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A sensitivity analysis of the projected median fertility trajectories in the *World Population Prospects*: Towards a better understanding and reassessment of the Bayesian model*

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Abstract

Within the framework of the biennial publication the *World Population Prospects* (WPP), the United Nations Population Division has been producing estimates and projections of populations by age and sex and other demographic indicators for all countries of the world for several decades. The information included in these datasets is used widely by the United Nations system, academia and civil society, among others, including for the monitoring of several indicators of the Sustainable Development Goals.

As part of this work, the Population Division has been deriving estimates and projections of fertility indicators using standard demographic techniques and approaches. Starting in the *2010 Revision*, the Population Division adopted a Bayesian hierarchical model (BHM) to produce country-specific projections of the total fertility rate. In this paper, a sensitivity analysis of the projected median fertility trajectories is conducted by comparing the results from the Bayesian model used in the WPP to those derived by using other approaches or models, and to specific simulations. In a first step, through a series of country examples, the kinds of variation in projected fertility trajectories included in the WPP are displayed. The illustrative examples are mainly related to countries with high-fertility levels for which the quality of the underlying demographic information may not always be reliable. Several of these high-fertility countries play an important role in the projected regional and global population trends. The aim is to better understand the causes of these variations and to identify desirable features of other approaches that could be incorporated in the current Bayesian model. The objective is to develop recommendations, for consideration on the way forward using the BHM, to achieve greater consistency in projected trajectories of the total fertility rate (TFR) across countries as well as across revisions.

Keywords: Fertility, projections, median, trajectories, consistency, Bayesian

Sustainable Development Goals: 3

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Contents

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I. Introduction

Every two years, the United Nations releases an updated version of the *World Population Prospects* (WPP), which includes population and demographic information for all countries and areas of the world; the latest revision was released in June 2019 (United Nations, 2019a). As part of this work, the United Nations Population Division has been generating estimates and projections of fertility indicators for several decades using standard demographic techniques and approaches.

Starting in the *2010 Revision*, the Population Division adopted a Bayesian hierarchical model (BHM) to produce country-specific projections of the total fertility rate (TFR) (Alkema and others, 2011; United Nations, 2019b). The new approach was motivated by the desire to provide users with a measurement of the uncertainty associated with the medium trajectory: “it is important for decision makers not only to have a point forecast that indicates the most likely scenario for a future population but also to know the uncertainty around the forecast” (Alkema and others, 2011, p. 816). It had also been discussed that choices, based on a menu of model options used in previous revisions, contributed to significant variations across countries in future TFR trajectories.

Indeed, there is inherent uncertainty in demographic projections and there is value in measuring that uncertainty for selected components and in providing such an assessment to users. However, an ongoing challenge is that most users of these projections focus on the medium trajectory or the central scenario, often considered the most likely outcome and referred to as the “medium variant” in the WPP.[1] For this reason, a critical aspect to consider with these projections is the coherence or consistency of the medium variant across countries in similar demographic situations, as well as across revisions when there have been no fundamental changes in the underlying data or estimates. In short, in some situations, a degree of conformity in projected trajectories should be expected, unless specific information justifies large variations (e.g., return to a “regular” fertility pattern or level following a war or crisis). The analysis presented here focuses on the medium trajectories of the TFR at the country level, not on the associated uncertainty bounds derived using the BHM.

Based on the analysis of the results from several revisions of the *World Population Prospects,* including the *2019 Revision*, for which the Bayesian model was utilized to project the TFR, it was observed that the projection trajectories varied across some countries, even when the latest estimates of fertility levels were similar. Furthermore, while comparing results across revisions for a given country, changes have also been identified in the projections even though in some cases the estimates or inputs were only slightly modified or estimates within the WPP were modified without any solid evidence. Given that it is not possible to know with certainty what will happen in the future, measuring the uncertainty bounds, as mentioned above, is an important aspect of generating projections. However, variations in the projected medium or median trajectories across countries in similar demographic situations may suggest that something quite specific about the future path of each country is known. For instance, if two countries have similar levels of fertility today and have experienced, based on reliable data or estimates, similar levels in the past, it seems implausible that they would be very different (e.g., 50 per cent difference) in 30 years’ time, unless some mechanism or reason could be identified that might explain such diverging trends. Similarly, significant variations in results across revisions of the WPP, especially in the absence of major changes in underlying reliable data or estimates, could confuse users or make them question the validity of the methods and results.

The analysis within this paper focuses mainly on countries with relatively high levels of fertility, where variations in projected fertility trajectories can lead to major changes in projected population size. An

[1] As part of its work on probabilistic projections, the Population Division also published the 80 and 95 per cent prediction intervals of future fertility levels, along with the median trajectory. It should be noted that the median trajectory constitutes the medium-fertility assumption.

additional consideration is the quality of the underlying empirical data for such countries and the potential contribution of inaccuracies or biases in such information to variations in projected TFR trajectories.

In this paper, a sensitivity analysis of the projected fertility trajectories is conducted by comparing the results from the Bayesian model used in the WPP to those derived by using other approaches or models, and to specific simulations. After discussing some methodological aspects, we first illustrate, through a series of country examples, the kinds of variations in projected fertility trajectories that can be observed in the most recent edition of the WPP, focusing on countries with relatively high levels of fertility.[2] Several of these high-fertility countries play an important role in the projected regional and global population trends. In addition to illustrating projected trends for selected countries in the WPP, these results are then compared to those obtained using other approaches and simulations. By analysing variations in the results, we seek to identify desirable features of other approaches that could be incorporated into the current Bayesian model. The objective is to develop recommendations, for consideration on the way forward using the BHM, to achieve greater consistency in the TFR projected trajectories across countries as well as across revisions.

II. The Bayesian hierarchical model and the WPP process: A Brief description in the context of fertility estimates and projections

In this section, a brief overview of some methodological aspects related to the production of fertility estimates and projections using the BHM, in the context of the WPP, is provided. Certain characteristics of the Bayesian model that are pertinent to the scope of the discussion within this paper are highlighted.

The methodological report of the *World Population Prospects* briefly describes how estimates have been prepared and then explains the methods that were used to project fertility (United Nations, 2019b). Overall, the preferred source of data on fertility is counts of live births, by age of mother, from a system of civil registration with national coverage and a high level of completeness (United Nations, 2017a). In countries where the registration of births is deficient or lacking, fertility rates are typically estimated using sample surveys. Among the 201 countries or areas with 90,000 inhabitants or more in 2019, all but 34 had available data on fertility collected in 2015 or later. For 33 countries, the most recent data was collected between 2010-2014, and for 1 country, Somalia, the most recent national data was from 2006 (United Nations, 2019b). However, at the world level, only a few countries had provided data or estimates up to the year 2018 at the time of producing the *2019 Revision*. Furthermore, when considering the data that was actually used to generate the five-year estimates in the WPP for the period 2015-2020, there was limited data, if any, used to generate that point estimate in the majority of countries in sub-Saharan Africa and/or in high-fertility countries (United Nations, 2019c).

As stated in the methodological report of the *World Population Prospects*: “A key aim within each revision of the *World Population Prospects* is to ensure the consistency and comparability of estimates and projections within countries over time and across countries” (United Nations, 2019b, p.1). For the estimation period (1950-2020), newly available demographic information is therefore assessed through various data quality checks and also evaluated by analysing the impact of its incorporation on recent trends in fertility and other components, and by comparing the simulated outcome with estimates of the population by age and sex over time. With respect to the projection period, probabilistic statistical techniques were used to determine the paths that fertility is expected to follow in the future (United Nations, 2019b).

[2] As a broad definition and considering the past estimates of each country’s fertility levels, “high-fertility countries” for the purpose of this analysis are defined as countries with a TFR above 3.5 live births per woman in 2015-2020; all of these countries have had estimated TFR levels of 5 births per woman or more for at least five quinquennial periods during 1950-2020. Some of the issues explored in this paper may also be relevant for other countries with slightly lower fertility levels in 2015-2020.

Accordingly, the Bayesian hierarchical model (BHM) was used to project future TFR based on both the country's fertility history and the pattern of all countries. The methodology is based on a model of fertility change that includes different phases: it is assumed that counties move from a high-fertility pre-transition phase, through the fertility transition itself, and then to a low-fertility post-transition phase (Alkema and others, 2011). Aside from the countries already in the post-transition phase, the process of fertility decline consists of two phases that are modelled by a double-logistic function (United Nations, 2006; Alkema and others, 2011).[3] In the Bayesian model, the parameter vector of the decline function is estimated for each country, contrary to the former group of deterministic models which included a set of three different vectors, with each parameter describing a different overall pace for the fertility decline based on the experience of several countries (Raftery and others, 2009).

More precisely,

> …the parameters of the double-logistic function were estimated using a Bayesian hierarchical model (BHM), which resulted in country-specific distributions for the parameters of the decline. These distributions are informed by historical trends within the country as well as the variability in historical fertility trends of all countries that have already experienced a fertility decline. This approach not only allows taking into account the historical experience of each country, but also to reflect the uncertainty about future fertility decline based on the past experience of other countries at similar levels of fertility. Under the model, the pace of decline and the limit to which fertility was able to decline in the future varied for each projected trajectory. …The future potential trajectories as well as the speed of decline in fertility of countries at the beginning of the fertility transition are mainly informed by the world's experience and the variability in trends experienced in other countries at similar levels of fertility in the past. (United Nations, 2019b, p. 16).

Within the WPP time frame, that is, since 1950, the TFR in all high-fertility countries has started to decline, but countries differ with respect to the timing of initiation of their fertility transition and the starting level, as well as the pace of this decline (Alkema and others, 2011). Deterministic rules were used to define the transition periods between successive phases of the BHM model of fertility decline (ibid). Considering that the underlying estimates that are used to determine the onset of the fertility transition are not always based on reliable empirical data, if any, the actual impact of the timing of its onset on the projected trajectories may need to be further explored.

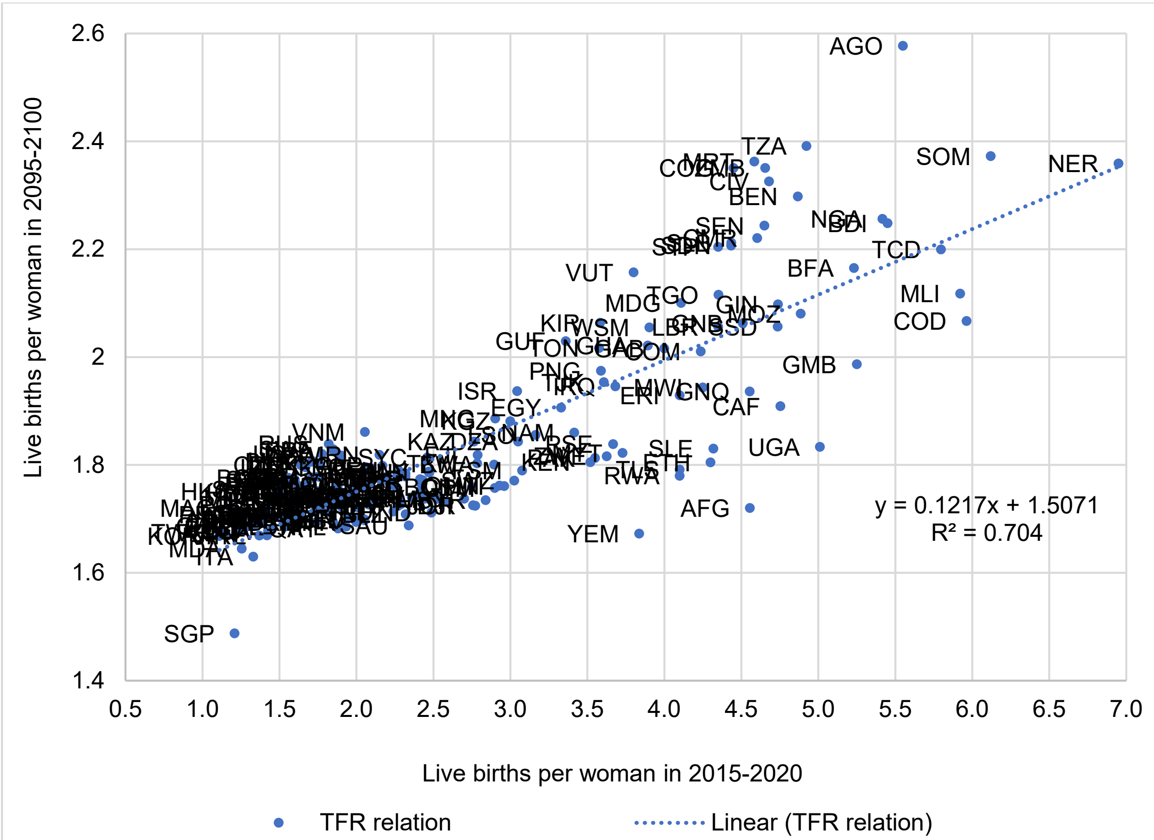
III. An overview of fertility trajectories: From a global perspective to selected countries

Prior to analysing TFR trends for selected countries, the relationship between the projected TFR levels in 2095-2100 and the estimated TFR levels in 2015-2020 is examined. Figure 1-A depicts, via a scatter plot, the relation in these TFR levels for all countries of the world based on the results of the *2019 Revision* of the *World Population Prospects* (WPP2019). The figure includes the linear trend from a regression model with an R-squared value of 0.704 (the corresponding Pearson correlation coefficient was estimated at 0.8390). Overall, the variation in projected TFR levels in 2095-2100 around the predictions of the linear model is larger for countries with estimated TFR above 3.5 live births per woman in 2015-2020. Overall, at lower levels of TFR, there is less variation in absolute terms, which could be anticipated, though it is also

[3] For country-specific results illustrating the decline curves based on the double-logistic function used in the BHM model, see:https://population.un.org/wpp/Graphs/Probabilistic/FERT/CHG/4.

the case, in relative terms, for most countries with above-replacement fertility for which the same component of the model was utilized to generate the projections (data not shown).[4]

Figure 1-A. Relation between TFR levels in 2015-2020 and 2095-2100 for all countries, WPP2019



Source: United Nations (2019a). (For the list of ISO3 Alpha-codes, see Locations file at https://population.un.org/wpp/Download/Metadata/Documentation/)

In figure 1-B, the relation between the estimated TFR in 2015-2020 and projected TFR in 2095-2100 is plotted only for countries with a TFR above 3.5 births per woman in 2015-2020. The fitted linear trend is slightly different from the one in figure 1-A above, though the degree of variation around the line is similar. However, by limiting the analysis to this subset of countries, the R-squared of the linear model was reduced substantially to a value of 0.3196 (the corresponding Pearson correlation coefficient was estimated at 0.5653). Countries for which the observed value in 2095-2100 lies farther than one standard deviation from the regression line include Yemen (YEM), Afghanistan (AFG), Uganda (UGA), Angola (AGO), the United Republic of Tanzania (TZA), Zambia (ZMB) and Côte d'Ivoire (CIV), among others.

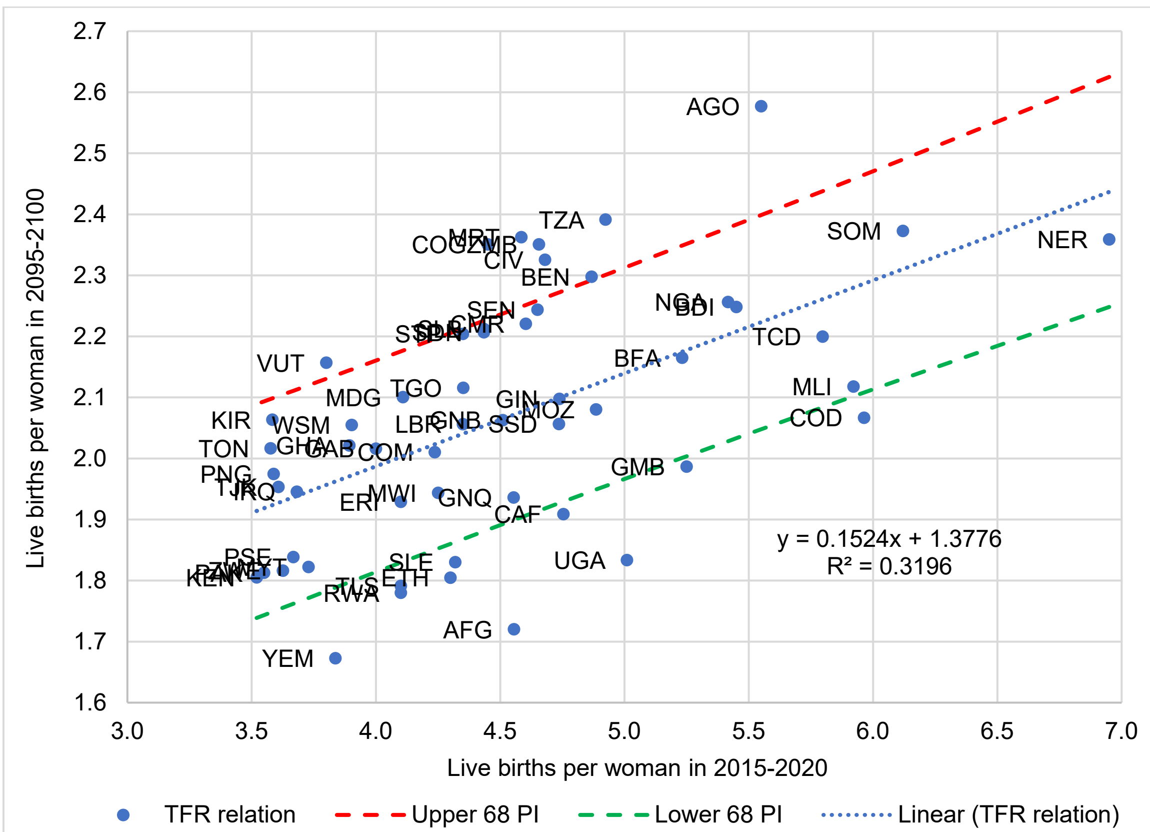
Another means of depicting variation in projection trajectories is to compute the average annual rate of decline in fertility levels during the 80-year period from 2015-2020 to 2095-2100 (or 2018 to 2098). Figure 1-C shows the relation between the TFR level in 2015-2020 and that rate for the same countries included in figure 1-B. Among those countries, rates of decline in the TFR range from 0.69 per cent in Kiribati to 1.35 per cent in Niger. Though in line with the central linear relation, an average rate of 1.35 per cent does imply a faster decline in fertility than for any other country included in this figure. And among the countries with a TFR of five births per woman or more in 2015-2020, Angola has by far the slowest rate of decline

[4] In the WPP, a different model, or the second component of the projection procedure, was used for projecting the fertility of countries that have experienced sub-replacement-fertility levels (see United Nations (2019b)).

at 0.96 per cent. Considering that these are average annual rates over an 80-year span, even slight variation across countries can translate into significant differences in TFR trajectories, which in turn can yield important changes in projected population levels. Countries that lie farther away from the regression line are similar to those observed in figures 1-A and 1-B.

It was observed above that for some countries, the projected TFR in 2095-2100 was either relatively high or low as compared to that of other countries with similar fertility levels in 2015-2020. These variations are more significant in high-fertility countries, for which the pace of fertility decline (measured as the average annual rate of change) also varied significantly across those countries.

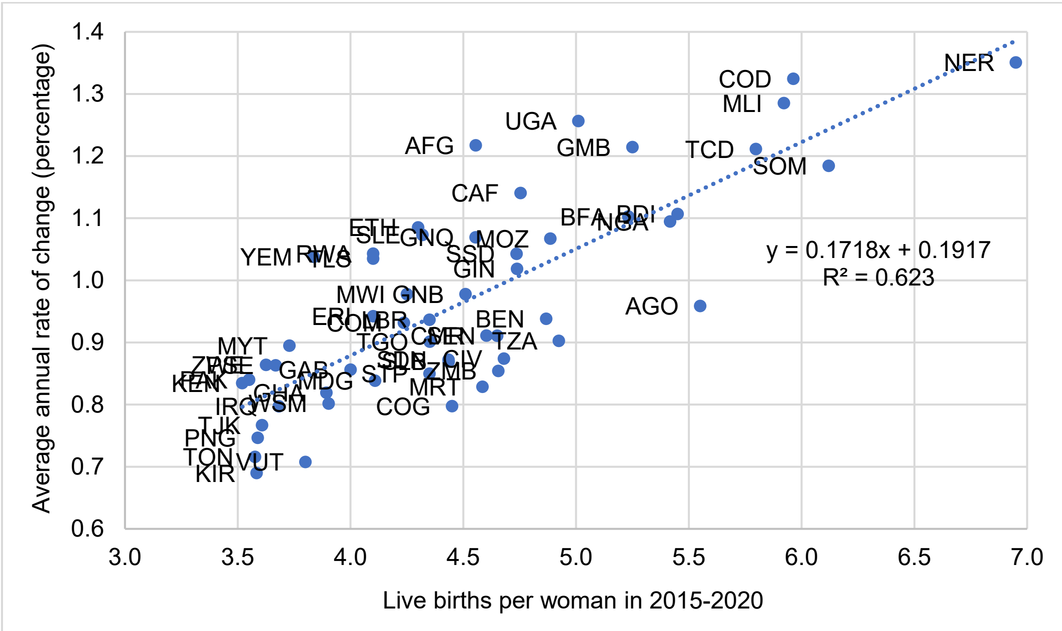
Figure 1-B. Relation between TFR levels in 2015-2020 and 2095-2100 for countries with TFR above 3.5 births per woman in 2015-2020, WPP2019, and 68 per cent prediction intervals*



Source: United Nations (2019a) and own calculations.

* The dotted red and green lines have been included to help identify countries that lie farther from the regression line while using the 68–95–99.7 rule, also known as the empirical rule. By using the numerical value of 68.27 per cent these bands identify the values that lie within one standard deviation of the mean.

Figure 1-C. Relation between TFR level in 2015-2020 and average annual rate of decline in fertility levels from 2015-2020 to 2095-2100 for countries with TFR above 3.5 births per woman in 2015-2020, WPP2019

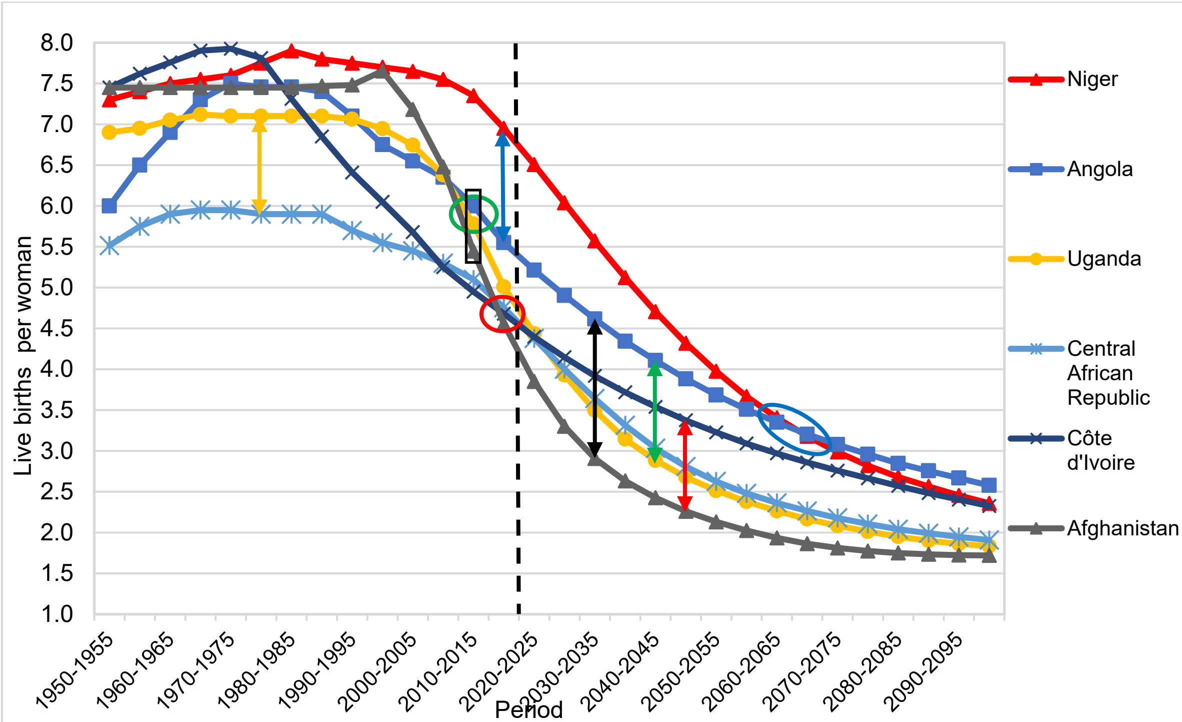


Source: United Nations (2019a) and own calculations.

In order to move the analysis one step further, the fertility trajectories from 1950 to 2100 for selected countries are compared (figure 2), including for some of the countries highlighted above. Some of these countries have relatively fast declines (e.g., Afghanistan, Uganda) or slow ones (e.g., Angola, Côte d'Ivoire), among other specificities. Furthermore, the countries were selected on the basis of interrelations to one another. For instance, Niger and Angola had significantly different TFR levels in the estimation period, with Niger having higher levels in the past 70 years, while Angola's projected TFRs are higher at some time in the future. Other countries had similar levels in selected periods (e.g., 2010-2015 or 2015-2020) with different projected fertility levels, or very different past estimates and similar future trajectories. Indubitably, other countries could have been included in this analysis to get a better understanding on how the "model behaves" in different situations, and the patterns being highlighted are not limited to the countries included in figure 2.

Figure 2 includes estimates and projections of total fertility rates (TFR) for selected countries based on the *World Population Prospects 2019 Revision*. Within the *2019 Revision*, fertility levels from 1950-2020 are considered estimates while values thereafter are projections; values are presented as five-year averages. Among the selected countries, the "latest estimate" for the period 2015-2020 varied from a low of 4.6 births per woman in Afghanistan to a high of 7.0 births in Niger. It is important to explain that in WPP2019, even though the "latest estimate" refers to the period 2015-2020, not all countries have observed or empirical data for that period. The reference year of the latest empirical data or estimate that are not provisional, for each country illustrated in figure 2, is 2015 or before. Therefore, for all these countries, values for 2015-2020 are not based on observed data and the "estimated" level may have influenced the recent trend and consequently the trajectory of the projection. The actual Bayesian projection model was applied starting in 2020 and prior values were introduced as inputs until the last estimation period (2015-2020, in this case).

Figure 2. Total fertility estimates and projections for selected countries, 1950-2100, WPP2019



Source: United Nations (2019a).

Note: To facilitate the reading of the different trajectories included in figure 2, individual plots with each two country-trajectories are also included in the annex figure A-1. Other examples of country-trajectory comparisons follow in annex figure A-2, mainly to illustrate that the discussed variations in TFR trajectories are not limited to the ones highlighted in the core of this paper.

In order to shed some light on the performance of the Bayesian fertility projection model, mainly in the context of high-fertility countries, a simple analysis and comparison of the fertility levels and trends for the six countries included in figure 2 is conducted. As can be observed, Afghanistan, Côte d'Ivoire and the Central African Republic all have similar fertility levels during the period 2015-2020 (respectively 4.56, 4.68 and 4.75 birth per woman[5]). However, by 2045-2050, the projected levels are quite different, ranging from 2.3 births in Afghanistan to 3.4 in Côte d'Ivoire, translating into a difference of 50 per cent (see red arrow and circle). The difference across the trajectories of Côte d'Ivoire and the Central African Republic is also significant and raises some questions considering the slight variation in the more recent trends for these countries during the period 2005-2020.[6] Based on that observation, one could ask whether such variations in the recent slopes or trends, that is driven by estimates for which there is not necessarily a high degree of precision, should influence to that extent the direction of future trajectories, or not? (for further details on the quality of past estimates and underlying empirical data, see annex figure A.3 and related comments). Lastly, it is worth mentioning that when comparing the 2010-2015 estimates for the three countries referred here, which in this case are based on "observed or empirical data", Afghanistan's fertility was estimated to be the highest while Côte d'Ivoire was the lowest.

Moving to the comparison of other countries, the 2010-2015 estimates for Angola and Uganda are close to each other (respectively 6.0 and 5.8 births per woman) while projected figures for 2040-2045 reach 4.1 and 2.9 births, respectively (see green arrow and circle). It can also be observed that the fertility estimate

[5] These are five-year average estimates, as required for inputs in the WPP2019. Annual TFRs shown in figures 3-A and 3-B below were interpolated in a subsequent procedure.

[6] Prior estimates in both countries differ and this may also influence the projected trajectories.

for Niger is substantially higher than that of Angola in 2015-2020 (7.0 versus 5.6 births per woman) while by around 2065 there is a cross-over in the projected trajectories, with Angola having the highest projected fertility in the world from thereon till the end of the century (see blue arrow and oval).

It was observed that Afghanistan and Côte d'Ivoire as well as Angola and Uganda had similar TFR levels, respectively in 2015-2020 and 2010-2015, though quite different future trajectories; the sharper declines in TFRs in both Afghanistan and Uganda may have been influenced by the 2015-2020 estimates, which are not derived from observed data and have contributed to the downward trends. Furthermore, when comparing the levels and trends of Afghanistan and Angola, it can be noticed that a difference of about half in child in TFR levels in 2010-2015 more than triples by 2030-2035 (see black arrow and rectangle); a similar pattern can also be observed when comparing the trends from Angola and Uganda. Lastly, though secondary to our analysis, it is interesting to note that the projected trajectories of both Uganda and the Central African Republic are quite similar even though past estimates prior to 2015-2020 differ substantially (see orange arrow), within a model for which variations in projected trends are often related to differences in past estimates.

The variations in projected fertility levels that have been identified across the selected countries may seem trivial to many users. However, such variations in fertility levels, even when relatively small, may have a significant impact on the projected population size across countries as well as across revisions for a given country. In this section, a degree of variability across projected TFR trajectories was identified; in subsequent sections, the analysis is pushed forward in order to better understand what may be occurring and to shed some light on the corresponding implications.

IV. Afghanistan and Côte d'Ivoire's diverging trends

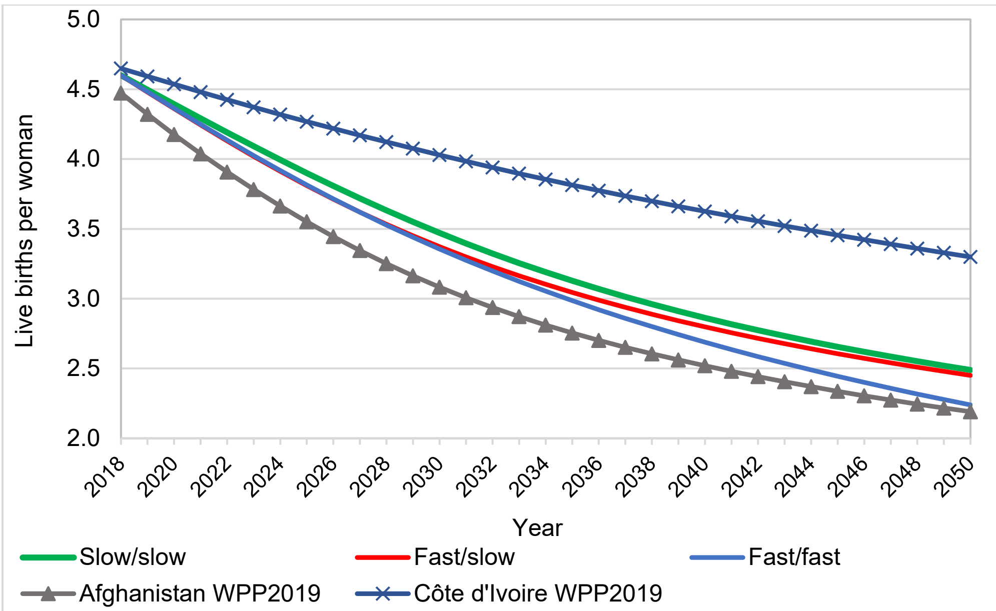
It was observed in figure 2 (above) that the TFR levels of Afghanistan and Côte d'Ivoire were projected to reach a difference of 1.1 birth per woman by 2045-2050 even though the latest WPP estimates in 2015-2020 were similar with a difference of about 0.1. Before further exploring the projected median TFR trajectories of Afghanistan and Côte d'Ivoire based on the Bayesian model that generates probabilistic results, the deterministic models that were previously used by the Population Division for several years are introduced for comparison purposes.[7] Based on the combined experience of all countries where fertility was above the replacement level, when the models were developed for the WPP, and that had experienced fertility decline since 1950, three models were fitted to be used for demographic projections. The models were built to capture a variety of pathways from high to low fertility and were labelled "Slow/Slow", "Fast/Slow" and "Fast/Fast", which translated into different paces of fertility decline throughout the projection (for further details, see United Nations, 2006). In practice, one of the three models was selected by observing the past trends in a given country and on the basis of knowledge about the experience of fertility declines in groups of countries or regions with similar socio-demographic backgrounds. Accordingly, in the context of "high-fertility countries", namely in sub-Saharan Africa, the predominant practice at the time was to apply the Slow/Slow model and to a lesser degree the Fast/Slow one; the Fast/Fast model was rarely used. It should be noted that the models used for comparison in this paper have not been re-fitted for several years and do not incorporate the latest observed trends based on a greater availability and more timely data. Also, they were developed at the time with the objective to project fertility levels till 2050 not to 2100.

In order to compare the trajectories of both Afghanistan and Côte d'Ivoire as published in the *2019 Revision* with the outcomes based on the three different deterministic models briefly discussed above, a similar starting value—4.6 births per woman in 2018—was used to generate three new trajectories (2018

[7] This brief introduction is also required to understand the example provided below while using different trajectories for Uganda.

refers to the mid-point of the 2015-2020 period). Figure 3-A showcases the trajectories based on these three models along with the annually interpolated fertility rates from Afghanistan and Côte d'Ivoire based on WPP2019. With a similar level of TFR in the last estimation period (or for 2018 in this figure), the variability across the projected deterministic trajectories is relatively narrow regardless of the choice of model, as compared to the results for Afghanistan and Côte d'Ivoire published in the *2019 Revision*.

Figure 3-A. Deterministic trajectories of TFR based on three models with an initial level of 4.6 births per woman and annually interpolated WPP2019 estimates and projections for Afghanistan and Côte d'Ivoire based on BHM, 2018-2050

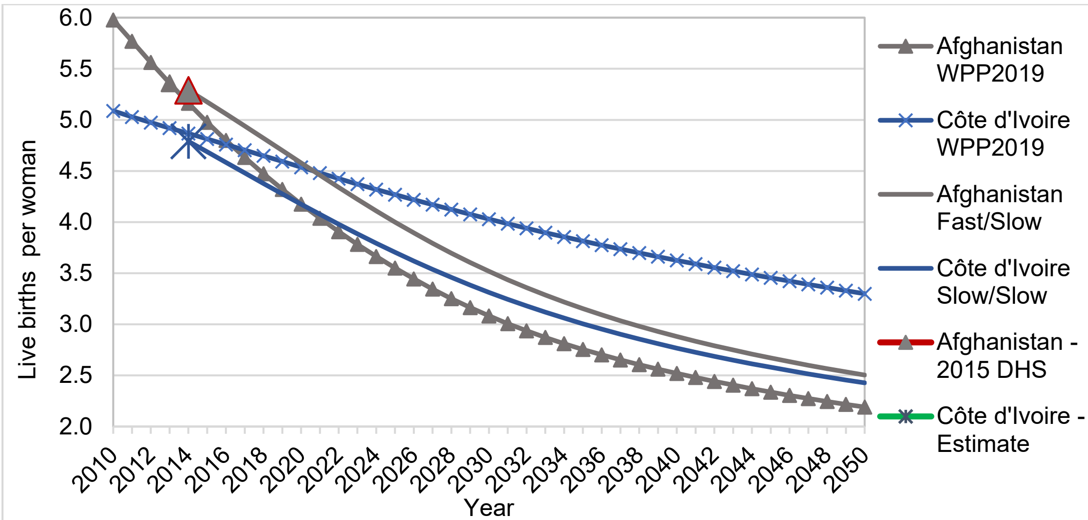


Sources: United Nations (2019a) and own simulations based on deterministic models.

While the probabilistic trajectories are more influenced by country-specific past trends, the deterministic models rely more on the latest estimated input and the choice among the three models which encompasses the pooled experience of "several countries". In the introduction it was mentioned that one of the motives to adopt new approaches to project the demographic components was that choices of models with different paces of decline, available at the time, generated variation across countries. However, based on this example, at similar levels of TFR in 2018, there is seemingly a wider range of outcomes across the median trajectories based on the Bayesian model than on the deterministic ones. Admittedly, countries with similar levels of fertility today are likely to differ in the future, though there is no strong basis to determine the magnitude of that variation or to pinpoint which country would have higher or lower levels.

As implied earlier, in the case of Côte d'Ivoire, and considering the past trends of that country, it is surprising to see how "slow" the projected pace of decline has been modelled in the Bayesian framework. Conversely, in the case of Afghanistan, the pace of decline is relatively "fast", though, as mentioned above, this is probably related to the estimate that was included for the period 2015-2020. For the Bayesian model, data for the period 2015-2020 for Afghanistan had to be estimated since no observed data was available for that period, where the latest available data was for the year 2014. Indeed, in the event that the last input data or estimate for a given country would be for the year 2014, such as in this case, the current practice while using the Bayesian model has been to include an "estimated" TFR value for the period 2015-2020. However, the deterministic models used the year of the latest observed data or estimate as a starting point for the projections. Therefore, such as in this case, it would derive the values not only for the projections from 2020 onward but also produce "standardized" estimates from 2015 to 2020. Indeed, starting the "projection" period after the last observation (e.g., in 2015 instead of in the middle of the 2015-2020 period —i.e., 2018—in the case of Afghanistan) has the potential to influence the TFR trajectory. Figure 3-B illustrates the country-specific trajectories using the last observed data in 2014 and two different paces from the deterministic model (Fast/slow for Afghanistan and Slow/slow for Côte d'Ivoire). In this example, there is convergence of the projected trajectories derived from the deterministic models while the trajectories from WPP2019, shown for comparison, already started to diverge during the period 2015-2020, based on inputs that had to be estimated.

Figure 3-B. Trajectories of TFR derived from selected deterministic models with initial levels for the year 2014 based on empirical data (2014-2050) and annually interpolated WPP2019 estimates and projections based on BHM (2010-2050), Afghanistan and Côte d'Ivoire



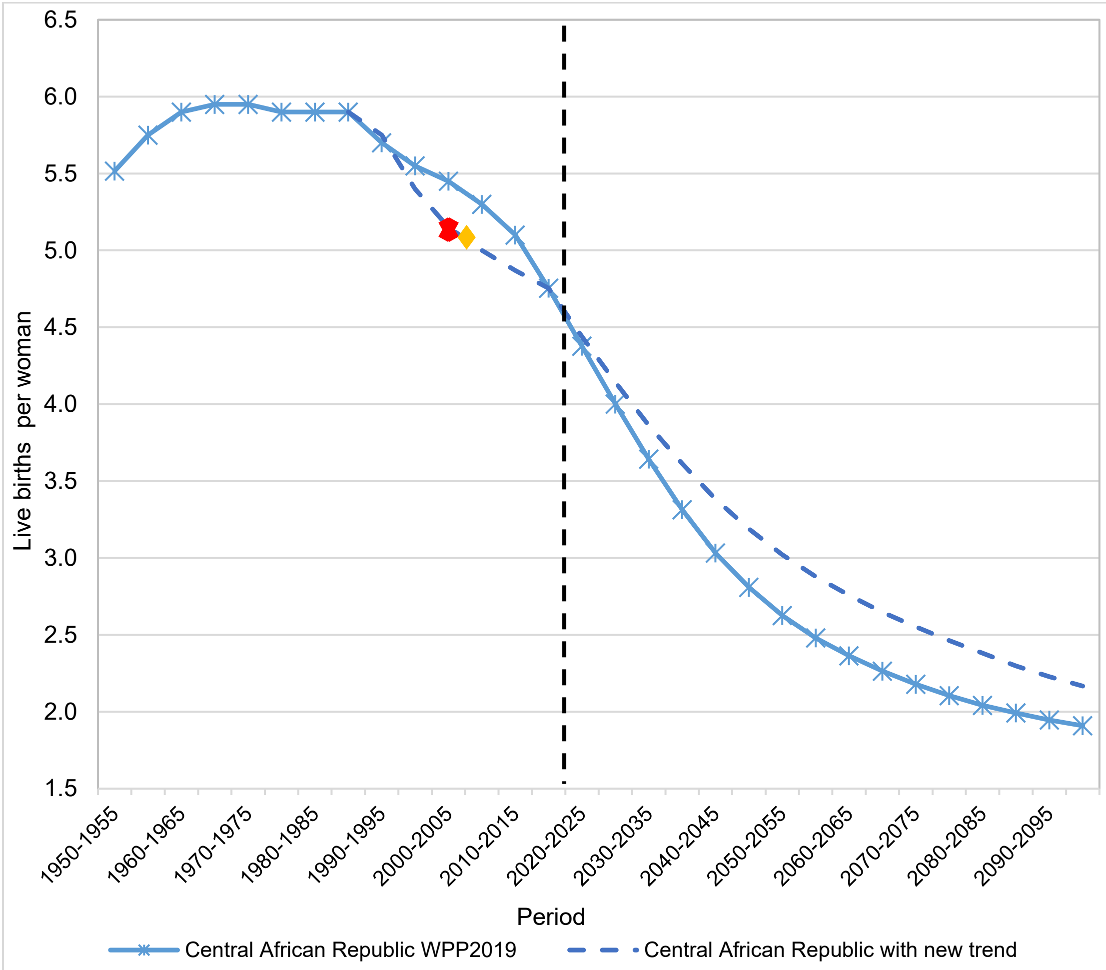
Sources: United Nations (2019a and 2019d) and own simulations based on deterministic models.

Note: The implied trends from 2010 to 2014 based on the annually interpolated estimates from WPP2019 for both these countries have been influenced by the 2015-2020 estimates.

V. Central African Republic: Recent trends shaping the future

Figure 4 compares the TFR trajectory of the Central African Republic based on the *2019 Revision* with that of a simulation with different TFR estimates during the 1990-2015 period. The changes made in that period have modified the more recent estimated trend though the estimate for the 2015-2020 period was kept the same. Also plotted on the figure are estimates (or empirical data) derived from the 2003 census and the 2006 MICS-3 survey (Multiple Indicator Cluster Surveys), with TFR levels of about 5.1 births per woman, approximately for the years 2003 and 2006. Based on that information (and other data not shown here; see annex figure A.3) there is no clear indication on the "shape" of the recent trend. As can be observed, based on those modifications in the estimates, the projected trajectory is quite distinct from the original one, reaching an average peak difference of 0.39 of a birth during 2045-2070. Such variations in TFR levels, that were triggered by even smaller changes in the estimation phase (both in absolute and relative terms), have significant implications on projected population levels. Furthermore, as raised previously, when estimated recent trends are not based on highly reliable data, small changes in estimated trends should not influence so much future paces of change in projected TFR levels.

Figure 4. Total fertility estimates and projections with different inputs for the period 1990-2015, Central African Republic, WPP2019 and simulation with new trend, 1950-2100



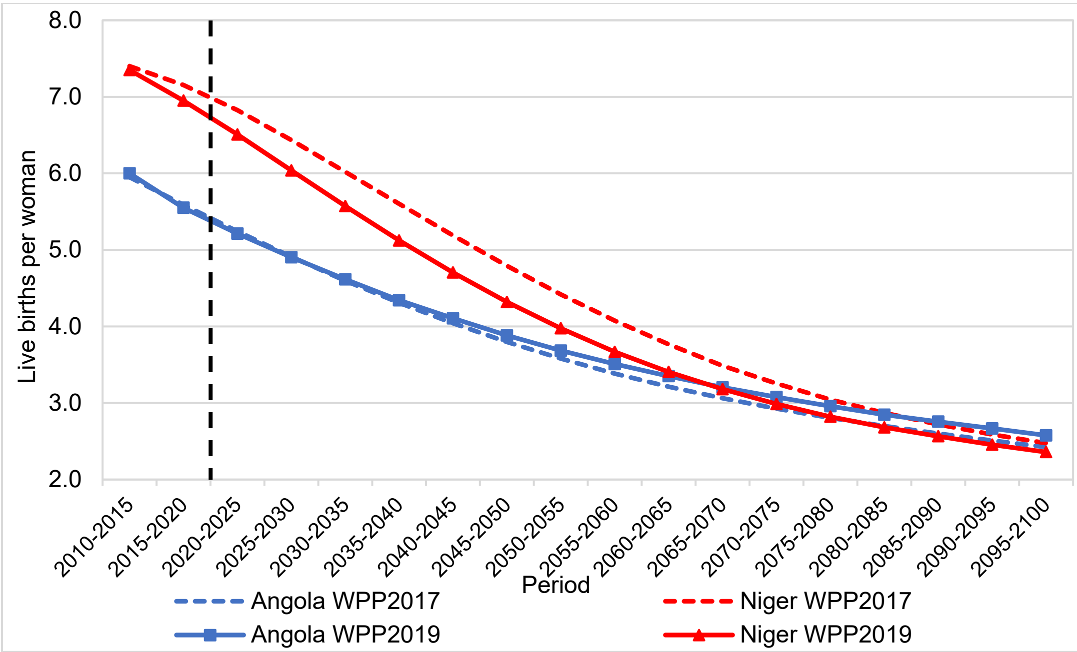
Sources: United Nations (2019a and 2019d) and own simulation.

VI. Angola and Niger: The highest-ranking countries of today and tomorrow in terms of fertility levels

It was observed above in figure 2 that the projected levels of fertility in Angola started to surpass those of Niger around 2065 onwards, based on the results of WPP2019, even though the current estimates of Niger were substantially higher (7.0 versus 5.6 births per woman). In figure 1.C, it was also highlighted that while Niger had the fastest pace of decline during 2015-2100 amongst all high-fertility countries, Angola had the slowest for countries with a TFR of 5 births per woman or more in 2015-2020.

In 2015-2020, Niger had the highest fertility in the world; though Angola ranked number six during that period, it was projected to have the highest fertility in the world after 2065. In WPP2017, Niger remained the country with the highest fertility level throughout the entire projection till 2100, even though there was some convergence between the trajectories (see comparison in figure 5). Having observed these variations across revisions, it was decided to inspect what may have triggered these changes. In the case of Niger, the TFR value of 2010-2015 was reduced by .05 of a birth and that of 2015-2020 was modified downwardly by 0.2 in WPP2019 compared to WPP2017, which triggered a faster decline in the projected trajectory along with a lower projected total population. In the case of Angola, the estimates for the same periods were hardly changed (+.05 and -0.04, respectively) though past estimates, mainly in 1950-1970, were reduced substantially.[8]

Figure 5. Total fertility estimates and projections based on the *2017 and 2019 Revisions* of the WPP, Angola and Niger, 2010-2100



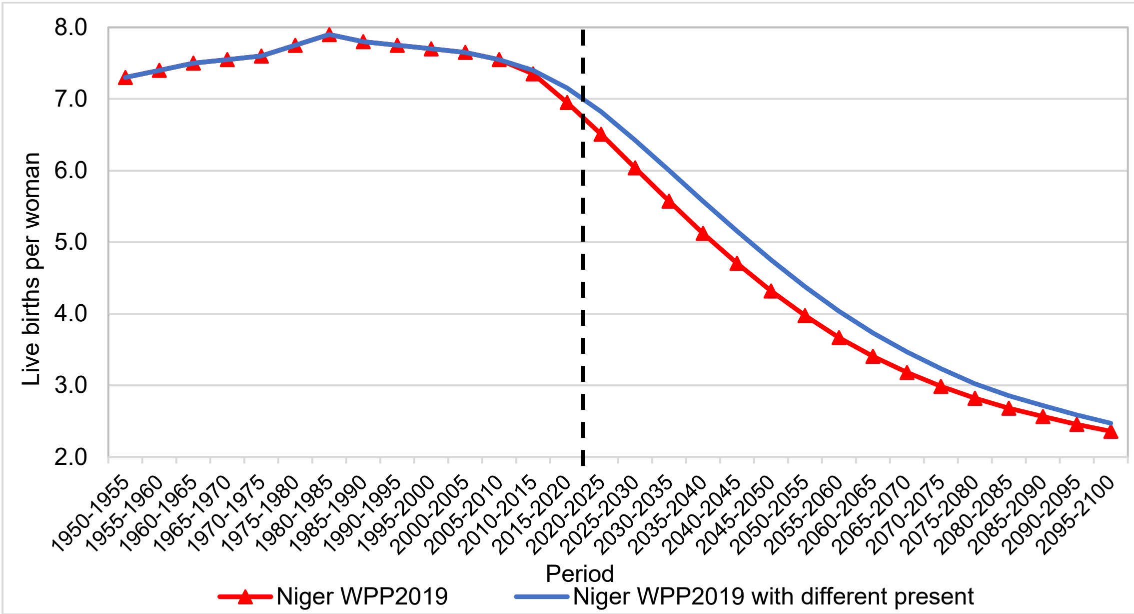
Sources: United Nations (2017b and 2019a).

It is important to point out that these changes in the fertility trajectories of Angola and Niger are partly related to the modifications that were made in the individual country data sets across revisions but also with the modifications that were made in all other countries, being that the modelling application relies on a Bayesian framework. Within the Bayesian framework, the experience of other countries also influences the future trajectory of a given country. Therefore, in order to isolate the effect of modifications in the TFR levels of specific countries, the country projections of both Angola and Niger were re-processed in the "universe" of the *2019 Revision*, while changing the input data for specific periods.

Figure 6 shows the TFR trajectories of Niger based on the results from WPP2019 as well as a simulation with slightly higher TFR in 2010-2020.[9] The difference between the two trajectories increases over time reaching an average peak of around 0.44 of a birth during 2030-2050. These variations in TFR levels were triggered by even smaller changes in the estimation phase and have significant implications on projected population levels.[10]

[8] Quinquennial estimates from WPP2017 were considerably higher within that period (data not shown).
[9] The 2010-2015 and 2015-2020 values are the same as in the *2017 Revision* though the projected levels differ slightly. Between both revisions, the onset of the projection phase was shifted onwards by 5 years (from 2015 in *World Population Prospects 2017* to 2020 in *World Population Prospects* 2019).
[10] The projected populations for the year 2100 between the *2017 and 2019 Revisions* were reduced from 192 million to 165 million.

Figure 6. Total fertility estimates and projections with different inputs for the period 2010-2020, Niger, WPP2019 and simulation with different "present", 1950-2100

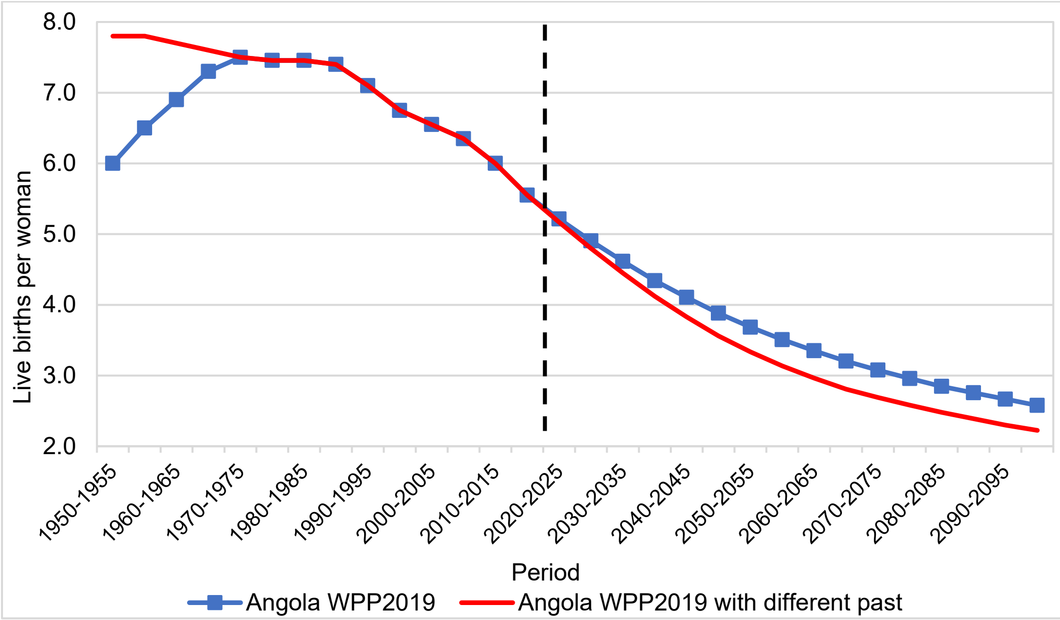


Sources: United Nations (2019a) and own simulation.

In the case of Angola (figure 7), having noticed the modification in TFR estimates from 1950-1970 across revisions, the country projection from the *2019 Revision* was re-processed using a new set of higher TFR values for the period 1950-1970. This change was responsible for a substantial variation in the projected TFR levels.

Though it could be anticipated that changes in current levels of TFR influence the projected trajectories, in the case of Niger, the differences in projected TFR in subsequent periods are overall greater than that from the actual change in the estimation period (and, as noted above, the impact on the population is significant). Nonetheless, it is of greater concern to have noticed, with the example of Angola, that variations in fertility estimates in the period 1950-1970, for which limited knowledge is available, and while all other estimates during 1970-2020 are identical in both sets of time-series, had significant implications on the projected TFR levels. This modification in the projected outcome is related to the effect of the onset of the fertility transition within the Bayesian model and the different timing experienced across these series of estimates. It was noted earlier in the section explaining briefly that Bayesian model that deterministic definitions for the start and end periods of the fertility phase were developed. Considering the above, further investigation on the role of the timing of the onset of the transition is required.

Figure 7. Total fertility estimates and projections with different inputs for the period 1950-1970, Angola, WPP2019 and simulation with different "past", 1950-2100



Sources: United Nations (2019a) and own simulation.

VII. The case of Uganda: What can we learn from it?

Analysing variations in levels and trends of fertility across countries, over time and by projection methods used has its merits and certainly deserves more attention. However, in the context of population estimates and projections, what often receives the most attention are the trends in the size of the population. As mentioned earlier, and especially in the context of countries with relatively high fertility levels, the future trajectories of TFR are also the driving force of the projected population size. And even with relatively small changes in TFR trajectories, the projected population can vary considerably. The case of Uganda will now be used to explore the implication of such changes.

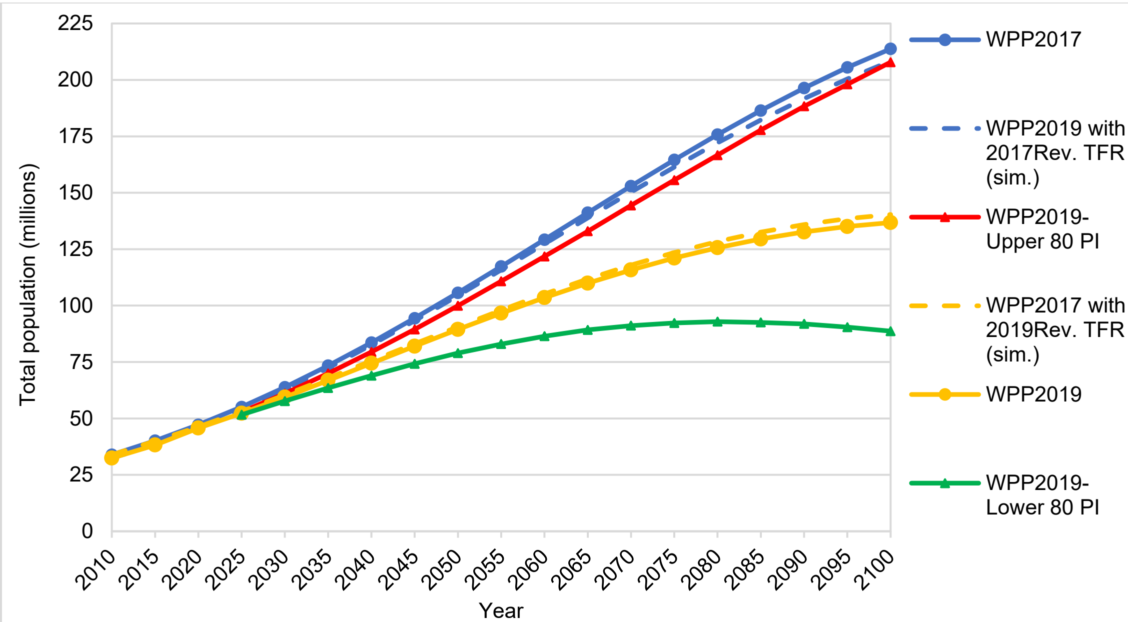
When comparing the total population of Uganda in the year 2100, based on the official results of the *2017 and 2019 Revisions* of the *World Population Prospects*, it was quite striking to notice that the projections, as shown in figure 8, were revised from 214 million to 137 million, a 36 per cent decrease across two consecutive editions of the WPP (see blue and orange circles). Figure 8 also includes the 80 per cent prediction intervals for WPP2019, and the median variant result from the *2017 Revision* is actually above this upper bound. [11]

In order to isolate the role of the total fertility estimates and projections used in the respective revisions, the *2017 Revision* projection of Uganda was re-processed with the *2019 Revision* total fertility values from 2010 onwards and vice versa. By comparing the projected populations of the respective simulations (see dotted blue and orange lines), it is quite clear that the fertility estimates and projections are the main drivers of these different population trends. In the case of the *2019 Revision*, 93 per cent of the population difference

[11] The upper and lower 80 per cent bounds from the *2017 Revision* reach values of 336 million and 126 million, respectively, in 2100 (data not shown). Overall, the lower bound trajectory from the *2017 Revision* is similar to the median trajectory from the *2019 Revision*, though encompasses lower population levels mainly after 2070.

in 2100 as compared to that of the *2017 Revision* can be explained with the revised fertility estimates and projections.

Figure 8. Total population based on the *2017 and 2019 Revisions* (plus 80 per cent prediction intervals for WPP2019) and simulations with different fertility trajectories, Uganda, 2010-2100

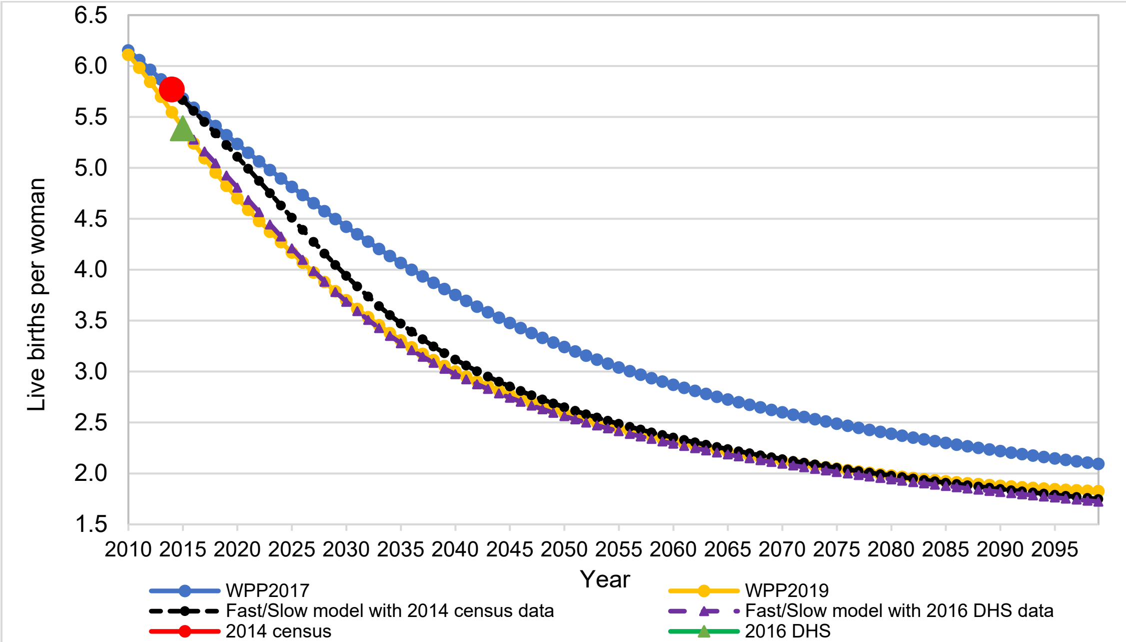


Sources: United Nations (2017b and 2019a) and own simulations.

As implied above, the main drivers for the encountered population differences are the total fertility estimates and projections that were modified across the two revisions based on newly available information (see figure 9). In both revisions, the latest available reported fertility estimates were used and fitted appropriately. The total fertility estimates of Uganda for the periods 1950-1955 to 2005-2010 are identical in both the *2017 and 2019 Revisions* of the *World Population Prospects*. Based on new data from the 2016 Demographic Health Survey (DHS), with a reported TFR of 5.4 live births per woman for the period 2014-2016, the estimates start to differ in the period 2010-2015 or as of 2010.[12] In the *2017 Revision*, this information was not yet available; the latest available data was from the 2014 census, which yielded a higher estimate of 5.8 live births per woman. As shown in figure 9, the respective TFR trajectories (see blue and orange circles) differ substantially, reaching a TFR of 2.09 and 1.83 by the end of the projection in 2099, though, most importantly, differences are actually greater in previous years (e.g., 0.76 of a birth in 2037). It is the cumulated effect of these differences in fertility levels that are responsible for the vast majority of the difference in the projected population size of Uganda across revisions.

[12] Annually interpolated estimates and projections of the total fertility rates are displayed in figure 8, starting in the year 2010.

Figure 9. Total fertility trajectories based on the *2017 and 2019 Revisions* and simulated trajectories based on a deterministic model using estimates from the 2014 census and 2016 DHS, Uganda, 2010-2099



Sources: United Nations (2017b, 2019a and 2019d), Uganda Bureau of Statistics and ICF (2018), and own simulations.

For comparison purposes, the deterministic models that are also based on a double-logistic function were used to generate two distinct trajectories[13] starting with the latest empirical data that were available at the time of the production of each revision. It can be observed in figure 9, that while using the results from the 2016 DHS and the Fast/Slow model, the TFR trajectory replicates quite well the Bayesian model trajectory from *World Population Prospects 2019*, and that, using a single input for a given year as a starting point. The same model was used with the 2014 census estimate which starts at a higher level of fertility though the trajectory converges by around 2050 to similar levels as the other two referred projections. Among the four trajectories illustrated here, the one based on the *2017 Revision* is substantially higher, yielding higher populations as seen in figure 8 above.

While using the underlying demographic information included in the *2017 Revision* for Uganda and applying the TFR trajectory labelled "Fast/slow model with 2014 census data", the populations were 40 million in 2015, 62 million in 2030, 96 million in 2050 and 152 million in 2100. With the *2019 Revision* information and the trajectory "Fast/slow with 2016 DHS data", the populations were 38 million in 2015, 60 million in 2030, 89 million in 2050 and132 million in 2100. Aside from the other demographic changes that occurred between these two revisions, the difference between the respective projected populations up to 2100 using the latest empirical data and the deterministic Fast/Slow model[14] is much smaller than when comparing the results of the *2017 and 2019 Revisions* based on the Bayesian model (a difference of 20 million versus 77 million in 2100).

[13] Again, these models were not designed for projections till 2100. The purpose of this comparison is merely to show the variation in the trajectories while using different models.

[14] In the above simulations the Fast/Slow model was chosen because it replicated relatively well the results of the *2019 Revision* based on the Bayesian model, though the implied decline is probably fast as compared to the overall experience of sub-Saharan African countries.

In light of these results and considering that an important aspect of producing population projections is to have some degree of coherence in the projected levels across countries and across revisions, it could be questioned whether the currently used projection fertility module may be too sensitive to variations in observed data or recent trends. The variation in fertility levels of the observed data, that is between the 2014 census and 2016 DHS, might be slightly strong, though such changes may occur as well in other countries. Therefore, it would be important to have a model that is less sensitive to those variation in inputs. It was also observed that the projected population of the *2017 Revision* was outside the 80 per cent prediction intervals from the *2019 Revision*, indicating that the “overall” uncertainty in the projected populations may be even greater than anticipated when considering the possible changes in past estimates (figure 8, above).

While the TFR trajectory in the *2017 Revision* might be high, the *2019 Revision's* relatively fast decline in TFR is atypical as compared to other countries. Part of this is related to the value that was estimated for the period 2015-2020. Annex figure A.4 shows that the percentage change of the total fertility rate of Uganda between the periods 2010-2015 and 2015-2020 is relatively high for the level of fertility (also see Afghanistan), as well as in the subsequent projection period (see annex figure A.5; this pattern can also be observed in the other subsequent projection periods; data not shown). Such findings call for a more thorough inspection of the observed empirical data and past estimates included in the WPP, and their impact on the trajectory of the projections.

VIII. Discussion and recommendations

When producing population projections using the cohort component method, it is possible to determine the contribution of the three components of demographic change—fertility, mortality and migration—on projected values of population size and other characteristics. Among these components, levels of fertility, especially in relatively high-fertility settings, are often the main drivers of future population dynamics[15] (Andreev and others, 2013). In this analysis, it was demonstrated that small variations in the more recent fertility estimates and/or at the starting point of a projection, combined to slight differences in future TFR trajectories, may sometimes translate into important variations in projected population levels and trends. These results illustrate the importance of having a robust method that generates results that do not vary too widely across countries with similar demographic histories, and for the same country across revisions of the WPP, especially in the absence of major changes in underlying reliable data or estimates.

In WPP2019, for which a Bayesian model was used to project fertility levels, it was observed through a series of examples in this paper that the TFR trajectories of several high-fertility countries varied considerably across countries (and across revisions with the example of Uganda, among others). To gain a better understanding of the Bayesian model and to inform possible changes of the model to minimize the magnitude of the variability, the performance of the Bayesian model was investigated by analysing and comparing existing results along with the outcomes from other models and simulations.

In the Bayesian model, the parameters of the decline function used to generate future TFR trajectories are estimated for each country. As noted previously, the TFR projections of Afghanistan, Côte d'Ivoire and the Central African Republic, which all had similar fertility levels during the period 2015-2020, followed distinct future trajectories. Furthermore, when comparing the 2010-2015 estimates for these three countries, which are based on observed data, Afghanistan's fertility was estimated to be the highest. The estimate derived for the period 2015-2020, for which observed data was not available, influenced the pace of fertility decline in the projection (a similar situation was observed for Uganda). To reduce the influence of estimated values for recent years that lack observed data, a standard approach in now-casting could be used to fill in

[15] Momentum, which is not considered here, is also an important aspect of population dynamics in many countries.

missing "estimates" to the starting point of the projection, or by starting the projection for each country in the year with the latest available observed data point.

Though one could expect, within a modelling exercise, that changes in recent and current levels of TFR influence to some degree, the projected trajectories, the magnitude of the variation is debatable and requires further investigation. However, through a series of examples, it was shown that these variations in TFR trajectories are sometimes significant. In the case of the Central African Republic, it was observed that the respective slopes in the more recent period were responsible for significant variations in the projected trajectories (seemingly, the shape of the slope influences future trajectories). A similar concern was also raised with the example of Niger, where it was illustrated that relatively small changes in current TFR estimates can modify the projected trajectory as well as the projected population. The simulation with the example of Angola showed how modifying the fertility estimates in the 1950-1970 period affected the projection.[16] In the case of Uganda, it was observed that results across revisions were very different partly because the Bayesian model generated significantly different trajectories based on slightly different inputs. Lastly, considering the quality and reliability of some observed data in several countries (and consequently of some estimates within the WPP), and while allowing some leeway in the demographic reconstruction of past trends, the impact of such uncertainty in the estimated trends on the projected trajectories should be limited.

Following the preceding analysis, it seems useful to address the following questions:

1) *Is a projection approach that generates variation in future trends across countries considered optimal and, are there arguments to generate less variable trends across countries?*

Over the years, demographic projection assumptions have predominantly relied on the underlying principle of convergence rather than divergence. The reality may be somewhere in between and may vary depending on the demographic component being projected (e.g., fertility versus mortality; also see Wilson, 2011). Though a projection approach that is more "neutral" and generates less variability across country-trajectories is supported, it is recognized that there will be some variation in future TFR levels and trends, even across countries that have similar past and present levels of fertility. However, not knowing in which particular direction these variations will occur, it would seem preferable, for instance, not to "claim" that two countries with similar TFR levels today will be substantially different in the future, while indicating which one will be higher or lower, unless there is a good reason for such specific forecasts. In other words, unless one can provide a sound argument to defend specific diverging trends, an approach that yields such variations may not be optimal. Furthermore, it could be argued that projections are not predictions and should be understood as an exercise designed to investigate what might happen in the years ahead according to various scenarios of possible future change (UNECE, 2018). As stated earlier, a key aim of the exercise is to ensure the consistency and comparability of estimates and projections over time and across countries with similar histories.

2) *Should a method rely on country-specific past trends that are not necessarily reliable, to determine future trajectories, and if not, what are the alternatives?*

Over the years, projection makers have been tempted to favour methodologies that provide some forms of uncertainty measurements, for example, based on the extrapolations of time series, to generate demographic projections (UNECE, 2018). Though the value of that approach is recognized in contexts where reliable data on past trends are available, it was observed that in other contexts, the projected TFR trajectories may vary considerably across countries. The main argument here, and this may apply more to countries with high fertility levels where the quality of the TFR estimates is sometimes debatable, is that

[16] It should be noted, that for this specific example and for the referred period, there is no data available to measure fertility; therefore, it is not optimal that the estimated levels influence the projections.

country-specific past trends are not always known with a high degree of precision. Therefore, those past levels and trends should be less influential in determining future trajectories. Again, the observed empirical data illustrated in annex figure A.3 for the countries highlighted in this paper, indicate that the "estimated" past trends in TFRs from 1950 to 2020 in the WPP for these countries, among others, could differ to some degree while still being deemed defendable or reasonable. Secondly, such variations in TFR trajectories, especially in high-fertility countries, have a major impact on the projected population levels. Therefore, a model that relies more on the past experience of "several countries" instead of country-specific experiences, while at the same time giving more emphasis or weight to the more recent level, could be favoured.

In recent years, with the development of probabilistic projections, there has been a tendency to assume that as long as the uncertainty bounds are plausible and encompass future possibilities, it is reasonable to assume that the median trajectories may vary and that consistency across countries with respect to median trajectories is not so crucial. As stated in the United Nations Economic Commission for Europe (UNECE) report (2018, p. 73): "The desire to produce probabilistic projections may lead projection makers to focus on the assessment of uncertainty at the expense of the "medium" or "most probable" scenario. This would be problematic, given that a large proportion of users will be interested only in values from that medium scenario". Though there seems to be an agreement that it is important for decision makers not only to have a point forecast that indicates the most likely scenario for a future population, it is also important to consider that most users focus on the median trajectory, and to provide greater weight to that reality.

Considering the important role that fertility trajectories have on the projected populations levels and how these population levels are used by policy makers and planners, and based on the analysis conducted in this paper, it is proposed that some modifications be considered in the Bayesian model in order to produce more consistent results across countries and across revisions.

Based on our analysis, the following is recommended:

a) Adopt procedures to generate "standardized" estimates following the last "observed input value" either by using the model as of that point or by adopting standard procedures to do short-term forecasts or now-casts. Develop an automated routine to verify that the estimated trend in the more recent years is not atypical, in order to avoid distortions in the projected pace of change. Considering that when doing projections for over 200 countries there may be some exceptional cases, providing a standard option to derive slower and faster paces of change in the TFR trajectories could be considered.

b) For countries with relatively high fertility levels and where the estimates of past trends of TFR may not always be reliable, downsize the role of the country-specific experiences and give more weight to the experience of a broader group of countries for determining future trajectories. In other words, minimize the effect of the recently estimated trends or implied slope on the projected trajectories by estimating the parameter vector of the decline function for a group or a cluster of countries, instead of for each country. Considering the complexity of implementing this recommendation and while not overlooking the role of the more recent trend on future trajectories, as an alternative, more efforts can be made to identify possible outliers in the input data by, among other approaches, verifying the average annual rate of change of the TFR, both in the estimation and the projection phases.

c) Modify parameters or functions in the model so that variations in past estimates such as in the example of Angola do not influence to that extent future trajectories. This requires updating the criteria to determine the onset of the fertility transition, which should be tested with the use of multiple simulations. In the event that this recommendation is not implemented, investigate which countries may have atypical "fertility transition patterns" and consider revising past estimates towards trends that may have less of an impact on the projected trajectories. This alternative approach should be considered only for countries where there is no data or no reliable data for the period considered.

In this paper, that focused mainly on the fertility trajectories of high-fertility countries, significant variations in the results from the WPP were identified. By comparing the results, including to those of other approaches and simulations, some of the underlying causes of these variations were identified and some suggestions have been made to try to minimize them. This exercise has demonstrated the utility of conducting a sensitivity analysis of model-based projections to inform possible changes and further improvements in Bayesian model currently used by the United Nations Population Division to produce the *World Population Prospects*.

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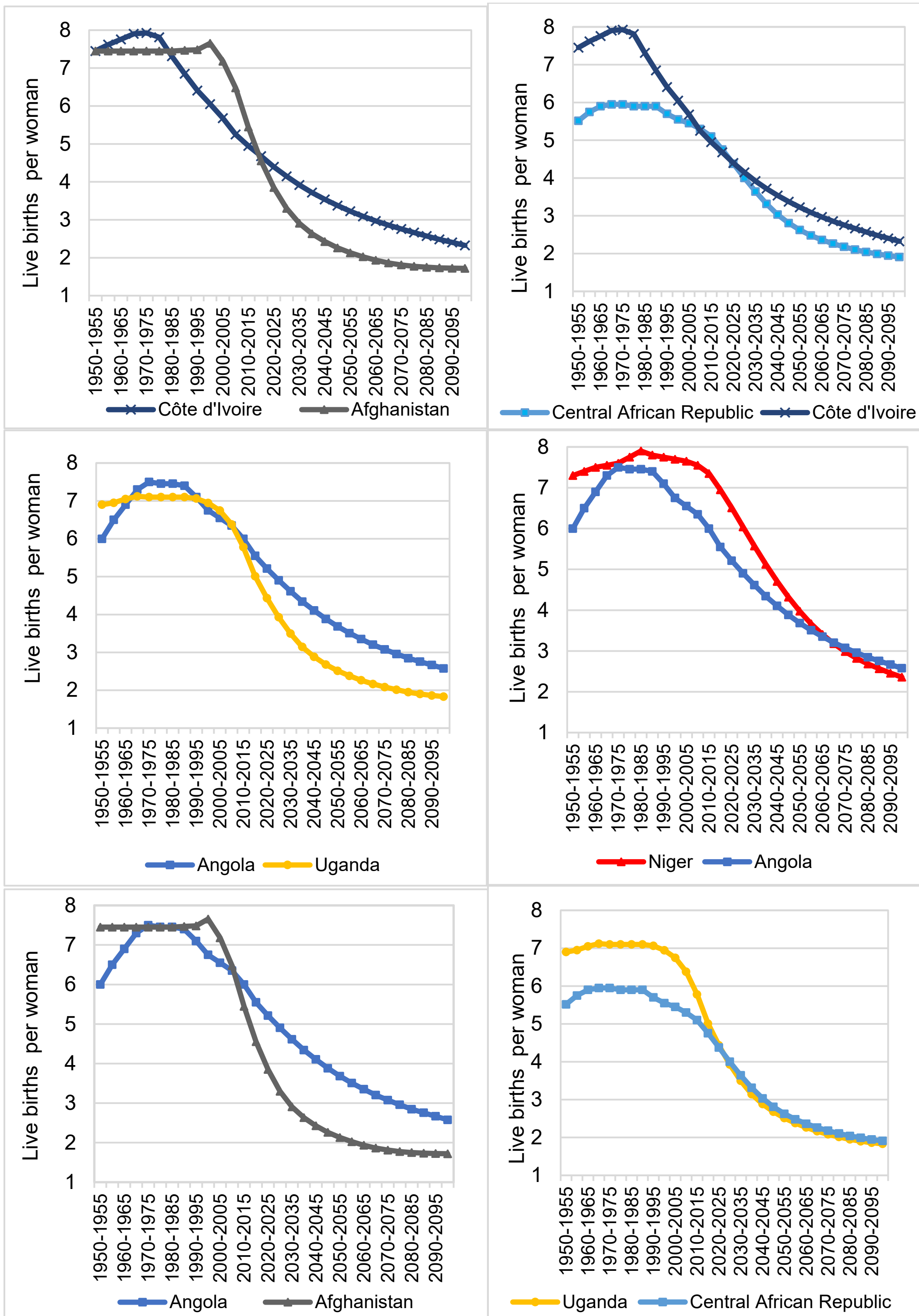
Figure A.1. Levels and trends of total fertility for selected countries, WPP2019 estimates and projections, 1950-2100



Source: United Nations, 2019a.

Figure A.2. Levels and trends of total fertility for selected countries, WPP2019 estimates and projections, 2000-2100 (examples of other countries not discussed in paper)

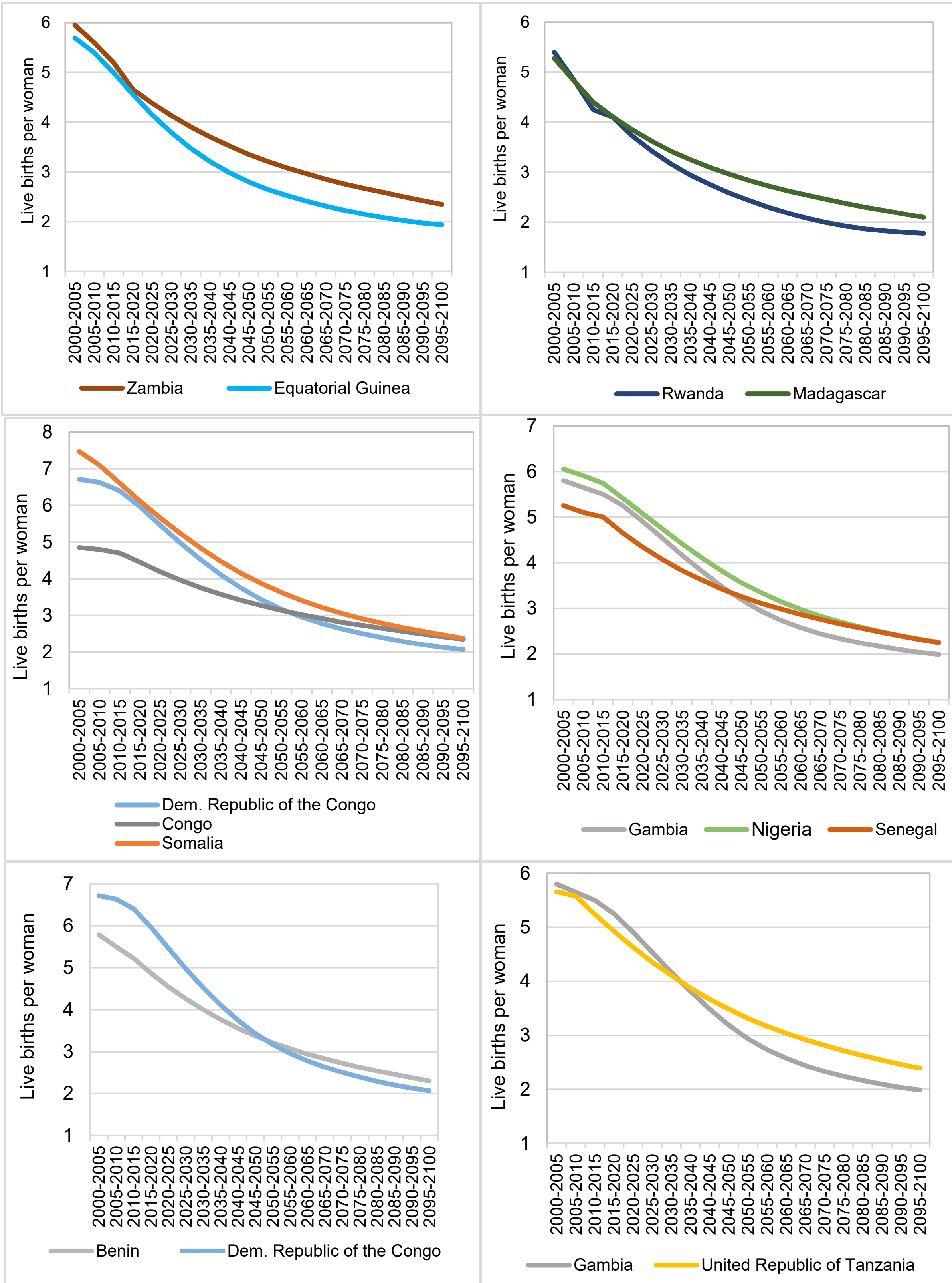
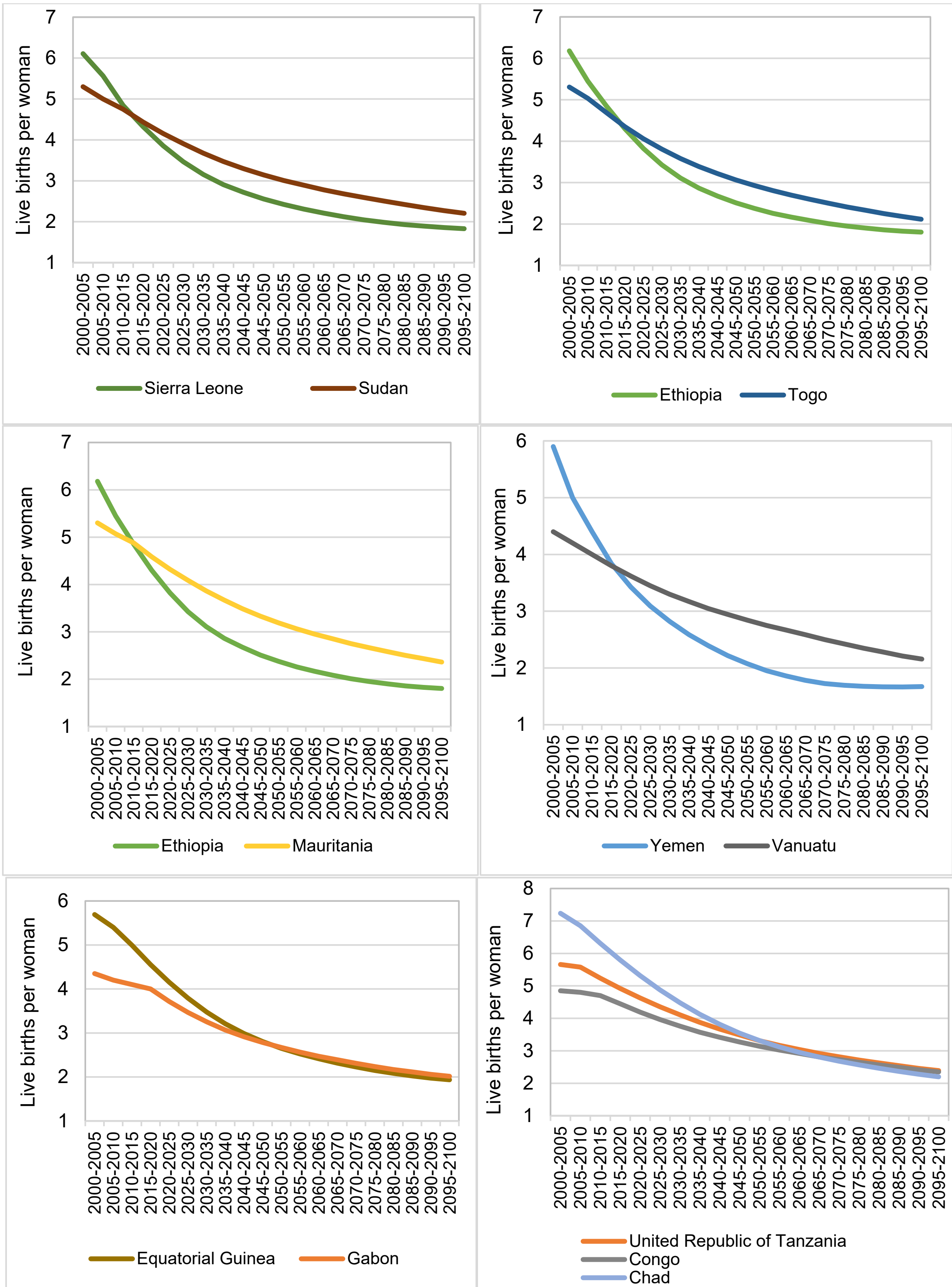
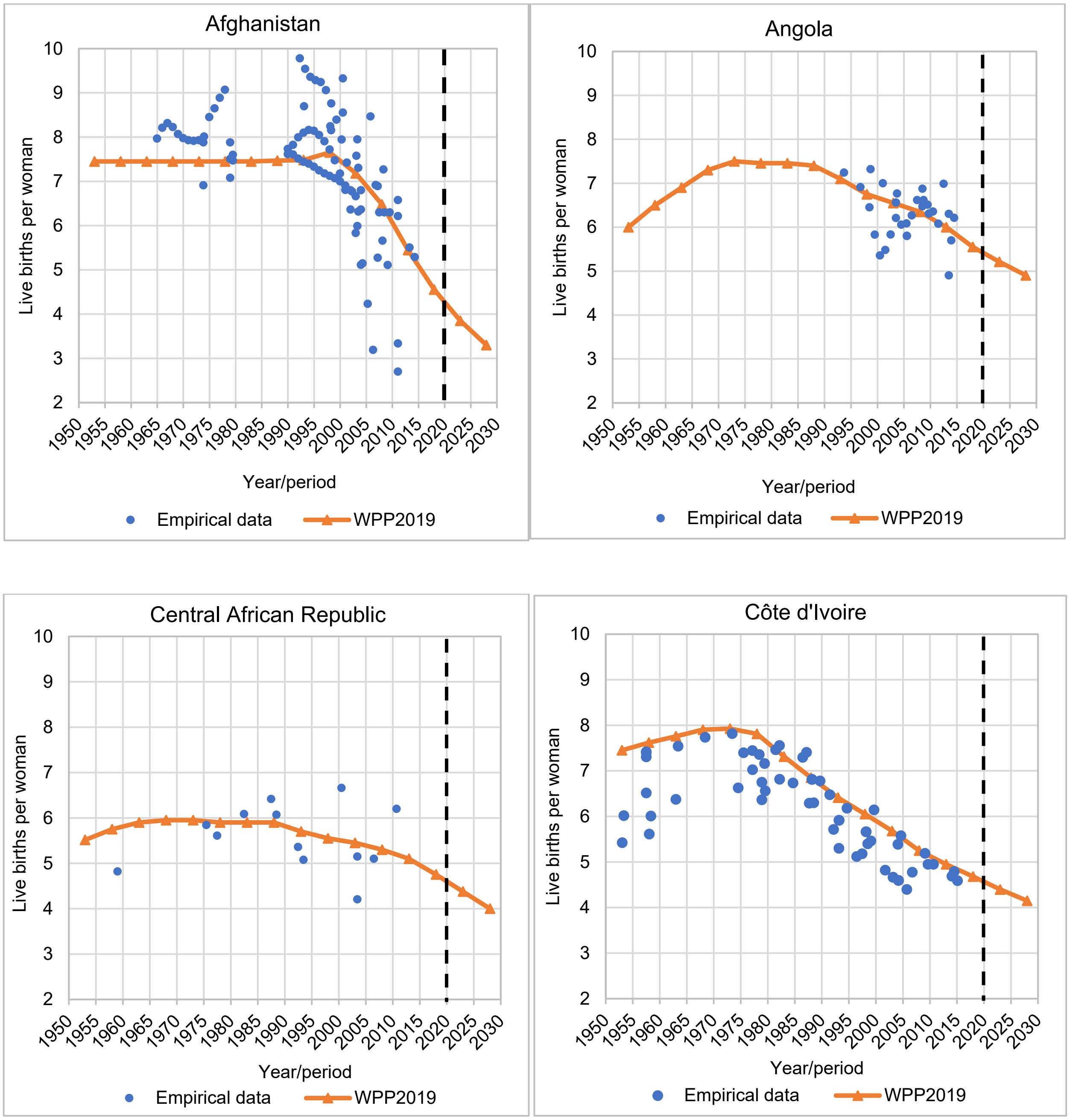


Figure A.2. …(continued)



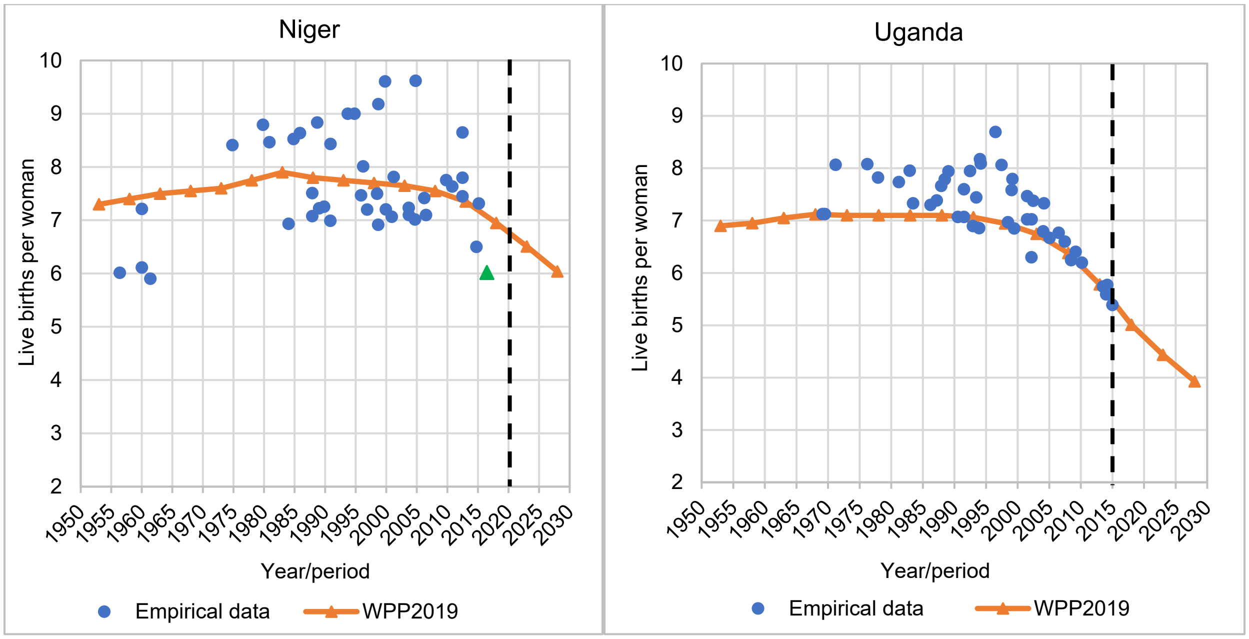
Source: United Nations, 2019a.

Figure A.3. Levels and trends of total fertility for selected countries, empirical data for given years and WPP2019 estimates and projections, 1950-2030

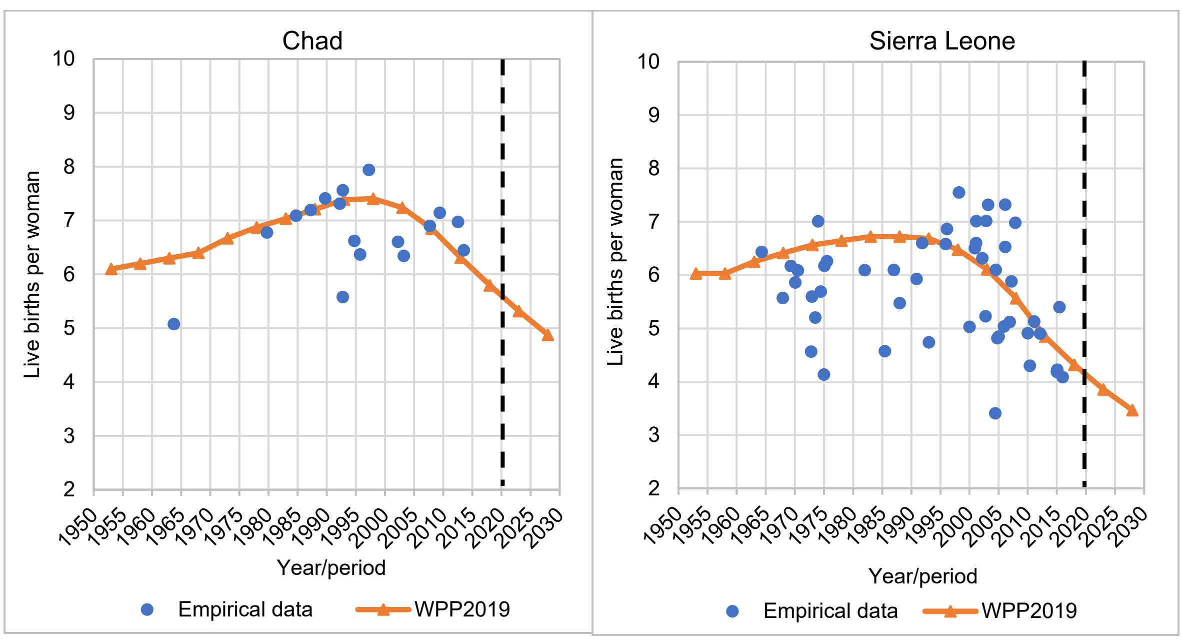


Comment: For the most part, the levels and trends depicted by the orange lines, which are based on the WPP2019 official estimates from 1950-2020 constitute reasonable sets of estimates (projected trends till 2030 were added for illustration purposes). However, based on the compiled empirical data points or estimates (blue dots) one could easily derive other sets of estimates that are also defendable. In that regard, there is leeway and the derived trends could easily vary among these different past "time-series". The quality of the underlying data varies by country though the concerns expressed here do not only apply to the countries listed in this paper. Among others, Chad and Sierra Leone are also illustrative examples (see Figure A.3, continued).

Figure A.3. …(continued)



(Other countries not analysed in this paper)



Sources: United Nations (2017c, 2019a and 2019d) and Uganda Bureau of Statistics and ICF (2018).

Notes: Estimates and projections from the WPP are quinquennial values (e.g., 1950-1955 estimates are plotted to the year 1953). For Niger, the preliminary estimate (green triangle) from the 2017 DHS was not used because of data quality issues (the DHS report was not released; for further details see: Rutstein (2018)).

Figure A.4. Percentage change in TFR levels between 2010-2015 and 2015-2020 by TFR level in 2010-2015, 201 countries or areas, WPP2019

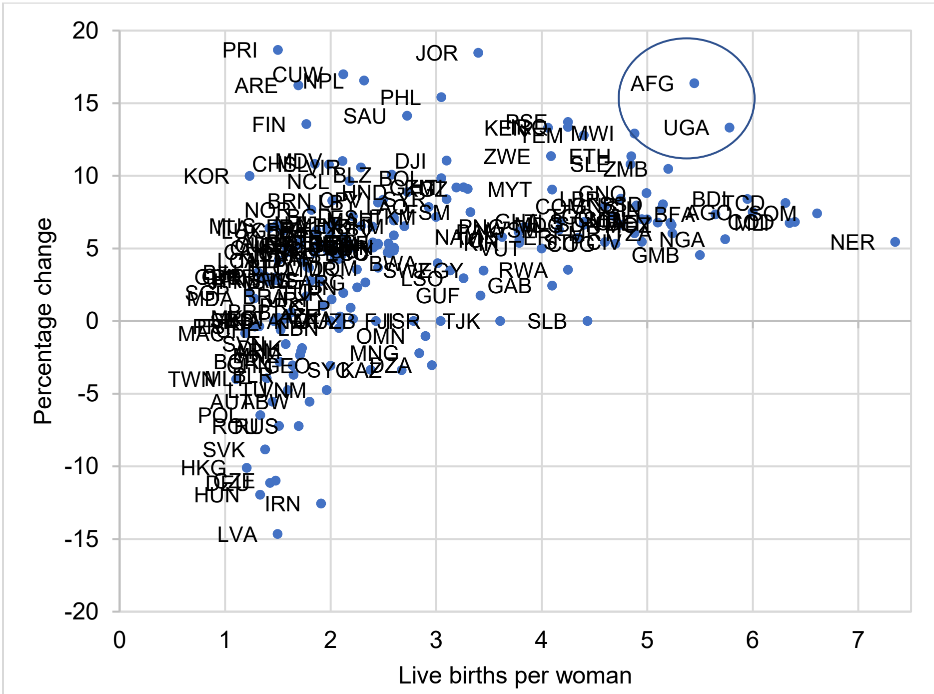
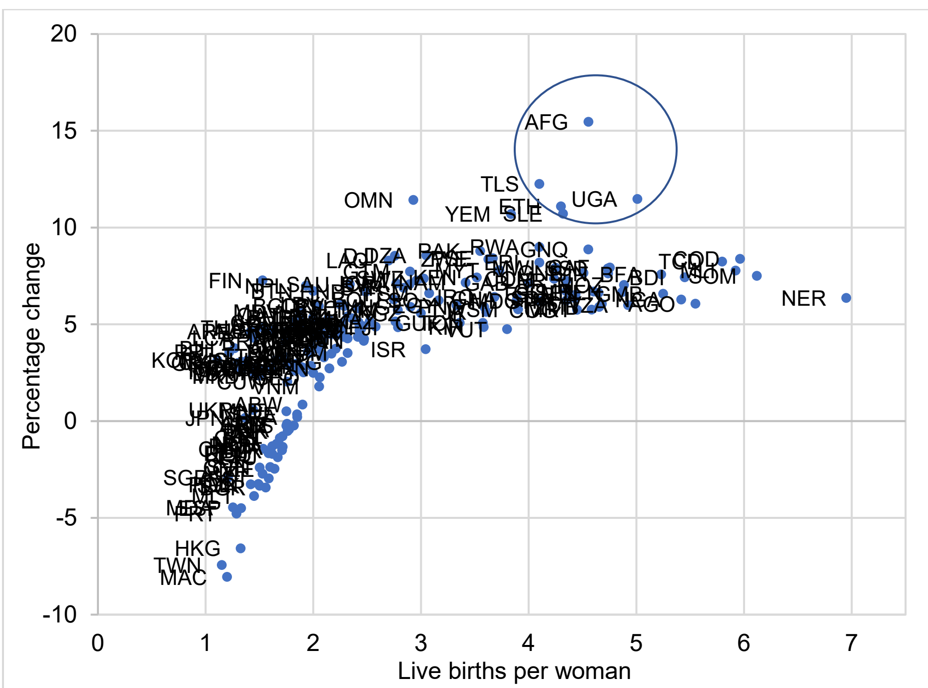


Figure A.5. Percentage change in TFR levels between 2015-2020 and 2020-2025 by TFR level in 2015-2020, 201 countries or areas, WPP2019



Source: United Nations (2019a) and own calculations.

Note: Both Afghanistan and Uganda have atypical levels of change. It could also be argued that other countries not discussed in this paper also have atypical levels of changes (e.g., Ethiopia, Finland, Kenya, Malawi, Nepal, and the Philippines, among others).