‘Early Rectangularization’ of under-5 mortality in sub-Saharan Africa: compression, convergence, inequality

Iván Mejía-Guevara[1,2,a] and Shripad Tuljapurkar[1]

[1] Department of Biology, Stanford University, Stanford, California, United States of America
[2] Center for Population Health Sciences, Stanford University School of Medicine
[a] Corresponding author: imejia@stanford.edu

Abstract

This study analyzes compression, convergence, and age-inequality of under-5 mortality patterns in sub-Saharan Africa (SSA). We hypothesize that accelerated reductions in under-5 death rates are associated with substantive changes in the age distribution and variation of deaths. To analyze age variation rather than mean values for under-5 deaths, we adapted indicators of compression, convergence, and inequality that were developed for the total length of life. We constructed conditional life-table death rates for under-5 age children from 31 SSA countries from 1990 to 2017, using retrospective data from the Demographic and Health Surveys for these countries. We used these to identify heterogeneities across countries in the age patterns of mortality, the pace of mortality decline, and convergence. Our results revealed stronger evidence of reduced age-inequality in countries experiencing large or accelerated reductions in average under-5 mortality levels (with annual reduction rates [ARR]≥3.2%), in comparison with those showing stagnant or slower mortality decline (ARR<3.2%). Data quality issues derived from the use of survey data to approximate age patterns of mortality may affect the accuracy of the estimates and represent a limitation of this study.

Introduction

The epidemiological transition from young to old deaths in high-income countries has marked the decline in mortality levels at all ages. Many studies of this transition have focused on senescent mortality and such issues as mortality compression—deaths concentrated at or near some unspecified age—and rectangularization—the idea that anyone surviving to a certain age must then die soon after—at old ages (Fries 1980; Myers and Manton 1984; Wilmoth and Horiuchi 1999; Kannisto 2000), and the decline in the variance of the age at adult death (Edwards and Tuljapurkar 2005; Schindler et al. 2012). But a determinative role in the mortality transition was played by the decline of infant and child mortality from exogenous causes (i.e., infections or parasites, accidents) (Fries 1980; Cutler and Meara 2004). Reductions of child mortality have led to substantial increases in life expectancy at birth (Keyfitz 2005; Cutler and Meara 2004), and an increasing modal age-at-death (Canudas-Romo 2008). Over time, the age pattern of under-5 deaths is also expected to shift: as declines in exogenous mortality continue, under-5 mortality should shift towards ages close to birth, but are likely to remain high during the first month of life due to the persistence of endogenous causes of death (i.e., congenital malformations, injuries connected with birth, or chronic degenerative) (Bourgeois-Pichat 1951b, 1951a). We call this phenomenon the 'Early Rectangularization of the Mortality Curve', and this change has been observed in high-income countries.

However, little is known about the age-pattern of under-5 mortality in low-income countries, particularly in sub-Sharan Africa (SSA), the region with the highest under-5 mortality (UN IGME 2017) and home to nearly one fourth of the under-5 population worldwide (UN 2017). The age-distribution of young deaths has not received much attention in the extensive literature on under-5 mortality trends in SSA and other low- and middle-income countries (Bendavid

2014; Mercer et al. 2015; Burke, Heft-Neal, and Bendavid 2016; Wang et al. 2016; Golding et al. 2017, 2017; Abajobir et al. 2017; Fadel et al. 2017; Chao et al. 2018), but just recently new methodologies have been developed that approximate child mortality patterns by age based on summary (Burstein et al. 2018) or full (Mejía-Guevara et al. 2019) birth history data. The importance of the age distribution of under-5 deaths has been underscored by methodological work (Guillot et al. 2012) demonstrating that traditional life table models do not adequately approximate child mortality patterns in SSA, and by the use of age profiles of under-5 mortality to forecast mortality rates (Mejía-Guevara et al. 2019) for the assessment of Sustainable Development Goals (SDGs) in SSA. In addition, between- and within-variation in the length of life is an important indicator of health inequality (Edwards and Tuljapurkar 2005; Raalte, Sasson, and Martikainen 2018) and then analyses of the differences in the age pattern of under-5 mortality across and within countries should reflect health disparities at young ages.

Here we focus on the 'Early Rectangularization of the Mortality Curve' in countries in SSA, investigating age compression, convergence, and inequality in infant and early child mortality. To do so we adapt to young ages many of the methods used previously in studies of the age-distribution of adult deaths (Fries 1980; Myers and Manton 1984; Kannisto 2000; Wilmoth and Horiuchi 1999; Shkolnikov, Andreev, and Begun 2003; Edwards and Tuljapurkar 2005; Nau and Firebaugh 2012; Engelman, Canudas-Romo, and Agree 2010; Gillespie, Trotter, and Tuljapurkar 2014). Note that there are important differences in the expected trends of age compression and inequality between adult and child mortality patterns. Compression of adult mortality in middle- or high-income countries has been characterized by reductions in the standard deviation of age-at-death, generally followed by increases in the mean age-at-death—except in countries with periods of considerable instability in mortality like those in Central and Eastern Europe (Aburto

and van Raalte 2018), whereas for child deaths we expect declines in the mean age accompanied by decreasing variation by age. In addition, as inequality in length of life declines, a higher proportion of the adult population dies at older ages; conversely, declining inequality of under-5 age-at-death should mean that a higher proportion of the under-5 population dies at ages close to birth.

The main objectives here are to: 1) assess the compression of mortality patterns and the 'Early rectangularization' of under-5 deaths in SSA, 2) analyze convergence in the distribution of under-5 mortality patterns, and 3) evaluate age-inequality in children below 5. These analyses highlight the significance of variation and the speed of convergence in age patterns of under-5 mortality as important elements in the acceleration of mortality decline in SSA, and their potential to identify a wide range of epidemiological situations and trajectories.

Results

Compression of under-5 mortality: 'Early rectangularization of the mortality curve'

We show in **Figure 1** that, over time, mortality curves by age are becoming more 'rectangular' as mortality rates decline overall but remain high during the first month of life relative to later ages. This pattern is shared by most countries in SSA, but the age-specific speed of change has varied across countries and time. To highlight differences in the evolution of this age-pattern, we examine the youngest ages at which 50%, respectively 75%, of under-5 mortality takes place in a country; we denote these ages respectively by A_{50} and A_{75}. In Chad and Nigeria, age A_{50} only fell by 2 months in about 25 years (between 1990 and 2015) and at this rate would only fall to about 6 months by 2030 in both countries (from 10 to 6 in Chad, and 8 to 5 in Nigeria, **Table 1**), whereas age A_{75} would only fall moderately to age 22 (from 26 in Chad) or 17 (from 21 in

Nigeria) months, ages well over a year (**Figure 1**). In contrast, under-5 mortality has fallen more rapidly in Rwanda and the United Republic of Tanzania (Tanzania hereafter): in these countries age A_{50} declined 4 months [from 9 (8) to 5 (4) in Rwanda (Tanzania)] in nearly 25 years and at this rate would fall to 1-2 months by 2030, whereas A_{75} declined from 25 to 18 (Rwanda) or 21 to 16 (Tanzania) in the past and would fall to about 12 months by 2030, i.e., 75% of the under-5 deaths in Rwanda and Tanzania will be concentrated during the first year of life. Accelerated declines in neonatal (within the first month of life) and infant mortality (during the first 12 months of life) accounted for most of the progress in under-5 mortality reduction in the latter countries (**Figure 1**). The ages A_{50} and A_{75} show similar differences in all SSA countries in our sample (**Table 1**). Finally, it is worth noting that one fourth of the total under-5 deaths (A_{25}) are occurring—in the latest observed year—during the first month of life in all countries (not shown).

[Insert **Figure 1** here]

[Insert **Table 1** here]

Compression of under-5 mortality: differences across age groups

The results above evidence mortality compression of child deaths towards age zero, but the pace of mortality decline across age groups differed across countries, and slowed down or prevented mortality compression. The age pattern of young deaths can be clearly dissected by comparing deaths in all 5 years after birth, deaths between ages 1 month and 5 years, and deaths between ages 12 months and 5 years. For deaths in these age ranges, we define three conditional mean ages at death: from birth, $E_{[0]}$, after surviving the first month, $E_{[1]}$, and after surviving the first 12 months, $E_{[12]}$ (where subscript [x] indicates age x in months). The dispersion of death in the three age ranges is described by corresponding measures of the standard deviation of age-at-death,

denoted by $S_{[0]}$, $S_{[1]}$, and $S_{[12]}$. The upper panel of **Figure 2** plots time trajectories of the three mean ages at death for Chad, Nigeria, Rwanda, and Tanzania. In Chad, the conditional mean ages $E_{[0]}$ and $E_{[1]}$ decreased slightly over time, but $E_{[12]}$ increased over time, while the corresponding measures of the standard deviation of age-at-death ($S_{[0]}$, $S_{[1]}$, and $S_{[12]}$ shown in the lower panel of **Figure 2**) all increased during the same period. By comparison, in Nigeria $E_{[0]}$ declined more rapidly between 1991 and 2013, both $E_{[1]}$ and $E_{[12]}$ decreased at a slower pace; while $S_{[0]}$ increased, $S_{[1]}$ remained flat, and $S_{[12]}$ decreased slightly during the same period. In Rwanda and Tanzania, we observed declines of $E_{[0]}$, $E_{[1]}$, and $E_{[12]}$, accompanied by declines in $S_{[0]}$, $S_{[1]}$, and $S_{[12]}$, with a faster pace in Tanzania. Comparing these measures in both countries, $E_{[0]}$ and $S_{[0]}$ declined fastest, by about 3-4 months in the mean age-at-death and about 1 month in the standard deviation, respectively. These results provide evidence of stalled or expanding mortality in Chad and Nigeria reflected by constant or increasing variation of age-at-death, accompanied by mean changes moving independently by going in different directions depending on the age group. In contrast, in Rwanda and Tanzania the stronger and correlated trend of decreasing $E_{[.]}$ and $S_{[.]}$ evidences early compression in these countries (**Figure 2**).

[Insert **Figure 2** here]

Convergence in distribution of under-5 mortality patterns by age

We analyzed changes in the age distribution of under-5 deaths over time, using as a measure the Kullback-Liebler Divergence, $K_{[0]}$, with the age-distribution of deaths for Tanzania in 2016 as the reference for all country-years. Our reference age profile of under-5 mortality uses a country with a good record of mortality decline: that met the Millennium Development Goal 4 (MDG-4)—by reducing under-5 mortality by two-thirds between 1990 and 2015 (Afnan-Holmes et al. 2015)—and is on track to reach the Sustainable Development Goal 3 (SDG-3)—of reducing

neonatal mortality by 'as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births'—by 2030 (Mejía-Guevara et al. 2019). **Figure 3** illustrates the trajectories of $K_{[0]}$ (with smaller values indicating convergence) across time for the same group of countries (Chad, Nigeria, Rwanda, and Tanzania), which indicates that countries with a slow or moderate pace of mortality reduction (Chad and Nigeria) are associated with a less rapid convergence in distribution—$K_{[0]}$ declines slowly or moderately, compared to countries with more steeper declines in under-5 mortality (Rwanda and Tanzania)—where $K_{[0]}$ decreased more rapidly.

[Insert **Figure 3** here]

Inter-individual inequality in age-at-death

We analyzed conditional age-inequality in **Figure 4** using trajectories of the Lorenz curve ($L_{[0]}$, upper panel) and the Drewnowski Equality Index ($D_{[0]}$ =1- $G_{[0]}$, where $G_{[0]}$ is the Gini coefficient, lower panel) across time. Based on these indicators, age-inequality has declined ($L_{[0]}$ moved away from the total equality 45° line and $D_{[0]}$ decreased over time) for the 4 representative countries (Chad, Nigeria, Rwanda, and Tanzania), but more rapidly for Rwanda and Tanzania as the gap between $L_{[0]}$ from the initial (1990-95) and latest year periods (2015-16) widened at a higher pace in relation to that observed in Chad and Nigeria. The displacement to the right of $L_{[0]}$ represents a decline equivalent to nearly 9 percent in $D_{[0]}$ for Chad and Nigeria, but between 18 and 21 percent in Rwanda and Tanzania. That is, we found evidence of reduced age-inequality in the four countries, but the speed of decline was twofold or more in Rwanda and Tanzania. These findings are in line with our estimates for $S_{[0]}$, $S_{[1]}$, and $S_{[12]}$ in **Figure 2** that also provided evidence of reductions in the variance of age-at-death in Rwanda and Tanzania, but with stagnant or increasing variation in Chad and Nigeria.

[Insert **Figure 4** here]

Summary of results

We measured the trends in under-5 mortality from the initial to the latest year in each country using the Annual Rate of Reduction (ARR), and classified countries in two groups: countries with ARR below/above 3.2%—the ARR of SSA between 1990 and 2017 (UN IGME 2017)—in our sample were classified in group 1/group 2, respectively (**Table 1**).

We summarized our measures of compression of mortality (A_{50}, A_{75}, $E_{[0]}$, $E_{[1]}$, $E_{[12]}$, $S_{[0]}$, $S_{[1]}$, $S_{[12]}$), convergence ($K_{[0]}$), and age-inequality ($D_{[0]}$, $S_{[0]}$, $S_{[1]}$, $S_{[12]}$) for all countries in our sample in **Table 1**. We found marked differences in mortality patterns between countries in groups 1 and 2. In countries with ARR above 3.2%, we found substantive evidence of compression, convergence, and reduced age-inequality (e.g., more rapid decline of A_{75}, $S_{[0]}$, $K_{[0]}$, and $D_{[0]}$), but less strong evidence in countries with achieved ARR below 3.2% (e.g., less rapid decline of A_{75}, $S_{[0]}$, $K_{[0]}$, and $D_{[0]}$). For instance, A_{75} declined in average 2.8 times faster in group 2 compared to group 1: in group 1, A_{75} declined by 0.09 months (~2.6 days) per year in average, varying from a 0.10 month increase in Gabon to a 0.35 month decline in Sierra Leone per year; whereas it declined 0.24 months (~7.3 days) per year in average in group 2, varying from 0.6 to 0.0 month decline per year in Senegal and Malawi, respectively (**Table 1,** and graphs for all countries in **Figure S1** in the Supplementary Information). Further, $S_{[0]}$ declined 3.3 times faster in group 2 compared to group 1, by 0.01(~0.4 days)/0.04(1.2 days) months per year in average in group 1/2, ranging from a 0.04/0.02 months increase in Mali/Malawi to a 0.17/0.11 decline per year in Sierra Leon/Senegal, respectively. Lastly, $D_{[0]}$ declined 2.9 faster in group 1 than group 2: it decreased 0.3% per year in average in group 1—varying from a 0.6% increase in Namibia to 0.8% decrease in Kenya per year—and 0.8% per year in group 2—varying from a 0.1% increase

in Guinea to 1.5% decrease in Senegal per year. Forecasts of under-5 mortality, based on our Li-Lee-Tuljapurkar (LLT) model (Mejía-Guevara et al. 2019)—a variant of the Lee-Carter model (see Methods section below), indicate that had the trends in mortality decline observed in the past would continue, the countries with more rapid declines in the variation and age-at-death inequality would also be more likely to reduce their mortality levels by 2030 (**Table 1**).

Discussion

This study demonstrates that the under-5 mortality transition, currently taking place in sub-Sharan Africa, is characterized by an ongoing concentration of deaths towards age 0 (compression), a change in shape of mortality with age ('early rectangularization', and convergence in distribution), and a gradual reduction in the conditional age-inequality. These changes have not been homogenous, as countries with a faster mortality decline have experienced the most notable advances in compression, convergence, and age-inequality. In addition, we observed a pattern of decline in both the mean and standard deviation of age-at-death conditional on survival at different ages for countries with more rapid rates of mortality decline (group 2), evidencing compression of mortality towards birth; in contrast, the patterns were less clear for countries in group 1, where the mean and standard deviation were more likely to move independently—in some cases in opposite directions—across time or stagnating, evidencing expansion rather than compression at certain age groups. We find that neonatal mortality accounts for an important share of the variation in the mortality reduction, as it concentrated 25% of the total under-5 deaths during the last observed year for all countries in our sample. Lastly, based on mortality forecasts by 2030 (Mejía-Guevara et al. 2019), our findings highlight the importance of the age distribution, the shape, and differential patterns of decline

across ages over time for the acceleration of under-5 mortality reduction in the coming years and for the successful achievement of the SDGs.

We provided evidence of convergence in mean and distribution of mortality patterns in countries with higher rates of child survival. In particular, the convergence in distribution in this set of countries follows a pattern that is becoming increasingly rectangular, having an increasingly flat down and sharp upslope that we refer as the 'early rectangularization' of the under-5 mortality curve, a similar but distinct phenomenon studied previously for older populations (Fries 1980; Wilmoth and Horiuchi 1999; Kannisto 2000).

We identified salient differences across countries in terms of distribution of deaths by age and time, convergence, and inequality in mortality reduction by age; particularly after stratifying countries on the basis of their achieved ARR between 1990 and 2016. On the one hand, countries with an ARR below 3.2% experienced a slower convergence process both in terms of mean and distribution of age-at-death. Mortality reductions occurred at different rates across under-5 ages, the mean and dispersion of age-at-death remained constant or have increased in most countries, which is in line with results from previous studies (Guillot et al. 2012), showing unusual high values of ${}_4q_1$ (the probability of children dying between age 1y and 5y) relative to ${}_1q_0$ (the probability of dying during the first year of life) in several countries from SSA, that may be attributable to true epidemiological patterns (e.g., disease environments characterized by high prevalence of infectious diseases—malaria, measles, and diarrhea) rather than to data quality issues as similar patterns have been found in previous studies based on Demographic Surveillance Systems (DSS) data (Jasseh 2003; Guillot et al. 2012). On the other hand, our findings revealed substantive evidence of mortality convergence, both in terms of mean and distribution, for countries that have reached higher ARR (≥3.2%), including countries that have

met the MDG-4—e.g., Ethiopia, Malawi, Niger, Tanzania, and Rwanda (Moucheraud et al. 2016).

Compared to other forms of inequality, age-inequality has been characterized as the most fundamental because it is not conditional upon survivorship and mortality is the ultimate indicator of health (Tuljapurkar 2010; Raalte, Sasson, and Martikainen 2018). The association of socioeconomic status (SES)—or income—and health/mortality has been of great interest for quite a time, and some hypotheses—absolute-/relative-income and income-inequality hypotheses (Wilkinson 1996, 1997)—have emerged that provided supporting evidence on the positive relationship between the distribution of income and health—although mixed findings have also been reported in different studies (Wilkinson and Pickett 2006), the shape of that association, and the extent to which higher differentials in the income distribution affect the health of the whole population rather than just disadvantaged groups (Preston 1975; Adda, Chandola, and Marmot 2003; Deaton 2003; Marmot 2005; Mackenbach et al. 2005; Cesare et al. 2013; Abajobir et al. 2017; Marmot 2018). Further, although previous studies have examined the association between infant mortality and various social determinants of health—including maternal education, place of residence, socioeconomic status (Bendavid 2014; Moucheraud et al. 2016; Burke, Heft-Neal, and Bendavid 2016; Beatriz et al. 2018; Chao et al. 2018)—future research should assess the role of underlying and social determinants of mortality change in a country-basis (Marmot 2005; Accorsi et al. 2010; Amouzou, Habi, and Bensaïd 2012; Afnan-Holmes et al. 2015; Musafili et al. 2015; Chao et al. 2018) that interact with the age-at-death distribution/inequality that could provide further light on the state of mortality of the most vulnerable groups in each specific context and aiming to identify true epidemiological patterns (Guillot et al. 2012).

Our study builds on previous research that analyzed inequality in the length of life and convergence of mortality across the whole life span, but that emphasized mortality patterns at adult/old ages (Shkolnikov, Andreev, and Begun 2003; Edwards and Tuljapurkar 2005; Engelman, Canudas-Romo, and Agree 2010). Using under-5 mortality profiles from narrow-age groups from 31 SSA countries, developed by (Mejía-Guevara et al. 2019) for the forecasting of mortality rates and the assessment of the SDG-3 by 2030, this study is—to our knowledge—the first to explore this kind of mortality patterns to assess compression, convergence and under-5 age-inequality in SSA. We investigated the extent of age-inequality and variation in under-5 mortality, and we found important differences in the patterns of change across countries over time, with a positive association between the rates of mortality change and age-inequality. This evidence aims to inform in the design and scale-up of targeted interventions intended to reduce health inequalities across age groups and for those that most needed.

The scope of this study is limited for several reasons. First, results are based on age profiles constructed using full-life histories from survey data, which are subject to several sources of error; rather than high quality vital registration systems, which are inexistent or deficient in the countries included in our study (Bryce et al. 2016). Second, we used different measures of inequality to improve the robustness of our analysis as they differ in their underlying properties and sensitivity to age-specific mortality change (van Raalte and Caswell 2013). Third, a formal mathematical analysis of compression, convergence, and age-inequality, applied to under-5 mortality profiles, may provide further insights into their limitations, interpretation, and applicability in this context, as well as lead to investigate the theoretical limits of mortality decline in under-5 populations. Fourth, because of the nature of the survey data, we cannot infer causality in the association of the average decline of mortality and age-inequality, and further

research should explore the underlying risk factors, social determinants, and true epidemiological patterns behind under-5 mortality change by age in the SSA region and worldwide.

Methods

Data source and retrospective mortality data

We obtained birth history data from 106 nationally representative Demographic and Health Surveys (DHS) from 31 sub-Saharan African (SSA) countries from the period between 1990 and 2017. DHS collects health and demographic information for women in reproductive age (15-49 years old) and their children, using a two-stage stratified cluster sampling design that defines strata by region and by rural-urban within each region. A sampling frame consisting of census enumeration units or tracks or Primary Sampling Units (PSUs) that cover the entire country is used for the random selection of PSUs in the first stage, with probability proportional to sampling size. Clusters correspond to selected or further split PSUs (or blocks). In the second stage, households are selected systematically from a list of previously enumerated households within each selected cluster or block.

Mortality profiles by age were assessed using full birth history (FBH) data available for individual women aged 15 to 49 years in DHS surveys, where the respondent mother is asked about the date of birth of each of her ever-born children, and the age at death if the child has already died (Hill 2013).

‘Conditional’ life-table age distribution of under-5 deaths

We used life-table age distributions of death, constructed by Mejía-Guevara et al. (2019) based on the following demographic analysis.

First, using death reports by households and retrospective information from full birth history (FBH) data from DHS (Hill 2013), estimates of age-specific death rates $m_{[x]}$ ([x] stands for age

in months) were obtained from survey estimates of the number of events and total time to event (Hill 2013), and used to compute period life-table probabilities of dying, $q_{[x]}$ (probability of dying between month *x* and month *x+1*), assuming a uniform distribution of deaths across age.

Second, mortality rates by age were adjusted using the most recent estimates of neonatal, infant, and under-5 mortality rates from the Inter-agency Group for Child Mortality Estimation (IGME) (Hill et al. 2012; UN IGME 2017) to minimize the risk of measurement errors in direct estimates of under-5 deaths based on FBH [e.g., survivor and truncation bias (Silva 2012; Hill 2013)]. After the previous adjustment, mortality profiles were smoothed over ages and years by using a two-dimensional P-Spline smoothing and generalized linear model, assuming that the number of deaths at a given rate are Poisson-distributed (Camarda 2012).

Third, a variant of the Lee-Carter (LC) (Li, Lee, and Tuljapurkar 2004) model (LLT), suitable for mortality profiles using datasets that contain multi-year gaps, was used to fit the age mortality profiles after smoothing for each country. The resulting fits were first used to generate smoothed point estimates of age-specific death rates within the 1990-2017 period.

More details about the construction of age profiles, adjustment, fit, and goodness of fit are available elsewhere (Mejía-Guevara et al. 2019).

Mortality compression, convergence in distribution, and age-inequality

1) Mortality compression

To measure the degree of mortality compression towards age 0 as evidence of the "early rectangularization" of the under-5 mortality curves for each country across time, we computed the minimum interval where a percentage p of the total under-5 deaths takes place, that we denoted A_P. This indicator is equivalent to the C-family of indicators proposed by Kannisto (2000) for assessing compression of mortality, except that the author used it for adult mortality

and our indicator always includes the age of 0 (modal age for under-5 deaths)—the age where the higher percentage of under-5 deaths occurs. For instance, while A_{50} represents the interval where 50% of under-5 deaths take place, C_{50} is the age interval where 50% of deaths in the whole population takes place.

To account for differences across age groups, we assessed compression of mortality using 'conditional' mean-ages-at-death based on survival to age 'x' months (that we denote as [x] along this study) but death by age 5 years; we denote these by $E_{[x]}$. Thus, $E_{[0]}$, $E_{[1]}$, and $E_{[12]}$ respectively represent the 'conditional' mean age-at-death after surviving birth, survival to age 1 month, and survival to age 12 months. We assessed the between-individual inequality of age-at-death using the 'conditional' standard deviation $S_{[x]}$ that assumes survival to age 'x' and death by age 5 years. We selected this indicator on the basis of theoretical (Shkolnikov, Andreev, and Begun 2003) and empirical (Edwards and Tuljapurkar 2005) findings on measures of lifespan inequality. Formally, we estimated $E_{[x]}$ and $S_{[x]}$ using the following expressions:

$$E_{[x]} = \frac{\int_x^{\omega} a \cdot \phi(a)\, da}{\left(l_{[x]} - l_{[\omega]}\right)}, \tag{1}$$

$$S_{[x]} = \sqrt{\frac{\int_x^{\omega} \left(a - E_{[x]}\right)^2 \cdot \phi(a)\, da}{\left(l_{[x]} - l_{[\omega]}\right)}}, \tag{2}$$

where ω is the oldest age in the conditional life table (59 months), $l_{[x]}$ is the survivorship or probability of living to at least age x, and $\phi(a) = \mu(a) l(a)$ is a density representing the probability that an individual dies at age a [$\mu(a)$ is the age-specific mortality rate].

2) Convergence in distribution

To assess convergence in the age-pattern of mortality we used the Kullback-Leibler distance (hereafter KLD or $K_{[0]}$), a relative entropy useful to assess the similarity of a probability density to a reference density (Kullback and Leibler 1951), and applied to the convergence of mortality

in developed countries (Edwards and Tuljapurkar 2005). Here the reference distribution for each country is the age pattern of mortality observed in Tanzania in 2016 and decreasing values of $K_{[0]}$ imply convergence. To our knowledge, this study is the first to address convergence in distribution of under-5 deaths using narrow age groups. The formal definition of KLD is as follows:

$$KLD(P|Q) = \int_{-\infty}^{\infty} p(x) log \frac{p(x)}{q(x)} dx, \quad (3)$$

where *p(x)* and *q(x)* denote the densities of *P* (under-5 mortality curve of country *i* at time *t*) and *Q* (reference under-5 mortality curve: Tanzania in 2016 in this study), respectively.

3) Interindividual inequality in age-at-death

To assess age-inequality we build on the work from (Hanada 1983; Shkolnikov, Andreev, and Begun 2003) who introduced the Gini coefficient as a measure of inequality of life table data. Their work is inspired on the analysis of the Lorenz or concentration curve, the working horse for the study of inequality in economic analysis. We constructed Lorenz curves, denoted as $L_{[0]}$, following the formulae provided by (Shkolnikov, Andreev, and Begun 2003) that we applied to under-5 mortality patterns defined in a monthly basis. That is, the Lorenz curve is defined as a set of points with horizontal coordinates:

$$F_{[x]} = \frac{\sum_{a=0}^{x-1} d_{[a]}}{\sum_{a=0}^{\omega-1} d_{[a]}}, \quad (4)$$

and vertical coordinates:

$$\Phi_{[x]} = \frac{\sum_{a=0}^{x-1} d_{[a]} \cdot \bar{a}}{\sum_{a=0}^{\omega-1} d_{[a]} \cdot \bar{a}}, \quad (5)$$

where $d_{[t]}$ represents the probability of dying at age *t* month, and $\bar{a}$ the mean age-at-death of individuals dying between the exact ages of *a* and *a+1*. The Gini coefficient is defined as the

area between the diagonal (45° line of perfect equality) and the Lorenz curve, formally (Shkolnikov, Andreev, and Begun 2003):

$$G_{[0]} = 1 - \sum_{x=-1}^{\omega} \left(F_{[x+1]} - F_{[x]}\right)\left(\Phi_{[x+1]} + \Phi_{[x]}\right). \quad (5)$$

Decreasing values of $G_{[0]}$ generally represent reductions in age-inequality. However, when it is applied to child mortality, it increases because the Lorenz curve moves away (towards the bottom right) from the diagonal line as the age-at-death converge towards birth. For ease of interpretation, we decided to use the Drewnowski's equality index (denoted as $D_{[0]}$), as it declines when we observe reductions in age-at-death inequality. This indicator was introduced by (Hanada 1983) and was defined by $D_{[0]} = 1 - G_{[0]}$ to measure equality of length of life through life table data.

Acknowledgements

We thank Wenyun Zuo, Eran Bendavid, and Nan Li for discussion and comments to an early version of the manuscript. This work was partly supported by NIH grant 1R21AG06163901 to ST.

References

Abajobir, Amanuel Alemu, Kalkidan Hassen Abate, Cristiana Abbafati, Kaja M Abbas, Foad Abd-Allah, Semaw Ferede Abera, Haftom Niguse Abraha, et al. 2017. "Global, Regional, and National under-5 Mortality, Adult Mortality, Age-Specific Mortality, and Life Expectancy, 1970–2016: A Systematic Analysis for the Global Burden of Disease Study 2016." *The Lancet* 390 (10100): 1084–1150. https://doi.org/10.1016/S0140-6736(17)31833-0.

Aburto, José Manuel, and Alyson van Raalte. 2018. "Lifespan Dispersion in Times of Life Expectancy Fluctuation: The Case of Central and Eastern Europe." *Demography* 55 (6): 2071–96. https://doi.org/10.1007/s13524-018-0729-9.

Accorsi, Sandro, Nejmudin Kedir Bilal, Pasquale Farese, and Vincenzo Racalbuto. 2010. "Countdown to 2015: Comparing Progress towards the Achievement of the Health Millennium Development Goals in Ethiopia and Other Sub-Saharan African Countries." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 104 (5): 336–42. https://doi.org/10.1016/j.trstmh.2009.12.009.

Adda, Jérôme, Tarani Chandola, and Michael Marmot. 2003. "Socio-Economic Status and Health: Causality and Pathways." *Journal of Econometrics*, Analysis of data on health: 2, 112 (1): 57–63. https://doi.org/10.1016/S0304-4076(02)00146-X.

Afnan-Holmes, Hoviyeh, Moke Magoma, Theopista John, Francis Levira, Georgina Msemo, Corinne E Armstrong, Melisa Martínez-Álvarez, et al. 2015. "Tanzania's Countdown to 2015: An Analysis of Two Decades of Progress and Gaps for Reproductive, Maternal, Newborn, and Child Health, to Inform Priorities for Post-2015." *The Lancet Global Health* 3 (7): e396–409. https://doi.org/10.1016/S2214-109X(15)00059-5.

Amouzou, Agbessi, Oumarou Habi, and Khaled Bensaïd. 2012. "Reduction in Child Mortality in Niger: A Countdown to 2015 Country Case Study." *The Lancet* 380 (9848): 1169–78. https://doi.org/10.1016/S0140-6736(12)61376-2.

Beatriz, Elizabeth D., Beth E. Molnar, John L. Griffith, and Carmel Salhi. 2018. "Urban-Rural Disparity and Urban Population Growth: A Multilevel Analysis of under-5 Mortality in 30 Sub-Saharan African Countries." *Health & Place* 52 (July): 196–204. https://doi.org/10.1016/j.healthplace.2018.06.006.

Bendavid, Eran. 2014. "Changes in Child Mortality Over Time Across the Wealth Gradient in Less-Developed Countries." *Pediatrics* 134 (6): e1551–59. https://doi.org/10.1542/peds.2014-2320.

Bourgeois-Pichat, Jean. 1951a. "La mesure de la mortalité infantile. II. Les causes de décès." *Population* 6 (6): 459–80. https://doi.org/10.2307/1523958.

———. 1951b. "La mesure de la mortalité infantile. Principes et méthodes." *Population* 6 (6): 233–48. https://doi.org/10.2307/1524151.

Bryce, Jennifer, Agbessi Amouzou, Cesar G. Victora, Gareth Jones, Romesh Silva, Kenneth Hill, Robert E. Black, and RMM Working Group. 2016. "'Real-Time' Monitoring of Under-Five Mortality: Lessons for Strengthened Vital Statistics Systems." *PLOS Medicine* 13 (1): e1001904. https://doi.org/10.1371/journal.pmed.1001904.

Burke, Marshall, Sam Heft-Neal, and Eran Bendavid. 2016. "Sources of Variation in Under-5 Mortality across Sub-Saharan Africa: A Spatial Analysis." *The Lancet Global Health* 4 (12): e936–45. https://doi.org/10.1016/S2214-109X(16)30212-1.

Burstein, Roy, Haidong Wang, Robert C. Reiner Jr, and Simon I. Hay. 2018. "Development and Validation of a New Method for Indirect Estimation of Neonatal, Infant, and Child Mortality Trends Using Summary Birth Histories." *PLOS Medicine* 15 (10): e1002687. https://doi.org/10.1371/journal.pmed.1002687.

Camarda, Carlo G. 2012. "**MortalitySmooth**: An *R* Package for Smoothing Poisson Counts with P-Splines." *Journal of Statistical Software* 50 (1). https://doi.org/10.18637/jss.v050.i01.

Canudas-Romo, Vladimir. 2008. "The Modal Age at Death and the Shifting Mortality Hypothesis." *Demographic Research* 19 (July): 1179–1204. https://doi.org/10.4054/DemRes.2008.19.30.

Cesare, Mariachiara Di, Young-Ho Khang, Perviz Asaria, Tony Blakely, Melanie J. Cowan, Farshad Farzadfar, Ramiro Guerrero, et al. 2013. "Inequalities in Non-Communicable Diseases and Effective Responses." *The Lancet* 381 (9866): 585–97. https://doi.org/10.1016/S0140-6736(12)61851-0.

Chao, Fengqing, Danzhen You, Jon Pedersen, Lucia Hug, and Leontine Alkema. 2018. "National and Regional Under-5 Mortality Rate by Economic Status for Low-Income and Middle-Income Countries: A Systematic Assessment." *The Lancet Global Health* 6 (5): e535–47. https://doi.org/10.1016/S2214-109X(18)30059-7.

Cutler, David, and Ellen Meara. 2004. "Changes in the Age Distribution of Mortality over the Twentieth Century." In *Perspectives on the Economics of Aging*, edited by David Wise.

University of Chicago Press. http://www.press.uchicago.edu/ucp/books/book/chicago/P/bo3636371.html.

Deaton, Angus. 2003. "Health, Inequality, and Economic Development." *Journal of Economic Literature* 41 (1): 113–58. https://doi.org/10.1257/002205103321544710.

Edwards, Ryan D., and Shripad Tuljapurkar. 2005. "Inequality in Life Spans and a New Perspective on Mortality Convergence across Industrialized Countries." *Population and Development Review* 31 (4): 645–74.

Engelman, Michal, Vladimir Canudas-Romo, and Emily M. Agree. 2010. "The Implications of Increased Survivorship for Mortality Variation in Aging Populations." *Population and Development Review* 36 (3): 511–39. https://doi.org/10.1111/j.1728-4457.2010.00344.x.

Fadel, Shaza A, Reeta Rasaily, Shally Awasthi, Rehana Begum, Robert E Black, Hellen Gelband, Patrick Gerland, et al. 2017. "Changes in Cause-Specific Neonatal and 1–59-Month Child Mortality in India from 2000 to 2015: A Nationally Representative Survey." *The Lancet* 390 (10106): 1972–80. https://doi.org/10.1016/S0140-6736(17)32162-1.

Fries, James F. 1980. "Aging, Natural Death, and the Compression of Morbidity." *New England Journal of Medicine* 303 (3): 130–35. https://doi.org/10.1056/NEJM198007173030304.

Gillespie, Duncan O. S., Meredith V. Trotter, and Shripad D. Tuljapurkar. 2014. "Divergence in Age Patterns of Mortality Change Drives International Divergence in Lifespan Inequality." *Demography* 51 (3): 1003–17. https://doi.org/10.1007/s13524-014-0287-8.

Golding, Nick, Roy Burstein, Joshua Longbottom, Annie J Browne, Nancy Fullman, Aaron Osgood-Zimmerman, Lucas Earl, et al. 2017. "Mapping Under-5 and Neonatal Mortality in Africa, 2000–15: A Baseline Analysis for the Sustainable Development Goals." *The Lancet* 390 (10108): 2171–82. https://doi.org/10.1016/S0140-6736(17)31758-0.

Guillot, Michel, Patrick Gerland, François Pelletier, and Ameed Saabneh. 2012. "Child Mortality Estimation: A Global Overview of Infant and Child Mortality Age Patterns in Light of New Empirical Data." Edited by Peter Byass. *PLoS Medicine* 9 (8): e1001299. https://doi.org/10.1371/journal.pmed.1001299.

Hanada, K. 1983. "A Formula of Gini's Concentration Ratio and Its Application to Life Tables." *Journal of the Japan Statistical Society* 13 (2).

Hill, Kenneth. 2013. "Direct Estimation of Child Mortality from Birth Histories." In *Tools for Demographic Estimation*, Moultrie TA, RE Dorrington, AG Hill, K Hill, IM Timæus and B Zaba. Paris: International Union for the Scientific Study of Population. http://demographicestimation.iussp.org/content/direct-estimation-child-mortality-birth-histories. Accessed 13/07/2017.

Hill, Kenneth, Danzhen You, Mie Inoue, Mikkel Z. Oestergaard, and Technical Advisory Group of the United Nations Inter-agency Group for Child Mortality Estimation. 2012. "Child Mortality Estimation: Accelerated Progress in Reducing Global Child Mortality, 1990–2010." Edited by Peter Byass. *PLoS Medicine* 9 (8): e1001303. https://doi.org/10.1371/journal.pmed.1001303.

Jasseh, M. 2003. *Age Patterns of Mortality within Childhood in Sub-Saharan Africa [PhD Dissertation]*. Department of Population Health: London School of Hygiene and Tropical Medicine.

Kannisto, Väinö. 2000. "Measuring the Compression of Mortality." *Demographic Research* 3 (September). https://doi.org/10.4054/DemRes.2000.3.6.

Keyfitz, Nathan. 2005. *Applied Mathematical Demography*. Springer. http://www.springer.com/us/book/9780387225371.

Kullback, S., and R. A. Leibler. 1951. “On Information and Sufficiency.” *The Annals of Mathematical Statistics* 22 (1): 79–86. https://doi.org/10.1214/aoms/1177729694.

Li, Nan, Ronald Lee, and Shripad Tuljapurkar. 2004. “Using the Lee-Carter Method to Forecast Mortality for Populations with Limited Data.” *International Statistical Review / Revue Internationale de Statistique* 72 (1): 19–36.

Mackenbach, Johan P., Pekka Martikainen, Caspar WN Looman, Jetty AA Dalstra, Anton E. Kunst, and Eero Lahelma. 2005. “The Shape of the Relationship between Income and Self-Assessed Health: An International Study.” *International Journal of Epidemiology* 34 (2): 286–93. https://doi.org/10.1093/ije/dyh338.

Marmot, Michael. 2005. “Social Determinants of Health Inequalities.” *The Lancet* 365 (9464): 1099–1104. https://doi.org/10.1016/S0140-6736(05)71146-6.

———. 2018. “Just Societies, Health Equity, and Dignified Lives: The PAHO Equity Commission.” *The Lancet* 0 (0). https://doi.org/10.1016/S0140-6736(18)32349-3.

Mejía-Guevara, Iván, Wenyun Zuo, Eran Bendavid, Nan Li, and Shripad Tuljapurkar. 2019. “Age Distribution, Trends, and Forecasts of under-5 Mortality in 31 Sub-Saharan African Countries: A Modeling Study.” *PLOS Medicine* 16 (3): e1002757. https://doi.org/10.1371/journal.pmed.1002757.

Mercer, Laina D., Jon Wakefield, Athena Pantazis, Angelina M. Lutambi, Honorati Masanja, and Samuel Clark. 2015. “Space–Time Smoothing of Complex Survey Data: Small Area Estimation for Child Mortality.” *The Annals of Applied Statistics* 9 (4): 1889–1905. https://doi.org/10.1214/15-AOAS872.

Moucheraud, Corrina, Helen Owen, Neha S. Singh, Courtney Kuonin Ng, Jennifer Requejo, Joy E. Lawn, Peter Berman, et al. 2016. “Countdown to 2015 Country Case Studies: What Have We Learned about Processes and Progress towards MDGs 4 and 5?” *BMC Public Health* 16 (2): 794. https://doi.org/10.1186/s12889-016-3401-6.

Musafili, Aimable, Birgitta Essén, Cyprien Baribwira, Agnes Binagwaho, Lars-Åke Persson, and Katarina Ekholm Selling. 2015. “Trends and Social Differentials in Child Mortality in Rwanda 1990–2010: Results from Three Demographic and Health Surveys.” *Journal of Epidemiology and Community Health* 69 (9): 834–40. https://doi.org/10.1136/jech-2014-204657.

Myers, G. C., and K. G. Manton. 1984. “Compression of Mortality: Myth or Reality?” *The Gerontologist* 24 (4): 346–53. https://doi.org/10.1093/geront/24.4.346.

Nau, Claudia, and Glenn Firebaugh. 2012. “A New Method for Determining Why Length of Life Is More Unequal in Some Populations Than in Others.” *Demography* 49 (4): 1207–30. https://doi.org/10.1007/s13524-012-0133-9.

Preston, Samuel H. 1975. “The Changing Relation between Mortality and Level of Economic Development.” *Population Studies* 29 (2): 231–48. https://doi.org/10.2307/2173509.

Raalte, Alyson A. van, and Hal Caswell. 2013. “Perturbation Analysis of Indices of Lifespan Variability.” *Demography* 50 (5): 1615–40. https://doi.org/10.1007/s13524-013-0223-3.

Raalte, Alyson A. van, Isaac Sasson, and Pekka Martikainen. 2018. “The Case for Monitoring Life-Span Inequality.” *Science* 362 (6418): 1002–4. https://doi.org/10.1126/science.aau5811.

Schindler, Susanne, Shripad Tuljapurkar, Jean-Michel Gaillard, and Tim Coulson. 2012. “Linking the Population Growth Rate and the Age-at-Death Distribution.” *Theoretical Population Biology* 82 (4): 244–52. https://doi.org/10.1016/j.tpb.2012.09.003.

Shkolnikov, Vladimir, Evgueni Andreev, and Alexander Z. Begun. 2003. "Gini Coefficient as a Life Table Function: Computation from Discrete Data, Decomposition of Differences and Empirical Examples." *Demographic Research* 8 (June): 305–58. https://doi.org/10.4054/DemRes.2003.8.11.

Silva, Romesh. 2012. "Child Mortality Estimation: Consistency of Under-Five Mortality Rate Estimates Using Full Birth Histories and Summary Birth Histories." Edited by Peter Byass. *PLoS Medicine* 9 (8): e1001296. https://doi.org/10.1371/journal.pmed.1001296.

Tuljapurkar, Shripad. 2010. "The Final Inequality: Variance in Age at Death." In *Demography and the Economy*, John B. Shoven, 209–21.

UN. 2017. "World Population Prospects: The 2017 Revision." United Nations, Department of Economic and Social Affairs, Population Division.

UN IGME. 2017. "Levels & Trends in Child Mortality: Report 2017, Estimates Developed by the UN Inter-Agency Group for Child Mortality Estimation." United Nations Children's Fund, New York.

Wang, Haidong, Mohsen Naghavi, Christine Allen, Ryan M Barber, Zulfiqar A Bhutta, Austin Carter, Daniel C Casey, et al. 2016. "Global, Regional, and National Life Expectancy, All-Cause Mortality, and Cause-Specific Mortality for 249 Causes of Death, 1980–2015: A Systematic Analysis for the Global Burden of Disease Study 2015." *The Lancet* 388 (10053): 1459–1544. https://doi.org/10.1016/S0140-6736(16)31012-1.

Wilkinson, Richard G. 1996. *Unhealthy Societies: The Afflictions of Inequality*. London: Routledge.

———. 1997. "Socioeconomic Determinants of Health: Health Inequalities: Relative or Absolute Material Standards?" *BMJ* 314 (7080): 591. https://doi.org/10.1136/bmj.314.7080.591.

Wilkinson, Richard G, and Kate E. Pickett. 2006. "Income Inequality and Population Health: A Review and Explanation of the Evidence." *Social Science & Medicine* 62 (7): 1768–84. https://doi.org/10.1016/j.socscimed.2005.08.036.

Wilmoth, John R., and Shiro Horiuchi. 1999. "Rectangularization Revisited: Variability of Age at Death within Human Populations." *Demography* 36 (4): 475. https://doi.org/10.2307/2648085.

Figures and Tables

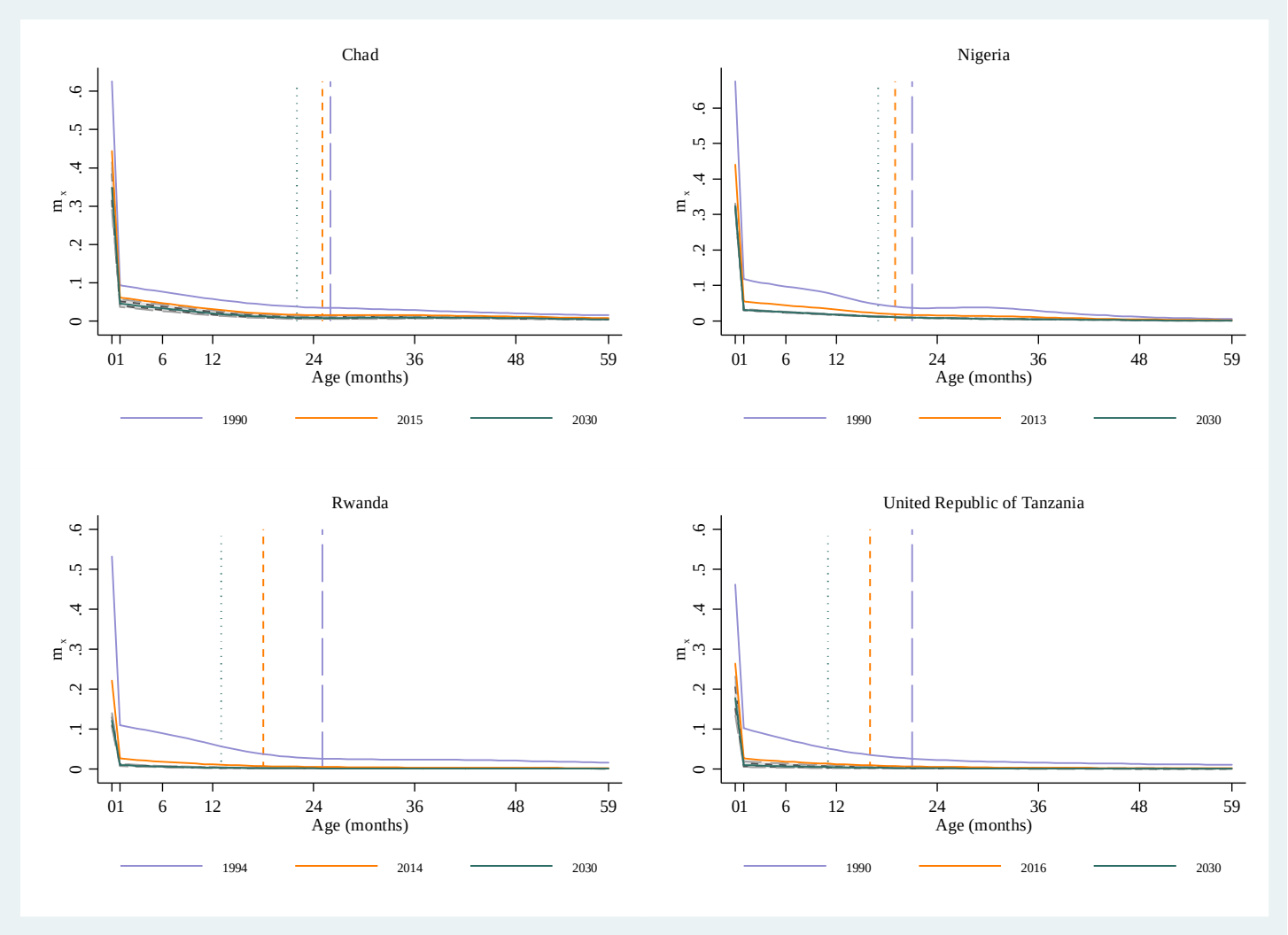

Figure 1. Compression of under-5 mortality. Change in mortality rates by age and the upper quartile of the conditional distribution of age at death (A_{75}) between the first and latest observed year, and projected by 2030 in selected SSA countries: Chad, Nigeria, Rwanda, and Tanzania

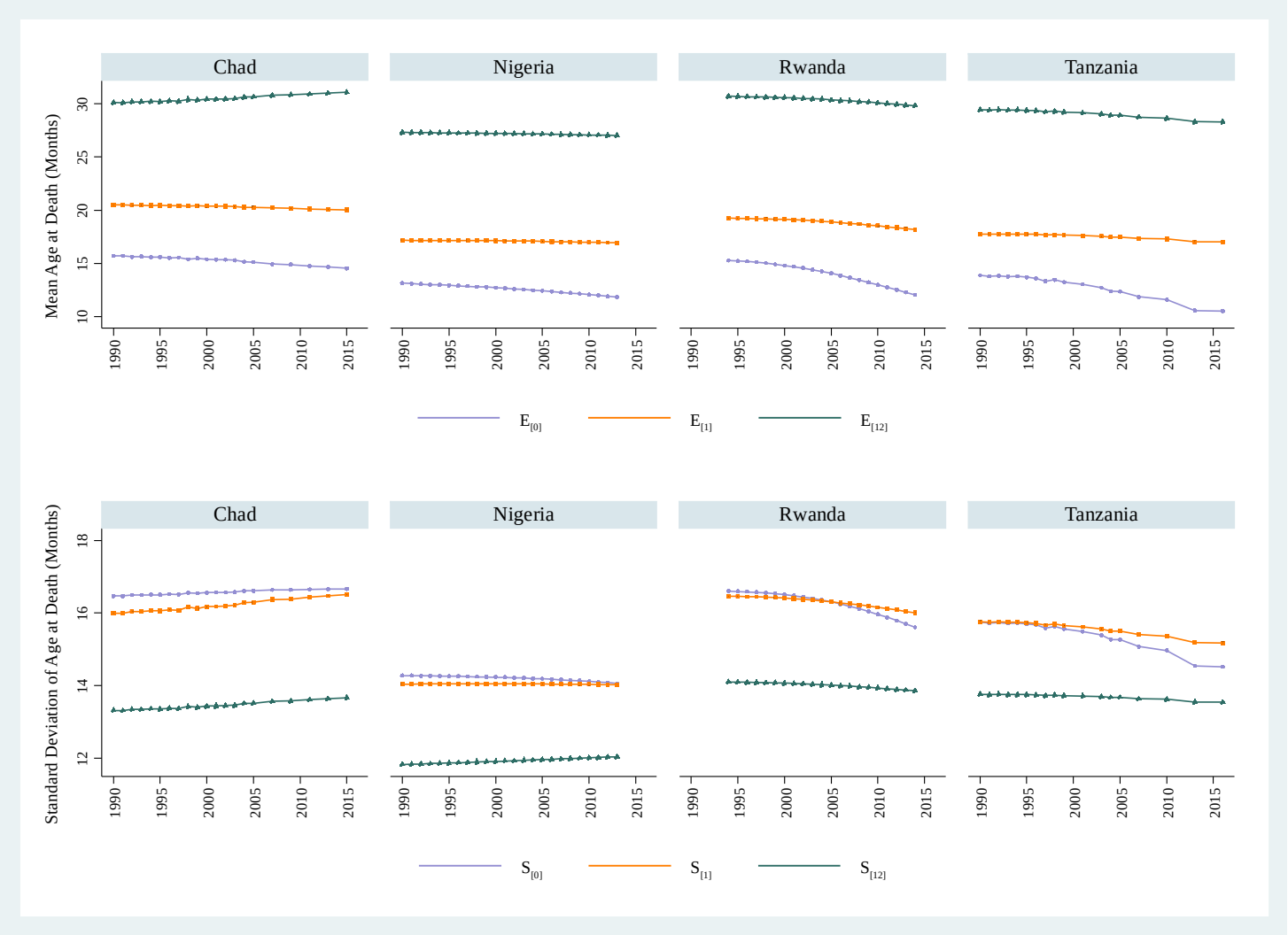

Figure 2 Age range in under-5 mortality compression. Trends of unconditional mean ($E_{[x]}$) and standard deviation ($S_{[x]}$) of age at death after birth ([0]), and after surviving the first month ([1]) and year ([12]) of life for under-5 children in selected SSA countries: Chad, Nigeria, Rwanda, and Tanzania.

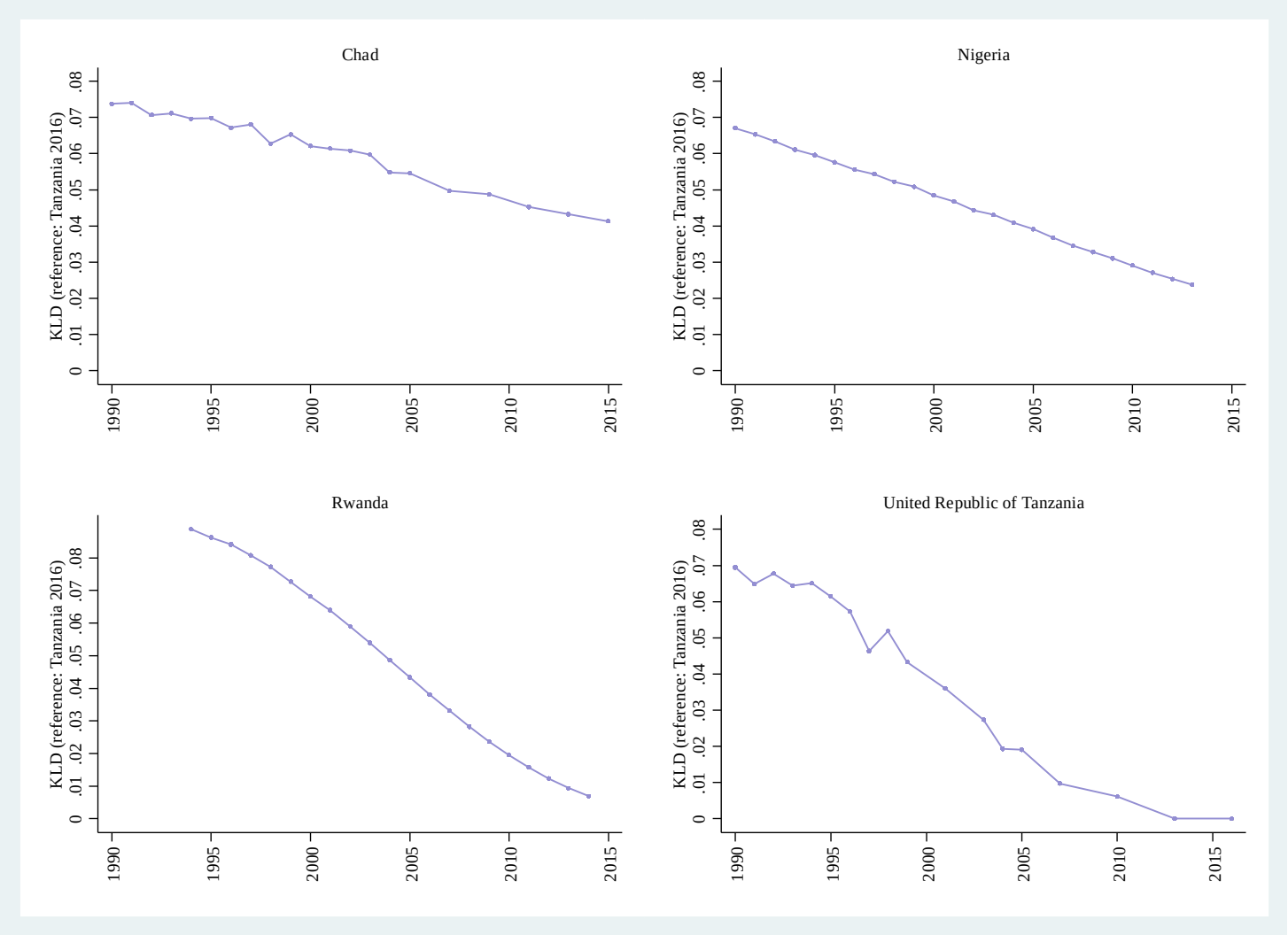

Figure 3. Convergence in distribution of under-5 mortality patterns. Trends of the Kullback-Lieble Divergence (KLD) between the first and latest observed year in selected SSA countries: Chad, Nigeria, Rwanda, and Tanzania. We used the distribution of Tanzania in 2016 as the reference for all countries.

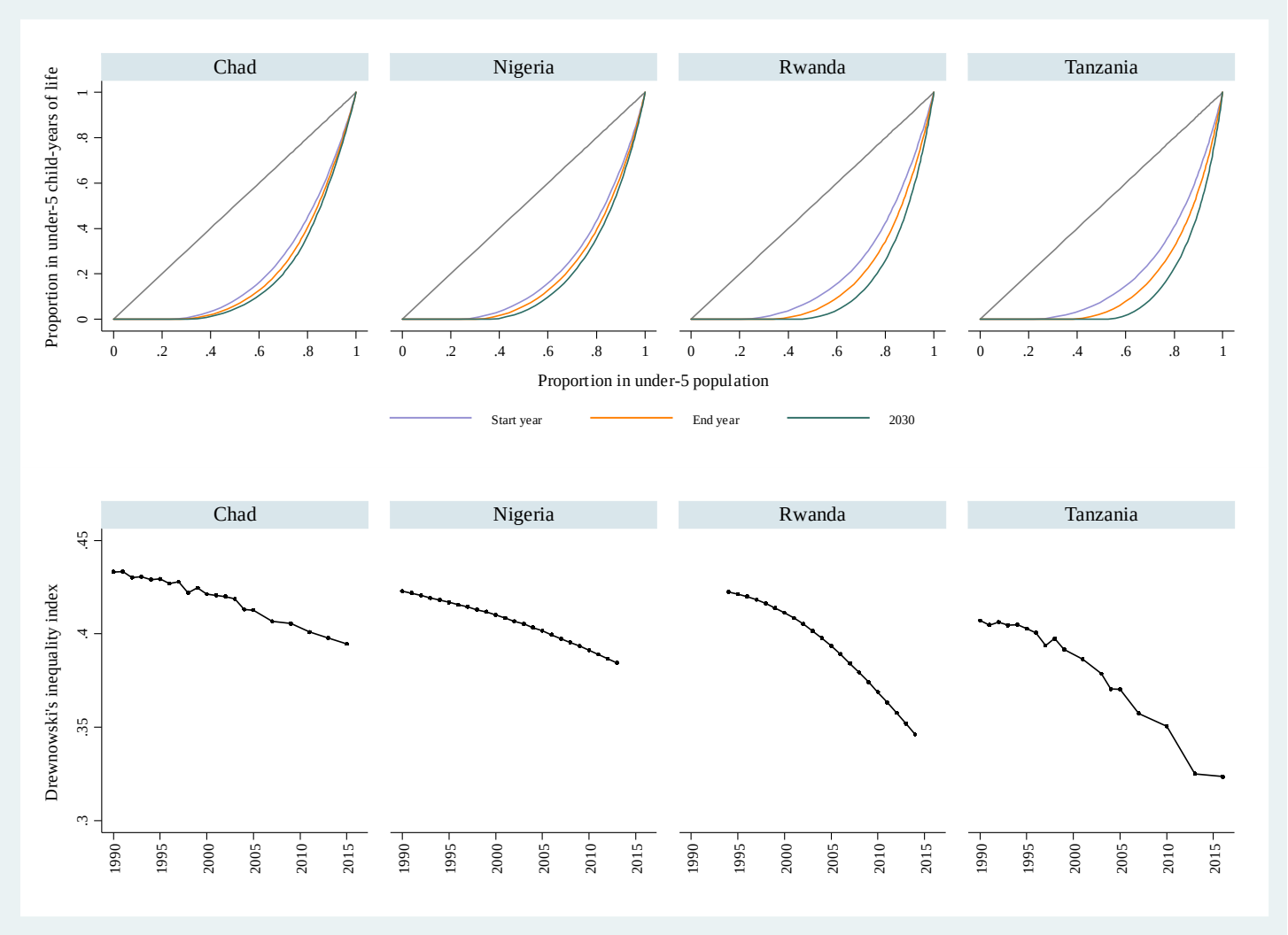

Figure 4. Under-5 inequality in the age at death. Lorenz curves (upper panel) between the first, the latest observed years, and by 2030, and trends of Drewnowski's Inequality Index ($D_{[0]}$) for selected SSA countries (lower panel): Chad, Nigeria, Rwanda, and Tanzania

Table 1 List of countries, earliest and latest years, Annual Reduction Rates (ARRs), mortality rates (NMR, IMR, and U5MR), and indicators of mortality compression/convergence/and age-inequality by country and group

	Year				ARR			A50			A75			E[0]			E[1]			E[12]			S[0]			S[1]			S[12]			K[0]		D[0]		
Country	(1)	(2)	(3)	T	NMR	IMR	U5MR	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(1)	(2)	(3)
Group 1																																				
Benin	1990	2012	2030	24	1.3	1.9	2.1	8	6	4	24	21	19	14.3	13.2	11.9	19.2	19.4	19.5	30.9	30.9	30.9	16.4	16.3	16.1	16.3	16.5	16.6	13.7	13.8	13.9	0.051	0.017	0.399	0.361	0.325
Burkina Faso	1990	2010	2030	22	2.0	2.0	2.7	10	9	7	27	24	21	15.9	14.6	13.2	20.4	19.8	19.2	29.8	29.4	28.9	16.3	16.0	15.6	15.7	15.6	15.4	13.1	13.2	13.3	0.086	0.047	0.443	0.414	0.384
Cameroon	1990	2011	2030	23	1.5	1.2	1.3	8	7	6	21	20	20	13.5	12.9	12.4	17.8	17.7	17.6	28.8	28.5	28.2	15.4	15.1	14.9	15.4	15.1	14.9	13.4	13.1	12.8	0.050	0.031	0.404	0.390	0.378
Chad	1990	2015	2030	22	1.5	1.5	1.9	10	8	6	26	25	22	15.7	14.5	13.6	20.5	20.0	19.6	30.1	31.1	31.7	16.5	16.7	16.6	16.0	16.5	16.8	13.3	13.7	13.9	0.074	0.041	0.433	0.395	0.366
Congo	1993	2012	2030	13	1.5	2.2	2.7	7	6	5	20	19	17	13.1	12.0	11.2	18.0	17.3	16.7	29.6	28.7	28.1	15.8	15.0	14.4	15.9	15.3	14.8	13.9	13.3	12.9	0.030	0.014	0.380	0.364	0.350
Cote d'Ivoire	1990	2012	2030	15	1.3	1.6	1.7	5	5	4	16	16	16	11.2	11.2	11.1	16.3	16.6	16.8	29.1	29.3	29.4	14.8	14.9	14.9	15.3	15.4	15.5	13.5	13.5	13.4	0.015	0.012	0.345	0.341	0.335
DRC	1991	2014	2030	22	1.3	1.9	2.6	7	4	3	20	13	10	13.1	10.1	8.1	16.8	14.4	12.7	28.6	28.3	27.9	15.1	13.9	12.7	15.1	14.6	13.9	13.3	14.0	14.4	0.069	0.033	0.404	0.339	0.299
Gabon	1992	2012	2030	10	1.2	1.9	2.1	5	5	4	18	20	22	11.9	12.5	13.1	17.9	20.2	22.7	30.0	31.1	32.2	15.7	16.5	17.2	16.2	16.8	17.2	14.3	14.2	14.1	0.008	0.012	0.343	0.336	0.330
Kenya	1990	2014	2030	15	1.2	2.5	3.0	7	4	0	21	17	13	13.4	11.6	9.7	17.9	19.0	19.7	30.1	31.5	32.5	15.9	16.1	15.7	16.0	16.9	17.4	13.9	14.3	14.6	0.047	0.009	0.388	0.317	0.255
Lesotho	1995	2010	2030	11	-0.2	0.0	-0.1	3	4	4	15	15	16	10.4	10.6	10.9	16.8	16.5	16.2	30.2	30.0	29.7	15.0	15.0	14.9	16.0	15.8	15.6	13.9	13.8	13.7	0.008	0.010	0.304	0.316	0.329
Mali	1990	2012	2030	24	2.8	2.5	3.1	10	8	5	27	27	25	15.6	15.1	14.4	21.2	21.8	22.2	30.2	31.9	33.3	16.4	17.3	17.8	15.8	16.9	17.8	12.9	13.7	14.3	0.065	0.041	0.429	0.389	0.356
Namibia	1992	2007	2030	7	2.0	1.2	0.9	4	6	7	17	18	20	11.2	12.2	13.5	17.3	17.1	16.9	28.9	29.1	29.5	15.0	15.3	15.6	15.5	15.6	15.7	13.6	13.7	13.8	0.003	0.023	0.337	0.366	0.403
Nigeria	1990	2013	2030	25	1.5	2.3	2.6	8	6	5	21	19	17	13.1	11.8	10.6	17.2	16.9	16.6	27.3	27.0	26.7	14.3	14.1	13.7	14.0	14.0	13.9	11.8	12.0	12.2	0.067	0.024	0.423	0.384	0.350
Sierra Leone	1993	2013	2030	6	1.7	2.3	3.1	8	6	5	21	14	13	13.5	9.7	9.0	17.1	13.4	12.7	28.5	24.0	23.1	15.2	11.7	10.9	15.2	11.8	11.0	13.4	10.6	9.9	0.080	0.068	0.415	0.392	0.384
Togo	1990	2014	2030	13	2.0	2.2	2.5	7	5	3	22	20	17	13.6	12.6	11.4	19.1	18.9	18.6	30.0	30.7	31.3	16.1	16.1	16.0	16.1	16.5	16.8	13.7	13.9	14.1	0.028	0.012	0.384	0.348	0.313
Zimbabwe	1990	2015	2030	16	0.2	0.9	1.2	7	5	4	24	21	19	14.1	13.0	12.0	19.7	19.1	18.6	30.8	30.6	30.5	16.5	16.2	15.9	16.5	16.5	16.4	13.7	13.8	13.9	0.034	0.017	0.384	0.357	0.335
Average					**1.4**	**1.8**	**2.1**	**7.1**	**5.9**	**4.5**	**21.3**	**19.3**	**17.9**	**13.4**	**12.4**	**11.6**	**18.3**	**18.0**	**17.9**	**29.6**	**29.5**	**29.6**	**15.6**	**15.4**	**15.2**	**15.7**	**15.6**	**15.6**	**13.5**	**13.4**	**13.4**	**0.045**	**0.026**	**0.388**	**0.363**	**0.343**
Group 2																																				
Angola	1991	2016	2030	7	2.3	3.4	3.8	8	4	3	25	20	18	14.7	12.4	11.6	19.2	19.2	19.1	31.2	31.5	31.5	16.7	16.3	16.0	16.6	16.8	16.8	13.8	13.9	13.9	0.066	0.014	0.401	0.337	0.315
Burundi	1990	2017	2030	11	2.2	3.3	3.8	8	4	1	23	16	11	14.7	10.6	8.3	19.0	16.5	15.2	30.9	29.2	28.4	16.7	14.6	13.2	16.7	15.3	14.6	14.4	13.1	12.4	0.070	0.009	0.404	0.323	0.269
Ethiopia	1990	2016	2030	28	2.6	3.9	4.5	6	2	0	26	16	12	14.4	10.7	8.6	20.5	20.1	19.7	33.0	31.2	30.1	17.4	15.8	14.5	17.5	16.8	16.3	13.9	14.0	13.9	0.043	0.028	0.370	0.286	0.238
Gambia	1993	2013	2030	6	2.2	2.5	3.6	11	4	1	33	22	14	17.8	12.7	9.3	25.8	21.7	18.6	33.9	31.1	28.9	18.8	16.6	14.3	17.4	16.5	15.3	13.8	13.5	13.0	0.100	0.031	0.424	0.336	0.275
Ghana	1991	2014	2030	13	1.8	2.7	3.2	6	2	0	21	15	10	12.9	9.7	7.1	19.6	17.7	16.3	30.3	28.1	26.3	16.1	14.2	12.2	16.2	15.0	13.9	13.7	13.1	12.4	0.013	0.013	0.359	0.295	0.237
Guinea	1990	2012	2030	24	3.6	3.4	3.7	7	7	7	22	20	19	13.4	12.9	12.2	18.6	17.6	16.6	29.9	28.1	26.6	15.8	15.0	14.1	15.8	14.9	14.0	13.3	12.9	12.4	0.031	0.033	0.385	0.394	0.400
Liberia	1991	2011	2030	12	3.4	4.6	5.0	6	5	3	16	15	13	11.6	10.4	8.7	14.8	14.9	14.7	27.8	26.8	25.9	14.2	13.5	12.6	14.5	14.0	13.4	13.6	12.9	12.1	0.081	0.022	0.386	0.357	0.308
Malawi	1990	2016	2030	23	2.9	4.6	5.2	8	6	3	21	21	18	13.8	12.7	11.3	17.3	18.9	19.5	28.8	29.8	30.2	15.1	15.7	15.6	15.1	15.8	16.1	13.2	13.3	13.4	0.089	0.013	0.422	0.363	0.314
Mozambique	1990	2011	2030	23	3.0	4.1	4.2	6	5	3	18	16	14	12.2	11.4	10.0	15.9	16.5	16.7	30.1	29.9	29.6	15.1	15.1	14.8	15.4	15.8	16.0	13.3	14.0	14.5	0.077	0.020	0.377	0.342	0.296
Niger	1990	2012	2030	24	2.7	3.7	4.8	14	10	4	30	27	20	18.0	15.5	12.1	21.4	21.0	19.6	29.0	29.9	30.3	15.7	16.3	15.7	14.9	15.6	16.0	12.6	12.9	13.1	0.204	0.065	0.512	0.429	0.338
Rwanda	1994	2014	2030	22	4.2	6.4	8.8	9	5	2	25	18	13	15.3	12.0	9.3	19.2	18.2	17.1	30.7	29.8	29.0	16.6	15.6	14.3	16.5	16.0	15.5	14.1	13.9	13.6	0.089	0.007	0.422	0.346	0.278
Senegal	1990	2017	2030	28	2.4	2.8	4.1	10	2	0	28	13	8	15.9	9.4	6.9	22.6	17.2	14.4	31.0	29.4	28.4	17.1	14.5	12.5	16.2	15.8	14.8	13.2	13.9	14.0	0.062	0.012	0.417	0.280	0.228
Uganda	1990	2016	2030	24	2.5	4.0	4.7	9	3	0	21	14	8	14.1	9.7	6.8	17.4	16.1	15.2	28.6	27.5	26.9	15.4	13.7	12.0	15.3	14.5	14.0	13.6	12.8	12.3	0.105	0.003	0.429	0.314	0.230
Tanzania	1990	2016	2030	19	2.1	3.5	4.1	8	4	0	21	16	11	13.9	10.5	7.7	17.8	17.0	16.3	29.4	28.3	27.4	15.7	14.5	13.0	15.8	15.2	14.7	13.8	13.5	13.3	0.069	0.000	0.407	0.323	0.248
Zambia	1990	2014	2030	23	1.9	3.6	4.1	9	5	1	22	17	12	13.8	11.2	9.0	17.4	17.2	16.9	27.9	28.8	29.4	14.9	14.9	14.3	14.8	15.4	15.8	12.9	13.7	14.3	0.082	0.003	0.428	0.338	0.268
Average					**2.7**	**3.8**	**4.5**	**8.3**	**4.5**	**1.9**	**23.5**	**17.7**	**13.4**	**14.4**	**11.5**	**9.2**	**19.1**	**18.0**	**17.1**	**30.2**	**29.3**	**28.6**	**16.1**	**15.1**	**13.9**	**15.9**	**15.6**	**15.1**	**13.5**	**13.4**	**13.2**	**0.079**	**0.018**	**0.410**	**0.338**	**0.283**

Note: (1) and (2) stands for corresponding value at earliest and latest year, respectively. Countries were classified in group 1/2 if their ARR of UMR5 was below/above the median ARR of 3.2.