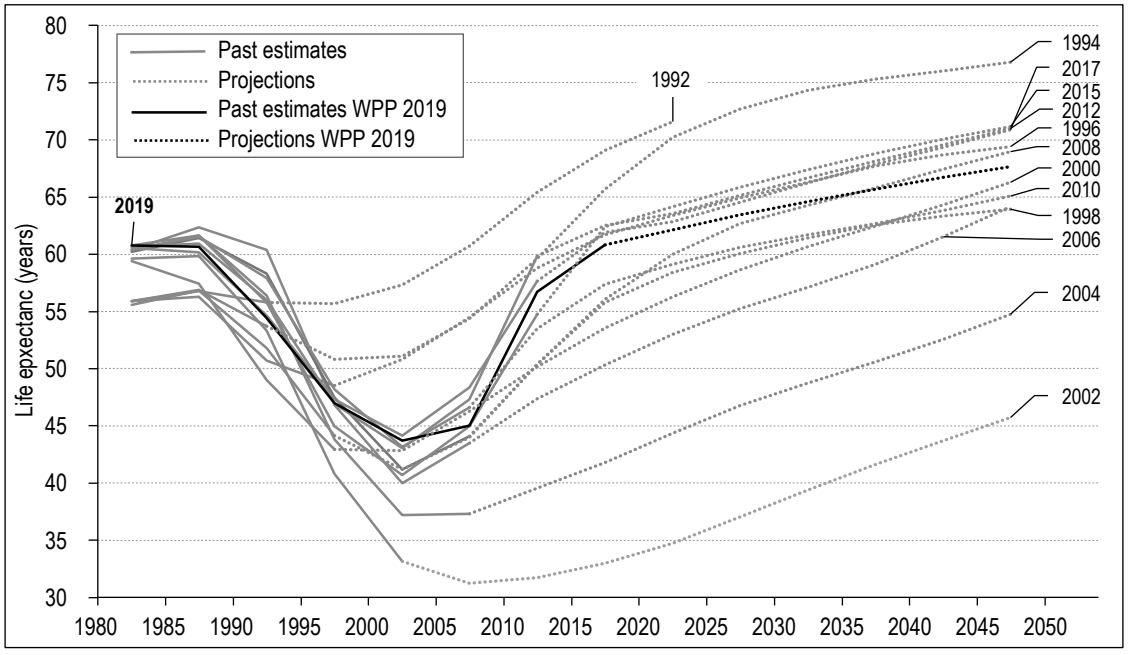
Note that the experience of WPP modeling HIV/AIDS shows that emerging issues require a patient and repeated revisiting the issue. One-time estimates are often of limited validity. In this respect, the Population Division is well prepared to the continuous observation, estimation, and evaluation of such phenomena[12] thanks to its institutional stability.

Is the transition to lower mortality expected to continue, and to which levels? The demographers at the UN provide tentative answers in their projections. Assuming, as usual, due progress in the future (here: progress against mortality), life expectancy for both sexes is projected to rise for the world as a whole (Figure II, Table 7): by 2095-2100, no country would have less than 65 years of life expectancy, and a majority of 211 countries even more than 75 years.

Global mortality projections for all countries of the world would not have been possible without models of mortality change and age patterns of mortality, predominantly based on historical data from developed countries. This reliance on models for many countries was and still is necessitated by a dramatic gap in registering mortality events, especially adult mortality, in developing countries. In 2007, a series of WHO analyses found almost no progress between 1970 and 2004 in covering adult mortality, especially in developing countries (AbouZahr *et al.*, 2007, 2015; Mikkelsen *et al.*, 2015; Setel *et al.*, 2007).

11. The United Nations Population Division incorporated the impact of HIV/AIDS since the 1992 Revision, using information from WHO's Global Programme on AIDS, and subsequently from the Joint United Nations Programme on HIV and AIDS (UNAIDS), which was formed in July 1994.
12. This is, of course, also true for UNAIDS providing continuous awareness of the HIV/AIDS pandemic.

Figure III – **Life expectancy estimates and projections for Zimbabwe since 1980 by revision**



Sources: WPP 1992 through 2019.

Table 7 – **Number of countries by mortality level and their share of world population, 2015-2100**

Life expectancy at birth, both sexes combined	Number of countries			% of world population		
	2015-2020	2045-2050	2095-2100	2015	2045	2095
<45	0	0	0	0	0	0
45-55	5	0	0	3	0	0
55-65	35	9	0	9	5	0
65-75	81	59	24	42	41	17
75+	114	167	211	46	53	83
Total	235	235	235	100	100	100

Sources: WPP 2019.

The empirical evidence of mortality trends has somewhat improved in most developing countries, mostly by sample surveys, not civil registration. Much efforts have been spent to distill the best estimates from the various sources available, but the evidence base remains shaky. It is therefore a great improvement that life expectancy projections are now showing ranges of uncertainty. This is even more remarkable as all revisions before the 2012 employed only one central variant.

For the projection period, the 2019 Revision assumes a steady increase in life expectancy, but at a decelerating pace (see Table 4). In 2095-2100, life expectancy for the world would reach about 82 years, an increase by more than 9 years. The largest increase is projected for the region with the highest mortality levels at the base period of 2015-2020: Africa's average life expectancy is expected to increase by almost 14 years, from 62.7 to 76.2 years. Regions with lower mortality in the base period are projected to gain smaller amount but retain their leading positions.

1.3. International Migration

International migration is the most challenging element in demographic accounting. Even countries with a well-developed statistical system often do not register international migration sufficiently, consistently, and reliably. Reasons for this are many. A prominent one is that countries rely on different definitions and procedures for what constitutes a migration event and who is to be registered as migrant. Therefore, statistics on international migration are often internationally not compatible. International migration is, therefore, often reduced to a residual measure. Yet, international migration as a flow of people involves at least two countries. International trade, e.g. flows of goods, is better documented than the movement of people.

Due to the lack of sufficiently complete and reliable migration flow data, WPP used net migration estimates and projections. Net migration is a complicated thing, as there is no real living "net migrant". It is better understood as a residual measure necessary to "close" the balance identity of demography, which is always also in danger of attracting the measurement errors of censuses, or births and deaths registration. In contrast, international migration flows, unlike net migration, are affecting both origin and destination countries. Thus, net migration is void of a critical aspect of international migration – the origin-destination link. Hence, it is spatially ignorant and relevant only for the country concerned.[13] It is also prone to exhibit unusual or inconceivable age patterns.

For the past, WPP show consistent and sustained geographical divisions regarding net migration of regions gaining and those region loosing people through migration. Since 1950, Europe has gained about 43 million people by 2020, Northern America 64 million people, and Oceania about almost 8 million people. At the same time, Africa lost 28 million people, Asia 44 million people, and Latin America about 43 million people (Table 8). These overall figures are significant, but not dramatic. After all, migration (net migration) is but a small component of population changes at the aggregate level. For individual countries and certain time periods, migration may play a considerable and critical role, however.

13. Because net migration is spatially ignorant, it does not balance automatically at the world level. Even if major migration flows were taken into consideration when estimating net migration estimates, a separate step of balancing the migration component is necessary to sum the migration component to zero for the world.

Table 8 – **Net migration estimates by regions, 1950-2020**

	Net migration (million)			
	1950-1980	1980-2000	2000-2020	1950-2020
World	0.0	0.0	0.0	0.0
Africa	-7.2	-7.7	-12.8	-27.7
Asia	+1.2	-12.4	-32.9	-44.1
Europe	-0.9	+12.1	+31.5	+42.7
Latin America	-11.6	-16.4	-14.6	-42.6
Northern America	+16.1	+22.8	+25.3	+64.2
Oceania	+2.4	+1.6	+3.4	+7.5

Sources: WPP 2019.

Expressing net migration intensity as Crude Net Migration Rate, that is the amount of net migration per 1,000 population,[14] reveals its relative small impact on demographic dynamics (Table 9).

For geographic regions, the net migration rate has been highest for those gaining population through net migration (net immigration) – Northern America and Oceania, followed by Europe. In comparison, the negative net migration rates – indicating population loss – are much smaller – below 1 per one thousand population.

Nevertheless, international migration is becoming increasingly important for population dynamics, especially in settings of low or very low fertility and the ensuing population ageing and eventually even population decline. In addition, international migration is also a factor of eminent political importance.

What are the prospects of future migration trends according to the WPP? Not surprisingly, assumptions for future migration are still starkly reflecting the lack of data, theories, even clear trends. Consequently, migration assumptions have been therefore quite simple.

The 2019 Revision has changed the assumption from a diminishing long-term trend to assuming a constant amount of net migration throughout most of the projection period. Figure IV shows the aggregate levels and Figure V the rates of net migration for the six geographic regions of the world. The picture is one of stasis, without temporal variations. The gain through net migration (Table 10) is largest for North America (105 million) and for Europe (64 million), while

14. The net migration rate is the average per quinquennium.

Table 9 – **Net migration rate estimates by regions, 1950-2020**

	Net migration per 1,000 population			
	1950-1955	1975-1980	1995-2000	2015-2020
World	0.00	0.00	0.00	0.00
Africa	-0.51	-0.72	-0.65	-0.37
Asia	0.14	-0.10	-0.33	-0.38
Europe	-0.62	0.59	0.87	1.83
Latin America	-0.52	-2.06	-1.86	-0.82
Northern America	1.58	3.38	6.35	3.30
Oceania	6.13	0.82	2.03	3.79

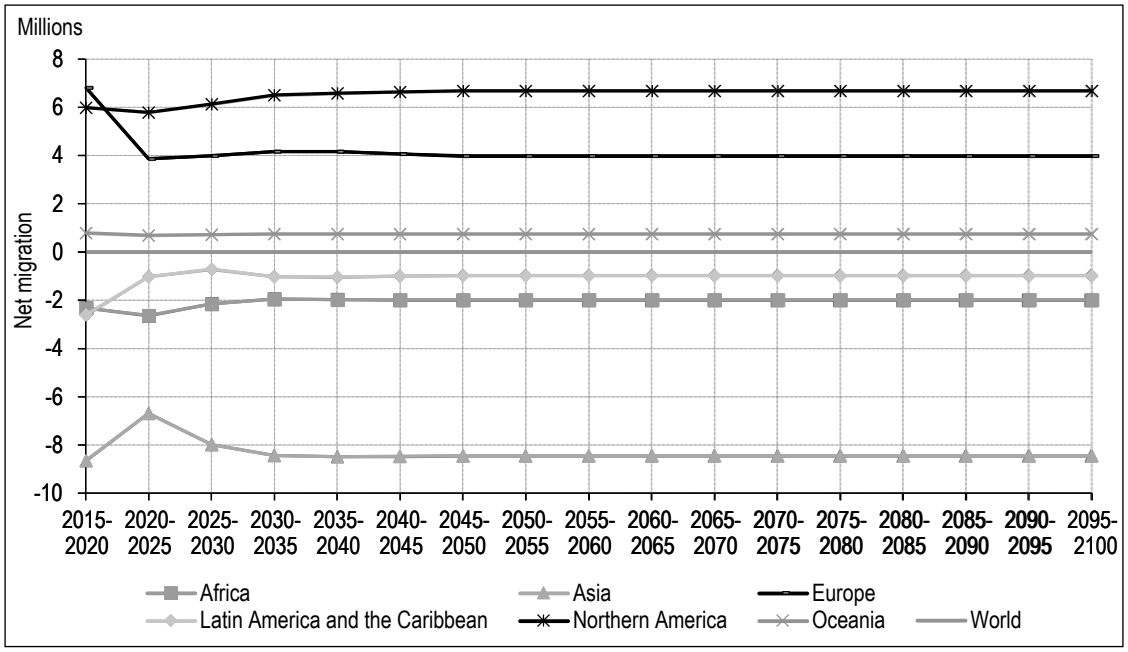
Sources: WPP 2019.

Table 10 – **Net migration projections by regions, 2020-2100**

	Net migration (million)		
	2020-2050	2050-2100	2020-2100
World	0.0	0.0	0.0
Africa	-12.7	-19.8	-32.5
Asia	-48.5	-84.4	-132.9
Europe	24.2	39.8	64.0
Latin America	-5.8	-9.8	-15.6
Northern America	38.3	66.7	105.0
Oceania	4.4	7.5	11.9

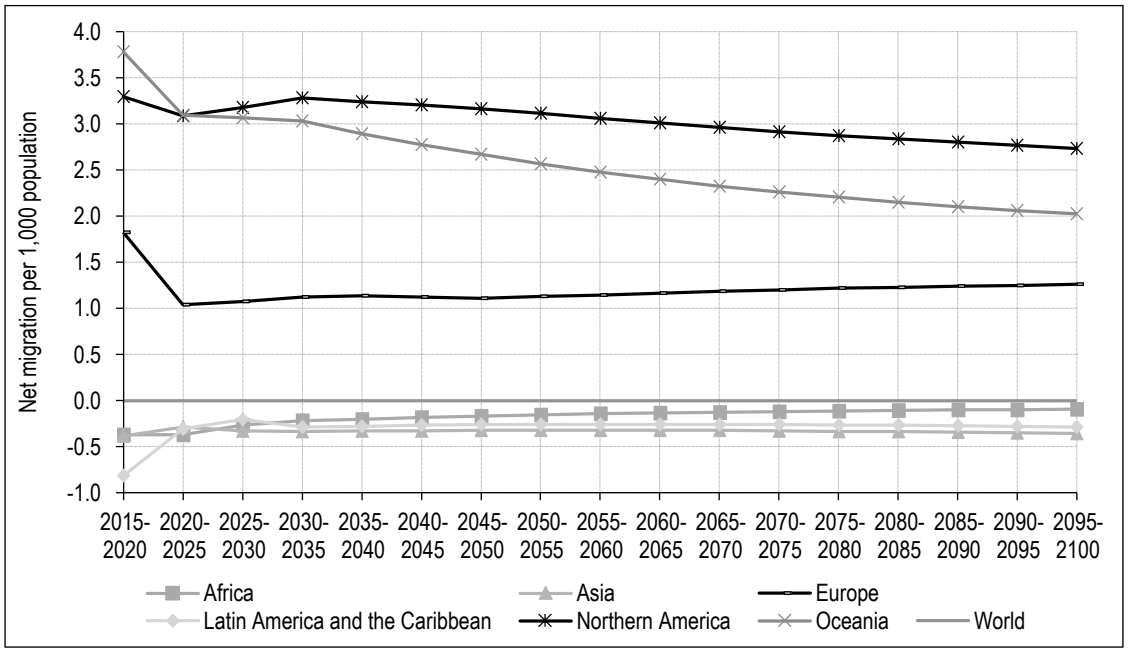
Sources: WPP 2019.

Figure IV – **Net migration projections by regions, 2015-2100**



Sources: WPP 2019.

Figure V – **Net migration rates by regions, 2015-2100**



Sources: WPP 2019.

Asia is the region with the highest loss through net migration (133 million).

In relative terms, e.g. as net migration per 1,000 population, the figures show changes caused by population dynamics: increasing intensities for declining populations and decreasing intensities for growing populations.

2. Population

Here it all comes together. Combining the assumptions about future fertility, mortality, migration, and the base population by using the cohort-component projection method[15] produces a consistent and detailed picture of the demographic future for each country.[16] Because the migration component operating as net migration is spatially ignorant, consistency at the aggregate level is not automatic. Therefore, after all countries of the world are projected, a second step of consolidation is often required to ensure a migration balance of zero for the world.[17]

Over the course of the 26 revisions of WPP, past population estimates were always an integral part of it, but in different levels of completeness, detail, and consistency. For many past revisions, past estimates were somewhat restricted to a reduced set of indicators: populations by age and sex at quinquennial dates and select indicators for the demographic components of change for quinquennial periods. Internal consistency was not ensured, only a full treatment with a cohort-component approach would do that. Step-by-step, the demographers moved the base year of the estimates and projections back to 1950 for ensuring consistency between the components of change and the population figures even for each age group and by sex. By the 2012 Revision, that process was finished, producing a full account of past demographic trends. The difference between past estimates and projections is now only that the former has only one variant, while the latter has several. It has been noted that the process of establishing the past and producing the best estimates of the base populations may well be the most laborious and time-consuming part of the whole exercise.[18]

The rich history of past population estimates between 1950 and 2020 is beyond the scope of the paper. Instead, we focus on the slow iteration of past world population figures to the most recent ones by past revisions. We calculated the relative difference between estimates and projections for certain calendar years – 1950, 1980,

15. The WPP have used the cohort-component method for most of its revisions but used simpler methods before the 1963 Revision. For a more detailed account of methods and assumptions see Timeline in Online Appendix C2.

16. Recall that technically the projections start in 1950, not 2020. In other words, projections are used for the demographic reconstruction of the past 1950-2020 and called past estimates, and the term projection is retained for the «true» projection period, here from 2020-2100 (characterized by different projection variants and, in some cased with prediction intervals).

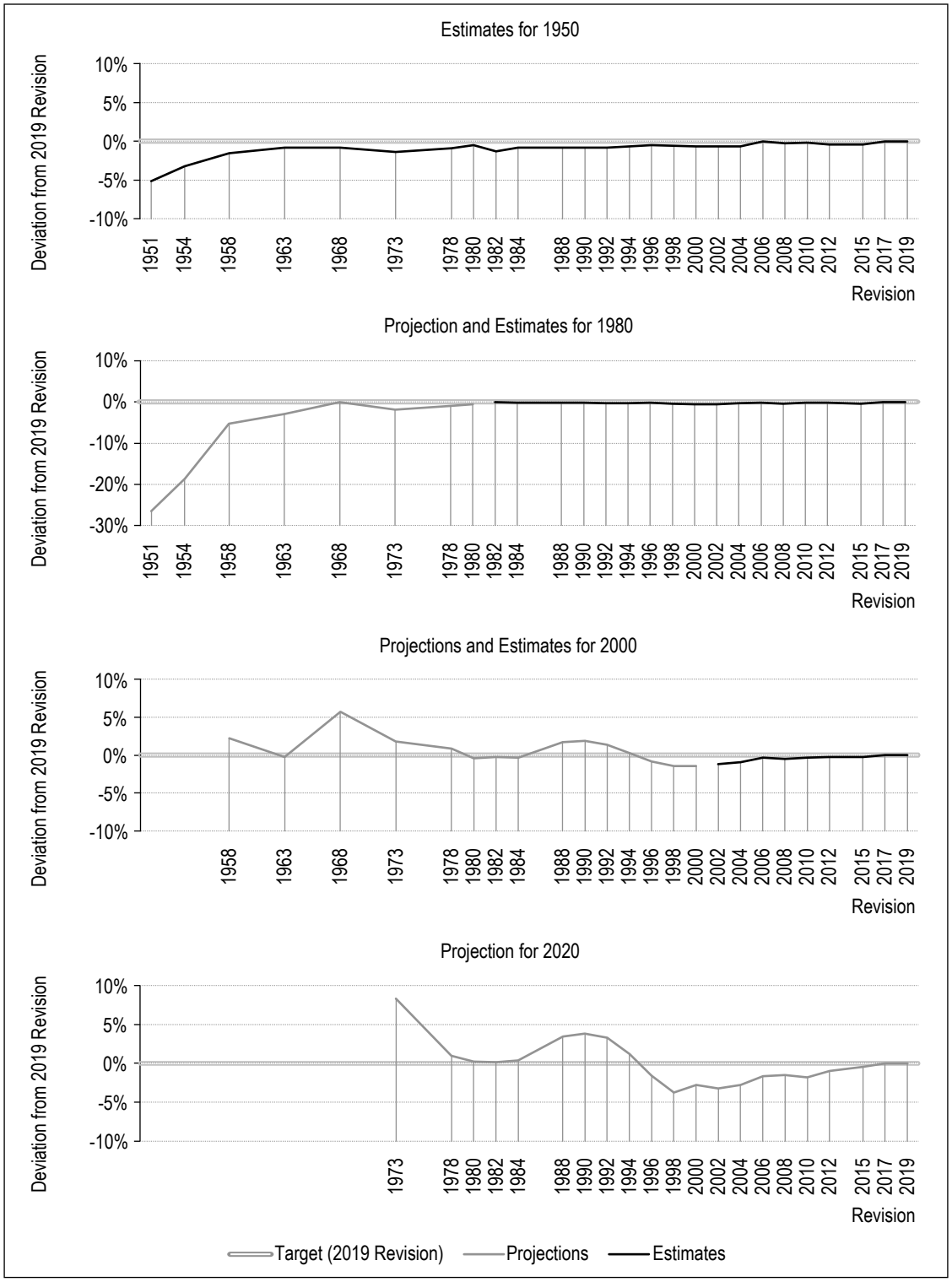
17. This necessity reflects, in part, the established usual workflow at the Population Division – countries are assigned to individual demographers in a first step, and then aggregated in a second step.

18. It is fair to assume that between 50 and 80% of the work invested in each revision is devoted to analyze, establish and revise past estimates, including the current projection's base population.

2000 and 2020 – for all past revisions and the figures published with the 2019 Revision.

For instance, the 1951 Revision estimated a population of 2.406 billion people for the year 1950, while the latest estimate for the year 1950 according to the 2019 Revision is 2.536 billion. This amounts to a 5.1% underestimation of the initial estimate compared to the current estimate. Ex-post adjustments for some countries were significantly larger (but not shown). The relative adjustments for the world population for the calendar years 1950, 1980, 2000 and 2015 are shown in Figure VI. For calendar year 1950, all

Figure VI – **Hitting the target: World population at 1950, 1980, 2000, and 2020, by revisions**



Sources: WPP, several revisions.

data are (revised) past estimates by all revisions, while for the chart showing the data for the year 2020, all data point are projections from past revisions (including the 2019 Revision). For the years 1980 and 2000, the data are either projections (for revisions prepared before that year) or estimates (for revisions prepared after that year).

It is interesting to note that all revision initially underpredicted the calendar years 1950 and 1980 before closing in on the reference numbers of the 2019 Revision. The history of approaching the 2019's reference number for the calendar years 2000 and 2020 are showing less variations but include positive and negative deviations.

Past WPPs incurred much larger errors for individual countries through missing, incorrect, or manipulated population statistics. Two examples are Bhutan, a medium sized country, and the populous African country Nigeria; both had to be corrected significantly in the past revisions (Figure VII).

Bhutan's population was completely revised in the 2006 Revision, reducing its population size dramatically. The story goes back to the beginning of the 1970s, when Bhutan joined the UN and reported a population of about 1 million inhabitants, based on a 1969 census. Because of the lack of follow-up censuses, the initial figure of about 1 million was backward projected to 1950 and forward projected assuming reasonable growth rates. It was not before the preparation of the 2006 Revision that new information from the 2005 Census became available that suggested a gross overestimation of Bhutan's past population. The initial figure of 1 million in 1970 (according to the 1973 Revision) was corrected to 297 thousand inhabitants in 1970, to less than one third. This affected the base population of the subsequent revisions; for the 2019 Revision, the figures for 2020 changed from about 2.1 million prior to the 2006 Revision to almost a quarter or 591 thousand inhabitants.

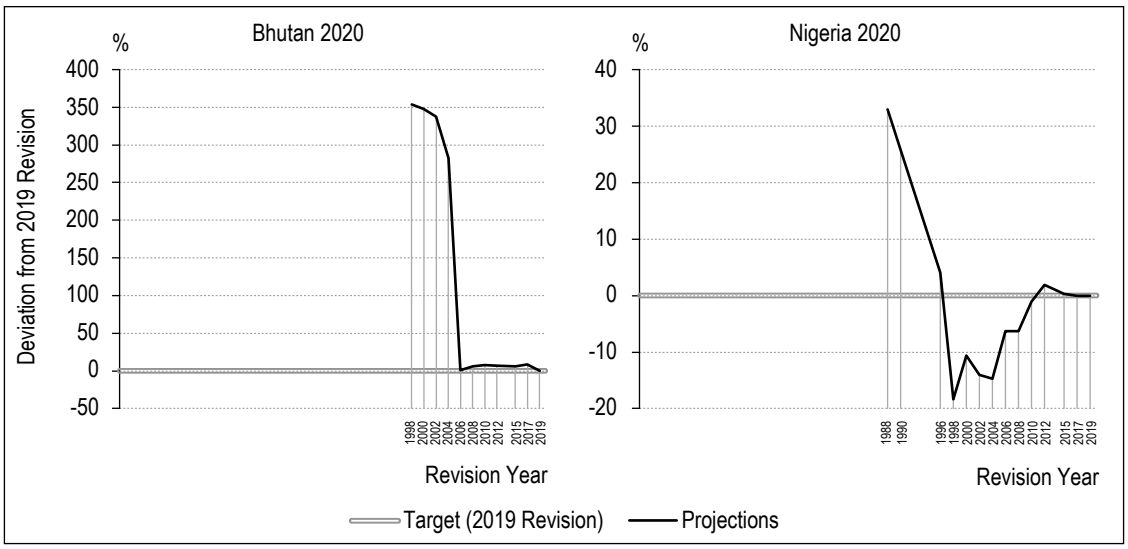
Another long-standing controversy about the "true" population figures of Nigeria is also reflected in the various revisions. All censuses of 1963, 1991 and 2006 censuses were found to need substantial adjustments for underenumeration.

The large fluctuations for the estimated population figures of Bhutan and Nigeria are exceptional, but smaller errors are common. For the world population, many of the variations are cancelling each other out. For the countries, establishing the true population estimates remains a challenge.

Projecting populations by age group and sex requires assumptions about the future course of fertility, mortality, and migration.[19] All three components must be prepared for all relevant age groups and by sex. Preparing these components of future population change was only feasible by developing and using mathematical models of trends and age patterns. The production of population projections is also, partly, informed by expert opinions, both from the outside (through workshops, etc.) and from inside the

19. This is, of course, also true for past estimates that are themselves projections.

Figure VII – **Hitting the target: Total populations of Bhutan and Nigeria in 2020, by revisions**



Sources: WPP, several revisions.

Population Division. The Population Division was also following technological advances, not always swiftly, by employing electronic computing devices (from mainframe computer to workstations to database server farms), plus various software, often developed in-house. Such technological progress was a significant factor in improving and expanding the scope of WPP, but it was also a tremendous challenge for staff and budgets. Change at every level and component was constant.

Indeed, it is the future population that is destined to attract the most attention every time a new revision is published. As long as the demographic transition is not complete, and the demographic momentum of many developing countries operates, continued population growth, at the world's level and for some regions, is easy to communicate, at least for now. But the prediction intervals now attached to the regular WPP projections suggest a less certain outcome than was anticipated in the past.

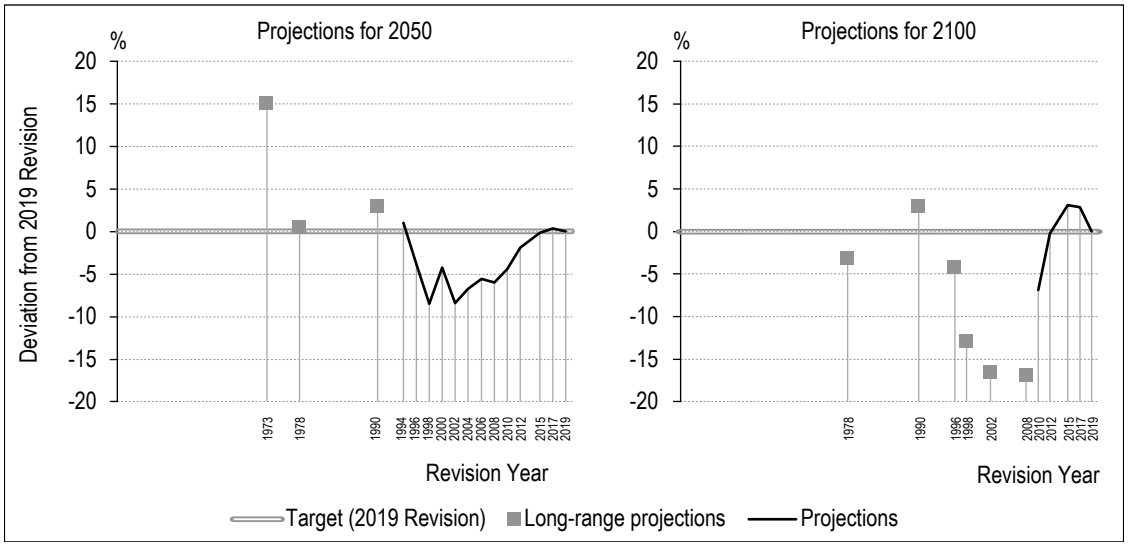
Some have argued, based on UN projections, that world population growth will continue until the end of the century (Gerland *et al.*, 2014). Others disagree (Lutz & KC, 2010; Lutz *et al.*, 2001). Some degree of projection uncertainty is apparent and justified, even between different producers and users of population projections. It is true that the United Nations Population Division maintained for a long time the replacement level of fertility – at about 2.1 children per woman – as an ultimate limit. The vision of population stabilization seemed not only a plausible, realistic, and neutral outcome. Alternative outcomes would be unsustainable population growth or continued decline. It may also be argued that population stabilization is a vision that countries in their different stages of the demographic transition could more easily accept.

How has the United Nations performed in projecting the future of global population growth? Focusing on projections up to the years 2050 and 2100, respectively, a comparison is made first with the results of past revision against the current revision of 2019. This assumes, implicitly, that the last such projection is more plausible than its predecessors, which may be doubted. But the accumulated evidence that the last revision had access to, and the methodological improvements make this assumption a plausible one.

Figure VIII depicts the total world population for the years 2050 and 2100, respectively, as produced by several past revisions. Included are early long-range projections (shown as data points), and regular projections (formatted as line) and referenced by the revision year. The x-axis is therefore not showing calendar years, but revision years. The comparison with the 2050 and 2100 projections results are shown as relative to the latest revision's projected figure as percentages.

Figure VIII shows, for the year 2050, that even relatively early projections (the long-range projections based on the 1978 Revision) came remarkably close to what the 2019 Revision established. But it also shows that an early attempt, based on the 1973 Revision long range projections, was off the mark by staggering

Figure VIII – **Approaching the future: World population in 2050 and 2100 by revisions**



Sources: WPP 1998 through 2019.

15% or 1.5 billion. The regular revisions with a projection horizon of 2050 or later were mostly underprojecting the world population in 2050, by up to 8% (1998 and 2002 Revisions). The last three revision (2015, 2017 and 2019) all produced very similar results of about 9.7 billion people in 2050.

The comparison of the various projections results up to the year 2100 showed more variation, due in part to the longer projection period. Most long-range projections[20] came out with results significantly lower that the reference from the 2019 Revision. Regular projections up to 2100, starting with the 2010 Revision, exhibited relatively small variation of less than 5%.

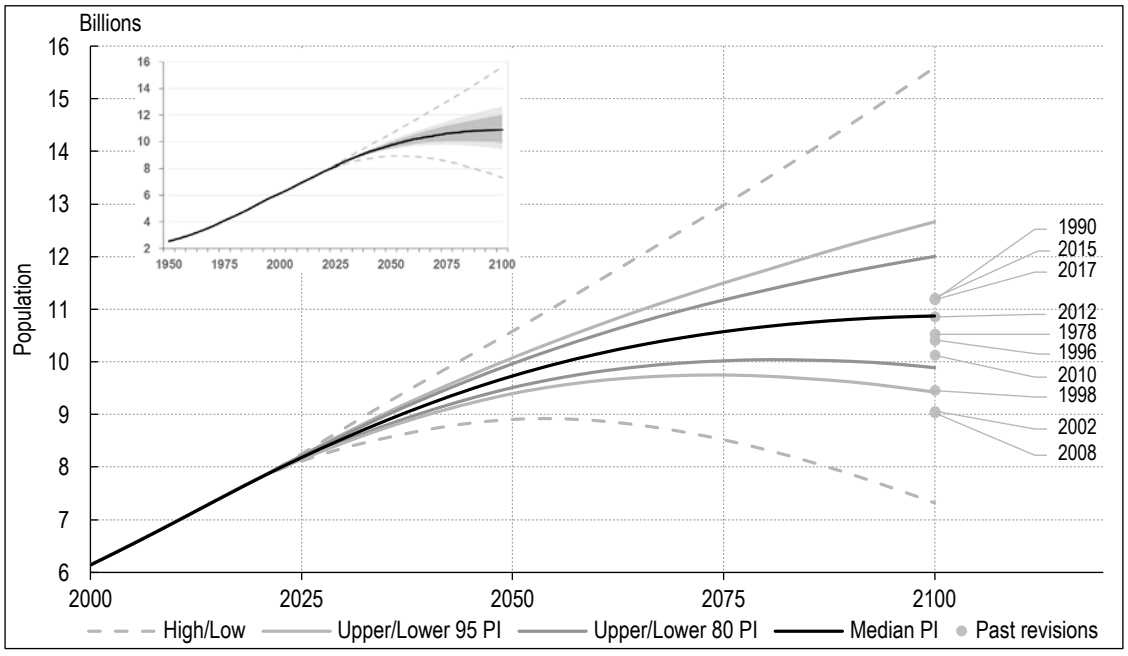
Another way to gauge how past revisions compare with the high-low variants and the prediction intervals of the 2019 Revision is shown in Figure IX. The figures for the world from 2020 to 2100 by high/low variants and prediction intervals illustrates the increasing uncertainty of that projection. The inclusion of long-range projection (1978 though the 2008 Revisions), and regular projections (2010 to 2017 Revision) shows that most of these earlier projections for the year 2100 landed with their medium variants within the 80% prediction intervals of the 2019 Revision.

Before the transition to probabilistic projections, the UN used a quite simple device to illustrate the inherent uncertainty of its projections. For most of its revisions, it defined a high and low variant that, after a short transition period after the base year, added or subtracted 0.5 children to the medium fertility variant.[21] In other words, there is a range of one child presumed to cover uncertainty. Such a uniform assumption of a fixed bound is neglecting many factors contributing to the uncertainty of future fertility. But it is easy to communicate and easy to understand. How do the past high-low ranges compare with Bayesian prediction intervals in terms of population numbers? The answer is mixed.

It appears that the 95% prediction interval and the traditional High-Low variants are similar for countries now exhibiting level of fertility between (roughly) two and three children per woman. For countries with higher fertility, the traditional high-low variants underestimate the range of possible outcomes. In contrast, for countries with below replacement fertility, the high-low variants overestimate uncertainty – the prediction intervals are much narrower. These results are plausible: low fertility countries at the end of the fertility transition are more likely to exhibit much smaller changes in fertility levels. For those countries still undergoing the transition from high to low fertility, there is more change possible. A simple comparison of the classic and the probabilistic approach is shown in Table 11.

20. Long range projection results for the years 2050 and 2100 are shown as data points to distinguish those from regular projections.
21. There was no variation in the assumed path of future mortality.

Figure IX – **Comparing the futures: World population to 2100 by revisions and prediction intervals**



Sources: WPP 1998 through 2019.

Table 11 – **Comparison of high/low population projection variants with 95% prediction intervals**

	Number of countries		% of world population	
	2050	2100	2050	2100
High and low variants are outside the 95% bounds	43	49	29	22
High or low variant is outside a 95% bound	51	71	13	16
High and low variants are within the 95% bounds	107	81	58	62
Total	201	201	100	100

Sources: WPP 2019, author's calculation.

For 43 countries in 2050 and for 49 countries in 2100, the high and low variants are indicating an uncertainty range exceeding the 95% prediction interval. For a relatively large number of countries, the classical high and low variants underestimate the 95% prediction intervals.

* *
*

What is next? Having reconstructed the evolution of the world population for the past 70 year, from 1950 to 2020 and producing, since the 2010 Revision, regular population projections to the end of this century, what could be improved, added, changed?

First what should be kept.

The reconstruction of the world's demographic history (the past estimates) from 1950 to 2020 is an asset. Now available for 70 calendar years, it provides a complete, internally consistent, and accessible data base with a host of demographic indicators for all countries, by age and sex. This database is the product of decades-long efforts to analyze, adjust, and update existing empirical sources, and close data gaps where they existed. It should be maintained and expanded. If feasible, an extension back to the beginning of the 20th century would certainly be much welcome by historians, epidemiologist, economist, and many more. The Population Division could build upon its expertise and existing, if still fragmented, data collections.

There is a natural tension between official statistics and estimates produced by non-state actors. Official statistics, produced by government authorities, are a political statement about a country's situation. Statistical estimates by international organizations, for instance, are produced independently, using additional sources of data and occasionally alternative methodology and methods. Tensions between official statistics and independent estimates arise when official statistics are incomplete[22] or use concepts and definitions that are not internationally comparable. Therefore, the Population Division often revises official statistics in terms of concepts, comparability, and consistency. Since past estimates are produced by cohort-component projections starting at 1950, they guarantee internal consistency across the time, age, and sex dimensions. As was shown, that internal consistency – a remarkable achievement – is also constantly under review. Thus, estimates produced by the Population Division are adding utility to the international statistical system, but do not replace official statistics.

Already in 1947, Trygve Lie, first Secretary-General of the United Nations, expressed the need for consistent and comparable population estimates for the United Nations System: "On one point we believe the central organization has a special obligation. Confusion could arise if a variety of slightly different population estimates were used by the various organizations. I suggest, therefore, that, in so far as possible, the United Nations should be called upon to provide the current estimates of population used throughout the various organizations […] In the most general terms, it will be the special duty of the Statistical Office to assure the flow from and to governments of basic data in the field of demography as in other fields. The Office also has special obligations in matters of statistical methods and standards. The Population Division, on the other hand, has the major obligation for investigation and analysis. Between these two fields of competence there is a considerable area; but we have decided not to delimit the boundaries more precisely at present." (United Nations, 1995, p. 870).

Ultimately, official statistics and the estimates produced by the Population Division should not be seen as competing, but as presenting a picture of the world, but with different objectives. The independence of WPP, especially its estimates, from official statistics should be maintained.

22. Areas of disagreement between some official statistic and the estimates prepared by the United Nations Population Division are the treatment of census undercounts, especially children and, sometimes, women (measured or inferred) and the retroactive correction of past estimates after a census.

What could be added or improved?

Migration has always been the most problematic element in international population projections. Recent methodological advancements (Abel, 2013, 2016; Abel & Sander, 2014; Azose & Raftery, 2019; Buettner & Muenz, 2018a, 2018b), plus the results of the decadelong efforts to collect, review and adjust migrant stock data (from censuses) and migration flows (from selected countries), have made it now possible to include migration in a much more transparent and policy-relevant fashion: as flows of people between countries.[23] This would be, no doubt, a challenging and resource-demanding project, and it is probably a longer-term enterprise. The Population Division could follow their own example by building the evidence patiently and consistently, and in cooperation with other agencies, organizations, and the academic community. Implementing migration flows into the WPP would be an important improvement.

Demographic projections are necessarily uncertain. While this was accepted from the beginning of the WPP exercise, there were different attempts to account for that uncertainty. In most of WPP's history, some measure of uncertainty has been constructed by calculating high and low variants around a central or medium variant, almost exclusively for fertility levels. Such a naïve approach reflected the lack of detailed data (for single calendar year, for instance) and the weak computing power of those times. The recent shift to a complex and sophisticated probabilistic projections model[24] based on hierarchical Bayesian models is a significant progress in this regard. It has also made interpretation and communication of results much more complex.

Keyfitz' warning against the misuse of projections variants rings also true for probabilistic projections: "If […], as more commonly happens, the user looks at the results and takes whichever of the three projections [low, medium and high] seems to him most likely, then the demographer has done nothing for him at all – the user who is required to choose on the basis of which of the results looks best might as well choose among a set of random numbers." (Keyfitz, 1981, p. 591).

But how to communicate uncertainty? Is one to favor the median results or the confidence margins instead? The 2019 Revision tried this: "Although the most likely scenario is that the world's population will continue to grow throughout the present century, there is an estimated 27 per cent probability that it could stabilize or even begin to shrink sometime before 2100".

In order to make the results of probabilistic projections more accessible, demographers have suggested "[…] in order to achieve a paradigm shift in practical applications of probabilistic population forecasts, the focus should not be on methods, but rather on possible impacts and consequences of decisions." (Bijak *et al.*, 2015, p. 542). The issue of handling and communicating uncertainty remains work in progress and must be developed further.

The outputs of current WPPs are impressive: Volumes with Key Findings, Comprehensive Tables, Demographic Profiles, Methodology; Data Booklets, Wallcharts, related technical papers and population facts; a complete online presence of the results, plus an interactive database, online documentation of data sources, interactive charts, thematic maps and data files in different formats for the occasional and the power user. Quite impressive but requiring a huge amount of resources.[25]

The issue of an optimal time schedule for publishing new/revised estimates and projections have been discussed already in the past (United Nations, 1984, p. 4). It may be worthwhile to reopen the discussion about how to react to new evidence and new or improved methodology while optimizing the amount and depth of results in its many forms. A careful reader may sometimes recognize some paragraphs in a new revision that are copied *verbatim* from a previous one. It seems recommendable to restrict some updates to electronic media and update the printed copies at longer intervals to reduce the burden of the demographers to produce lengthy documents that contain numerous repetitions.

Apart from the volume of publishing results, the frequency of updates appears to be a challenge for some users and might even have detrimental effects on data collection systems (Boerma *et al.*, 2018)., and the re-estimation of estimates is also not always welcome (Rigby *et al.*, 2019). It will remain a challenge for the demographers at the United Nations to find a balance between completeness, timeliness, and feasibility.

In conclusion, looking back at an impressive history of 70 years providing an authoritative account of the world's demography since 1950, and increasingly informative projections,

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23. A first attempt to include flows into international population projections was made by Lutz et al. *(2014).*
24. The inclusion of explicit probabilistic measures of uncertainty into population projections has been long suggested by many demographers (Ahlburg et al., 1998; Keilman et al., 2002; Lutz & KC, 2010).
25. The actual manpower producing the Population Division's estimates and projections is surprisingly small.

the Population Division's World Population Prospects remain an important and valuable project that will evolve and improve in the future. For the world is not a Panglossian paradise but needs work to improve. *Il faut cultiver notre jardin.* □

Link to the Online Appendices: https://insee.fr/en/statistiques/fichier/4997857/ES-520-521_Buettner_Online_Appendices.pdf

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