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The Race between Mortality and Morbidity: Implications for the Global Distribution of Health

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Assessments of countries' longevity and its variability around the globe often rely on life expectancy (LE) but tend not to differentiate between the years spent in "good" or "less-than-good" health. We explore how the evolution of the healthy and unhealthy components of LE has shaped the composition of LE within *countries, and the extent of LE inequality* between *countries. Using data from the Global Burden of Disease Study, we document the joint evolution of "health-adjusted life expectancy" (HALE) and "unhealthy life expectancy" (UHLE) for 204 countries and territories from 1990 to 2019, the age-specific contributions to changes over time in HALE and UHLE, and the corresponding cause-of-death profiles. We also assess the contribution of HALE and UHLE to "international health inequality" (IHI; i.e., inequality in LE across world countries). Between 1990 and 2019, HALE and UHLE have increased in most world countries, thus lengthening longevity worldwide. Globally, HALE has increased from 58.1 years to 63.4 years, while UHLE has increased from 8.4 years to 9.4 years, but there is a great deal of variation across regions and countries. The fraction HALE/LE has declined in three out of four countries. Over time, IHI followed an inverted U shape, peaking around the year 2000 and declining from that year onwards. IHI levels and trends are mostly explained by trends in HALE. Our findings indicate that global health inequalities are undergoing profound transformations. While health inequalities between countries tend to decline, those within countries tend to increase. In addition, we observe a compositional shift in which the unhealthy component of LE is playing an increasingly important role in explaining (1) further increases in longevity among low-mortality countries and (2) the extent of inequality in LE among world countries. Policies aiming at increasing LE* and *reducing its variability between countries should increase HALE among the world's least longevous countries.*

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Introduction

The unparalleled longevity gains recorded in virtually all countries during the last century (Oeppen and Vaupel 2002; Riley 2005, 2015) are a cause for celebration. Individuals around the globe can now expect to survive to ages that were unimaginable not long ago (Oeppen and Vaupel, 2002). Less clear, though, is whether the retreat of mortality towards older ages has been accompanied by commensurate morbidity declines (Jagger et al. 2020). Depending on the relative speeds at which the occurrence of mortality and the onset of morbidity are delayed (i.e., contingent on the results of the "race between mortality and morbidity"), the average number of years individuals can expect to live in "good health" (i.e., free from disease and disability) or in "less-than-good health" can evolve in different ways, both within and across countries (Jagger et al. 2020). Rises in longevity that are mostly attributable to increases in healthy life years (e.g., delaying the onset of morbidity) could be substantively different from those in which increased survivorship only benefits those already living in morbid states. Given the social and economic burden associated with the presence of disease or disability, global assessments of countries' longevity performance should take into consideration the crucial distinction between "quantity" and "quality" by inspecting "healthy" and "unhealthy" years separately—an issue that has been largely ignored in the literature and that we take up in this paper following both a national and an international perspective.

From a national-level perspective, the rates at which mortality and morbidity change over time have an impact on the composition of life expectancy (LE) in its healthy and unhealthy components *within* countries. As shown below, total LE can be broken down as the sum of "health-adjusted life expectancy" (or HALE) and "unhealthy life expectancy" (UHLE), and it is fundamental to assess which of the two components is the most important driver of longevity increases over time. Taking advantage of data from the Global Burden of Disease (GBD) project, here we document the pace at which the healthy and unhealthy components of LE have evolved between 1990 and 2019 to investigate which one has been the most important driver of longevity increases in countries, regions, and the world as a whole. To better understand the drivers of such dynamics, we also document (1) the age-specific contributions to changes over time in HALE and UHLE and (2) the corresponding cause-of-death (CoD) profiles. Such information is key to characterize the stage of the "epidemiological transition" that each country is going through (Omran 1971).

From an international perspective, mortality- and morbidity-specific dynamics also have an impact on the extent of inequality in LE *between* world countries (henceforth referred to as "international health inequality," or IHI). This indicator has been used in several studies to investigate whether countries' health status is converging or diverging around the world (Wilson 2001; Goesling and Firebaugh 2004; McMichael et al. 2004; Moser, Shkolnikov, and Leon 2005; Clark 2011; Edwards 2011) and is, therefore, a key metric to monitor global health inequality. Alongside "standard of living" and "education", "health" (as measured by LE at birth) is one of the fundamental dimensions included in the United Nations' human development index to assess whether people's basic capabilities (i.e., the freedom to attain different kinds of lives between which a person can choose) enlarge or shrink over time (United Nations Development Programme 2019). Scholars and policy-makers alike are thus increasingly interested not only in whether cross-country differences in LE and other dimensions of well-being increase or decrease but also in the drivers of such dynamics over time.

Whenever IHI declines, individuals' survival prospects are less and less dependent on the country where they happen to live. What is unknown, though, is the influence that changes in the intercountry HALE and UHLE distributions have had on IHI dynamics. This is a substantive research question with important policy implications, as it helps policy-makers to identify the most efficient mechanisms to curb IHI. In addition, it informs whether intercountry differences in LE are driven by variations of a normatively desirable indicator, like HALE, or another one whose normative desirability could be potentially controversial (UHLE). Applying decomposition techniques, in this paper we document the influence that the healthy and unhealthy components of LE have had on the levels and trends of IHI from 1990 to 2019. In this way, we can quantify the joint effects that mortality and morbidity have had on global health inequality dynamics.

Background

The analyses conducted in this paper are related to two broad strands of research: one that studies the *composition* of LE in its healthy and unhealthy components (i.e., distinguishing the quantity of years of life from the (health) quality in which those years are lived), and another one that investigates how LE, and other dimensions of well-being, are *distributed* across countries.

The epidemiological transition

Overall, LE at birth has been increasing vigorously all around the world during the last decades (Oeppen and Vaupel 2002; Christensen et al. 2009; Vaupel et al. 2021). For instance, between 1960 and 2020, the world's LE has gone from 47.7 to 72 years, an increase of 24.3 years (United Nations, Department of Economic and Social Affairs, Population Division 2022a). During that period, giants like China have increased their LE by more than 40 years. While several countries, such as those belonging to the former Soviet Union (like Russia, Ukraine, Belarus, or Latvia, among others), have experienced temporary declines in LE (e.g., owing to economic shocks, epidemics, or natural disasters), the survival prospects have increased considerably in most countries all over the globe.

These mortality declines have gone hand in hand with profound transformations in the major causes of illness and disease and in their interaction with their "demographic, economic and sociologic determinants and consequences" (Omran 1971, 510). According to the classic epidemiological transition model suggested by Omran (1971), populations are expected to move through different stages (e.g., the "age of pestilence and famine", the "age of receding pandemics", and the "age of degenerative and man-made diseases"), each characterized by its own combination of demographic indicators and epidemiological profiles. While infectious diseases and nutritional problems (typically affecting younger ages) predominate in the early stages of the transition, the late ones are characterized by a predominance of chronic and degenerative diseases (usually affecting older ages). In light of unexpectedly rapid declines in chronic disease mortality rates in low-mortality countries around the 1970s, a fourth stage of the "age of delayed degenerative death" was proposed by Olshansky and Ault (1986) as a possible extension of the model. With the unfolding of the different stages, there are good reasons to expect that countries' shifting epidemiological profiles can have an impact on the composition of IHI (for instance, with the emergence of morbidity potentially playing an increasingly prominent role when explaining international differences in LE)—an issue that remains unexplored and that will be investigated in this paper.

Living longer and healthier?

The unprecedented longevity increases experienced in the last decades have led many scholars to ask a question that has generated significant amounts of research: Are populations becoming healthier as well as longer lived? This and similar questions have sparked an intense, yet largely unresolved, debate on the interaction between morbidity and mortality dynamics in "postepidemiological transition" (i.e., low-mortality) societies, which has crucial implications for the implementation of health care systems and policies (Jagger et al. 2020). At one extreme, the "compression of morbidity" hypothesis proposed by Fries (1980) suggests that, as longevity increases, the onset of morbidity is gradually compressed towards the latest years of life, thus shortening the number of years individuals are expected to live in morbid states. While the original formulation of this hypothesis explicitly assumed a cap on individuals' maximum longevity, such restriction was lifted in more recent statements about the compression of morbidity (Fries, Bruce, and Chakravarty 2011).[1] At the other extreme, the "expansion of morbidity" hypothesis proposed by Gruenberg (1977) suggests that the decrease in mortality would not arise from lowered disease incidence rates, but rather from the survival of people with health problems, resulting in more disease in the population—a gloomy scenario he colorfully termed the "failure of success". Somewhere in between the two extremes, Manton (1982) proposed the "dynamic equilibrium" hypothesis, which suggests that, with longevity increases, severe disability decreases but mild and moderate disability increases.

Attempts at testing such hypotheses are fraught with difficulties. Most importantly, there is not a universally accepted definition of what it means to be in "good" or in "less-than-good" health, and researchers have adopted different measurement strategies. For instance, some have focused on cognitive abilities (Suthers, Kim, and Crimmins 2003), or daily activity limitations (Berger, Van der Heyden, and Van Oyen 2015; Van Oyen et al. 2013; 2018), others in the presence or absence of certain diseases (Nusselder et al. 2005; Nusselder and Looman 2004; Rentería and Zueras 2022), while others in the existence and degree of disabilities (Crimmins et al. 2009; Crimmins and Saito 2001); see Yokota and Van Oyen (2020).[2] As a result, different studies might not be strictly comparable owing to the discrepancy between alternative measurement approaches. In this study, we take advantage of the HALE indicators estimated by GBD, which are defined as "the average number of years that a person at a given age can expect to live in good health, taking into account mortality and loss of functional health" (Abbafati et al. 2020; Murray et al. 2015). The values of HALE (and UHLE) are a function of three ingredients: mortality (as measured in life tables), the prevalence of morbid conditions (as measured by the prevalence of a set of sequelae), and the severity of those conditions (which are measured through the so-called "disability weights")—see the Methods section. By applying standardized analytical procedures over the entire dataset, HALE estimates are comparable across countries and over time.

Distributional concerns

The study of inequalities has become a prominent topic in research and policy-making agendas around the globe. During the last decades, social scientists concerned with global distributive justice have attempted at monitoring not only how efficient societies are at increasing their well-being but also how the latter is distributed across individuals (UNDP 2019). Average attainments are of course important, but it is also important to go beyond means and assess whether some specific subgroups are racing ahead or lagging behind the rest. In this regard, the global development agenda is strongly committed to reduce global welfare inequality, both across and within countries (United Nations Department of Economic and Social Affairs 2022).

Owing to the increasing availability of datasets in most parts of the world, research on global welfare inequalities has spawned in multiple directions. Scholars from different fields have recently identified convergence processes *between* countries during the last decades in important dimensions of well-being, like income (Anand and Segal 2015; Bourguignon 2018; Firebaugh 2006; Firebaugh and Goesling 2004) and education (Dorius 2013; Jordá and Alonso 2017; Permanyer and Boertien 2021). Other studies examining how the human development index (the flagship indicator of the United Nations to measure countries' socioeconomic performance) is distributed around the world have also identified convergence dynamics between countries (Permanyer and Smits 2020; Permanyer and Suppa 2022). Alongside these changes, the aforementioned studies have also identified simultaneous increases in *within*-country inequality for the same dimensions of well-being. If these trends were to continue over time, the world would gradually shift to a "convergence towards divergence" scenario in which the welfare status of individuals would be less likely to be determined by the country where they were born and more by other structural determinants, such as social class.

Beyond socioeconomic indicators, mounting efforts have been recently made to understand whether populations around the globe are becoming increasingly similar or dissimilar regarding key demographic processes and outcomes. For instance, Wilson (2001, 2011) describes the period between 1950 and 2000 as one of "global demographic convergence" owing to the increasing share of world's people living under conditions of declining fertility and increasing LE. In contrast, less definite patterns have been observed when inspecting family change. Pesando and GFC Team (2019) identify a scenario of "persistent diversity with development" to describe the relationship between family change (measured with a wide range of marriage, cohabitation, household structure, and life-course timing indicators) and socioeconomic development. Regarding fertility change, Dorius (2008) concludes that intercountry inequality in total fertility rates increased monotonically between 1955 and 1995 and started declining afterward until 2005.

When it comes to mortality, several studies have investigated intercountry variations in LE.[3] Their findings suggest that IHI declined between 1950 and 1990 (Moser et al. 2005; Clark 2011) but then started increasing until the early 2000s—a change that has been attributed to the effects of the HIV-AIDS epidemic in Sub-Saharan Africa and the collapse of the Soviet Union (Goesling and Firebaugh 2004; McMichael et al. 2004). Beyond mortality, in the last decades several efforts have been made to document a wide array of health-related outcomes in an internationally comparable perspective. One of the most notable examples is the GBD project, which provides estimates of disease and disability patterns across world countries (Abbafati et al. 2020). This and other data collection efforts are fundamental to monitor progress towards improving health equity—both within and across countries—and achieving the health-related goals that are increasingly preeminent in the global development agenda; see, for instance, the WHO Commission on Social Determinants of Health (World Health Organization 2008) or the Sustainable Development Goals agenda (United Nations Department of Economic and Social Affairs 2022).

Unlike the previously mentioned indicators commonly used to assess countries' sociodemographic standing, LE has a special feature that makes a fundamental difference when studying its evolution and distribution across countries. As hinted above, LE can be broken down into "healthy" and "unhealthy" components. The fact that a nonnegligible and potentially large fraction of LE comes from a component whose normative desirability could be controversial (e.g., confronted with the choice between "a prolonged yet unhealthy life" and "a shorter but fully healthy life", it is not immediately obvious that the former would be universally chosen in favor of the latter; see (Gerstorf et al. 2008; Lawton et al. 1999)) calls for new conceptual and methodological approaches when assessing its variability across countries and its dynamics over time—an important issue that has been overlooked in the literature and that we address in this paper.

Methods

Data

We use data from the GBD Study 2019, which covers 204 countries and territories from 1990 to 2019 (Abbafati et al. 2020). Results are sometimes aggregated for the following six regions: "Africa", "Asia", "Europe", "Latin America and the Caribbean", "North America", and "Oceania" (the specific countries included in each region are shown in Appendix A). The GBD project provides sex-specific country-year estimates for LE and HALE, the latter measuring the average number of years individuals are expected to live in "good" health under each year's mortality and morbidity conditions (Abbafati et al. 2020). In addition, it provides estimations for age-specific death counts, prevalence, population exposures, and the causes from which individuals die (CoD). Here we rely on the broadest CoD classification scheme, that is, the one that partitions deaths into three categories: "communicable" (C), "noncommunicable" (NC), and "injuries" (I).

The estimation of HALE follows several steps, which are summarized here (further details can be found in Salomon et al. 2012 or Abbafati et al. 2020). First, the average health of individuals is estimated for every age group $[x, x+n)$ in the population under study. To arrive at such an estimate, one combines information on the prevalence for all possible morbid conditions and the corresponding disability weights (which capture the severity of those conditions). The latter are estimated from household surveys and open-access web-based surveys. When the average health level for each age group $[x, x+n)$ has been estimated (call it ${}_nH_x$), one applies the Sullivan method (Sullivan 1971), which multiplies the ${}_nH_x$ by the corresponding ${}_nL_x$ values of the life table (i.e., the average person-years lived within the age interval $[x, x+n)$). The rest of the life table is recalculated on the basis of the modified ${}_nL_x$ values to arrive at the corresponding level of HALE.

From the values of LE and HALE, we derive the values of UHLE, defined as the average number of years individuals are expected to live in "less-than-good" health—in such a way that LE = HALE + UHLE. As a robustness check, the analyses were replicated using World Health Organization (WHO) data (World Health Organization 2020), which publishes estimates for LE and HALE for 183 countries around the globe for the years 2000, 2010, 2015, and 2019 (results are available in Appendix F).

Statistical analysis

Since LE = HALE + UHLE, changes in LE over time (i.e., ΔLE) can be attributable to changes in HALE (ΔHALE) and changes in UHLE (ΔUHLE). To measure the contribution of these two components to changes in LE, we define the following indicators: $C_H = 100 * \Delta HALE/\Delta LE$ and $C_U = 100 * \Delta UHLE/\Delta LE$, respectively (so that $C_H + C_U = 100$).

Using standard demographic techniques, we perform age-specific decompositions to the changes over time in HALE and UHLE across the regions included in our analyses. More formally,

$$\Delta HALE = HALE(t_2) - HALE(t_1) = \sum_{i=1}^{k} h_i,$$

$$\Delta UHLE = UHLE(t_2) - UHLE(t_1) = \sum_{i=1}^{k} u_i,$$

where k is the number of age groups we are dealing with (21 in our setting), and h_i, u_i are the contributions of age group i to changes in HALE and UHLE, respectively. To arrive at such decompositions, we follow two steps. First, we apply the Arriaga method (Arriaga 1984) to period life tables—which can be obtained through the GBD database—to break down changes in LE over time as the sum of age-specific contributions c_i (i.e., $\Delta LE = \sum_i c_i$). Second, taking advantage of the fact that GBD reports the estimated values of LE and HALE at age i for all i equal to 0, 1, 5, 10, ..., 95, we break down each c_i as $h_i + u_i$ (i.e., the contribution of each age group to changes in LE is separated in its healthy (h_i) and unhealthy (u_i) components). In this way, we obtain the age-specific decompositions of $\Delta HALE$ and $\Delta UHLE$ (in such a way that $\Delta LE = \Delta HALE + \Delta UHLE$). Technical details on how the age-specific decompositions are arrived at are provided in Appendix B.

We use ternary plots to represent the mortality profiles of the countries included in the database in 1990 and 2019 (see Figure 3). Since the shares of deaths attributable to injuries (I), communicable (C), and non-communicable (NC) causes add up to 100 percent, they are amenable to such representations. The position of each country-year observation with respect to the three vertices of the plot explains how large is the contribution of each CoD to overall mortality. The closer a given observation is with respect to a given vertex, the higher the contribution of the corresponding cause to overall mortality. Whenever an observation lies on the barycenter of the triangle, the contribution of the three CoDs equals $\frac{100}{3}\,\% \cong 33\,\%$. Analogous representations have already been used in Solomon and Murray (2002).

To test the statistical significance of the results, we take advantage of the *uncertainty intervals* (UI) reported by GBD for all their indicators. We apply standard Monte Carlo simulation techniques to derive the different UIs associated with the different indicators reported in the paper (details can be found in Appendix C).

Inequality measurement and decompositions

In this paper, IHI is measured with the absolute Gini index, a well-known inequality indicator that, in our context, measures the average expected difference in LE among world countries (see Appendix D) and whose values are measured in the "number of years". Formally, the absolute Gini index is defined as

$$IHI = \frac{1}{2} \sum_i \sum_j p_i p_j \left| y_i - y_j \right| ,$$

where y_i and p_i denote the level of LE and the population share of country i, respectively. This is a very popular indicator that has been used in other related studies (e.g., Moser et al. 2005). Very similar findings are obtained when applying other inequality measures, like the relative Gini index (Appendix D.1). To determine what part of IHI can be attributable to the variation of HALE and UHLE across countries (in other words, what are the contributions of HALE and UHLE to IHI), we decompose IHI as the sum of a "healthy" (IHI_h) and an "unhealthy" (IHI_u) components (i.e., $IHI = IHI_h + IHI_u$; details in Appendices D.1–D.3). We rely on Monte Carlo simulation techniques to calculate 95 percent UIs around the values of IHI, IHI_h, and IHI_u (see Appendix C) taking advantage of the R package DescTools (Signorell et al. 2022). In this way, we can assess the impact that the uncertainty around the values of HALE, UHLE, and LE has on our estimates of inequality between countries.

The changes in IHI over time depend not only on the changes of the HALE and UHLE distributions across countries but also on the changes in countries' population size. Other factors kept constant, what happens in more populated countries, like China or India, have larger effects on inequality. To isolate the effect of shifting population compositions, we apply a counterfactual-based method that decomposes changes in IHI (ΔIHI) as the sum of three easily interpretable components: (i) changes in HALE ($\Delta_H IHI$), (ii) changes in UHLE ($\Delta_U IHI$), and (iii) changes in population size ($\Delta_P IHI$) (i.e., $\Delta IHI = \Delta_H\ IHI + \Delta_U IHI + \Delta_P IHI$; see details in Appendix D.3). In this way, we can separate what part of the changes in IHI can be attributable to changes in HALE and UHLE (the key outcome variables we are interested in) and what part to the compositional change generated by population growth. Even if they are not able to establish causation stricto sensu, such decomposition techniques are based on a methodologically transparent approach that can be useful to identify the main drivers of change.

Lastly, the same approach is used to decompose changes in the world's life expectancy (WLE, defined as the population-weighted average of countries' LE levels). The change in WLE between two given moments (ΔWLE) is the sum of the contributions of changes in HALE ($\Delta_H WLE$), UHLE ($\Delta_U WLE$), and population size ($\Delta_P WLE$) (i.e., $\Delta WLE = \Delta_H\ WLE + \Delta_U WLE + \Delta_P WLE$; details are shown in Appendix D.4).

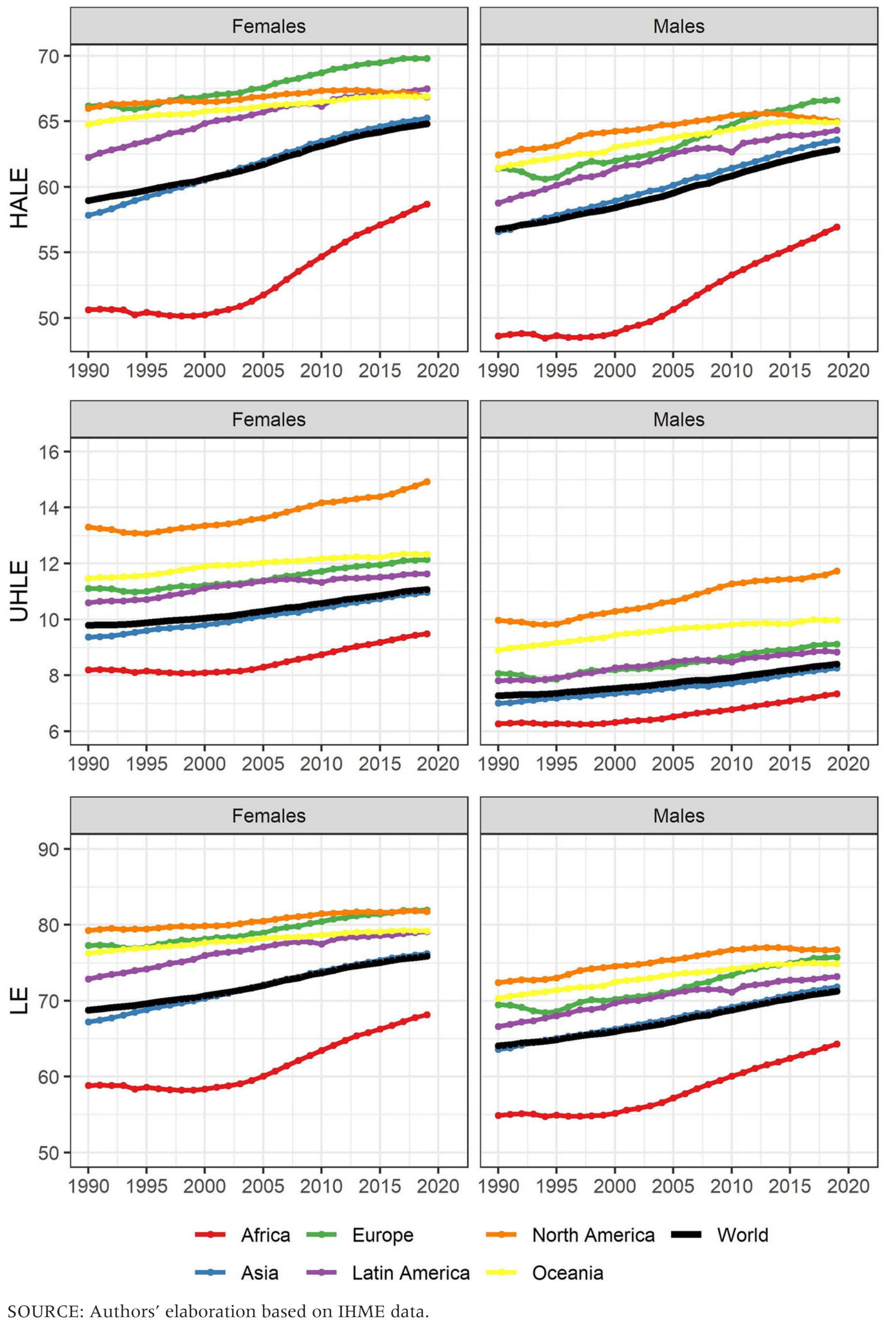
Results

Regional trends

Between 1990 and 2019 we observe generally increasing trends in HALE across the world and its regions (Figure 1). The world's average HALE moved from 59.6 (95 percent uncertainty interval [UI] 57.5−61.2) to 64.7 (62.2−67.1) for women and from 56.7 (55.0−58.3) to 62.2 (60.1−64.3) for men. Notably, Africa experienced slight declines until the turn of the century, which were followed by faster-than-world-average increases until 2019. In contrast, HALE has been growing sluggishly in North America and actually started declining from 2013 onwards—especially among men.

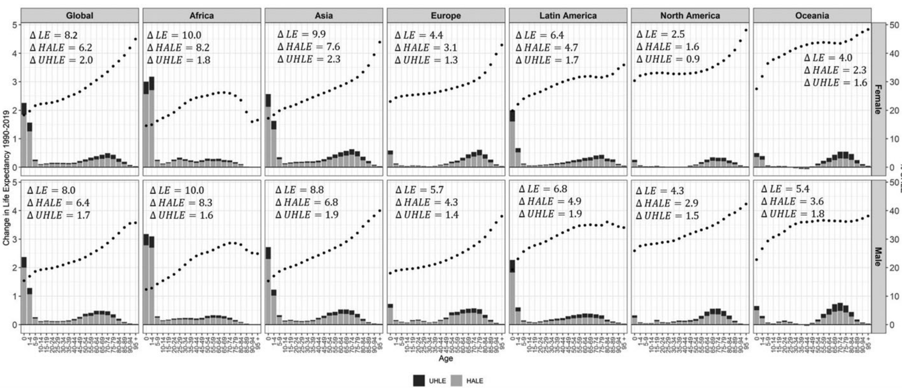
As regard regional UHLE trends, they are generally increasing as well and roughly follow parallel paths (Figure 1). North America stands out not only as the region with the highest UHLE levels throughout the observation period but also as the one experiencing the fastest increases from the mid-1990s onwards—thus racing well ahead of the rest (especially among women). Lastly, the regional LE trends reflect the behavior of its healthy and unhealthy subcomponents. Between 1990 and 2019, WLE has increased from 69.2 (68.3−70.1) to 75.4 (74.1−76.8) for females (i.e., an increase of 6.2 years), while for males it has increased from 63.9 (62.9−64.8) to 70.4 (68.8−72.0) (i.e., an increase of 6.5 years). Since the year 2000 onwards, Africa grows at a faster-than-world-average pace, thus leading to a compression in the distribution of LE levels across world regions.

FIGURE 1 Regional and global trends in HALE, UHLE, and LE between 1990 and 2019



SOURCE: Authors' elaboration based on IHME data.

FIGURE 2 Age-specific contributions of the changes in HALE (light gray bars) and UHLE (dark gray bars) to changes in LE between 1990 and 2019. For each region, sex, and age group, the height of the black dots represents the percentage of (age-specific) change in LE that is attributable to changes in UHLE (the scale is shown in the right vertical axis)

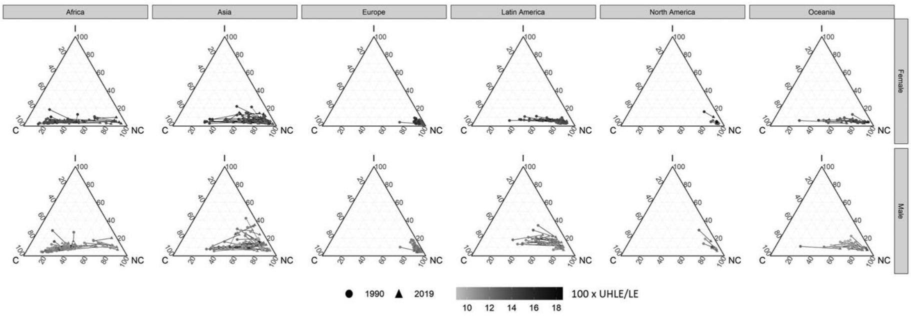


SOURCE: Authors' elaboration based on IHME data.

Figure 2 shows how each age group has contributed to increases in HALE (light-shaded gray bars), UHLE (dark-shaded gray bars), and LE (the sum of the previous two) between 1990 and 2019 across the world and its regions, for women and men separately. As regard increases in LE, in most cases we observe a twin-peaked profile, with important contributions in the first ([0, 1)) and second ([1, 5)) age groups, and then increasingly important contributions at mature ages (e.g., around ages between 50 and 70). The contributions of child-age groups to longevity increases are notably high in Africa, Asia, and, to a lesser extent, Latin America. In other regions of the world with higher average income levels (Europe, North America, and Oceania), the contribution of child-age groups is substantively smaller. For these regions, increases in LE have been mostly attributable to declines in mortality at increasingly older ages.

Figure 2 also shows how widespread survival improvements have generally led to increases in HALE and UHLE across most age groups (i.e., most light- and dark-shaded bars take positive values). However, the relative contribution of HALE and UHLE to these survival improvements varies considerably across groups. The position of the black dots included in each panel of Figure 2—which shows the relative contribution of UHLE to the corresponding increases in LE in percentage terms (scale shown in the right-hand vertical axis)—reveals that, at higher ages, increases in survivorship are more and more attributable to the increases of years lived in less-than-good health. At the highest ages, almost half of the increases in LE can be attributable to increases in UHLE in most regions except Africa and, to a lesser extent, Latin America (specially among women). At one extreme,

FIGURE 3 Ternary plots showing the fraction of life expectancy spent in less-than-good health (100*UHLE/LE) for 204 countries and territories in 1990 and 2019 by region and sex. The vertices "C", "NC", and "I" stand for the proportion of "communicable", "noncommunicable", and "injury" deaths

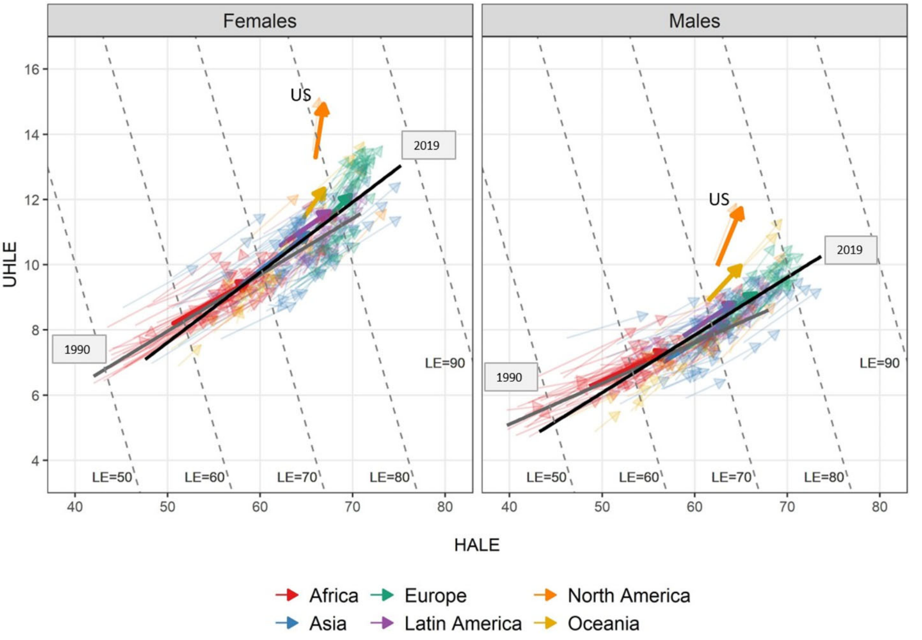


SOURCE: Authors' elaboration based on IHME data.

Africa exhibits the lowest age-specific contributions of UHLE to increases in LE (they never cross the threshold of 30 percent). At the other extreme, such contributions are highest in North America and Oceania (regions that are mostly determined by what happens in the United States, Australia, and New Zealand). Lastly, the age-specific contributions of UHLE to increases in LE are systematically higher among women than among men.

To explore the association between countries' main causes of death and the fraction of LE that is spent in less-than-good health (i.e., 100*UHLE/LE) in 1990 and 2019, we use the ternary plots shown in Figure 3. Each panel includes the results of a specific region–sex combination separately. Several interesting patterns are worth highlighting. First, we can observe that in high- and medium-mortality regions (like Africa, Asia, and, to a lesser extent, Latin America and the Caribbean and Oceania), many countries transition from the C vertex towards the NC vertex (i.e., from a majority of communicable deaths towards a majority of noncommunicable deaths). Many countries belonging to these regions are in the initial or intermediate stages of the epidemiological transition. Alternatively, the mortality profiles of countries in low-mortality regions (like Europe and North America) were already clustered around the NC vertex in 1990, and even more so in 2019—as is expected from countries in later stages of the transition. Second, the fractions of LE spent in less-than-good health increase more often than they decrease (they increase in three out of four countries approximately). Third, the values of 100*UHLE/LE tend to be larger for women than for men (i.e., women tend to spend higher fractions of their longer lives in less-than-good health than men). Lastly, the share of injury deaths tends to be higher among men than among women, but that share is particularly low in low-mortality countries.

FIGURE 4 HALE and UHLE levels across 204 countries and territories in 1990 and 2019 by world regions, together with regional averages highlighted in bold. Observations for the same country and region are connected with arrows pointing towards 2019 levels. The gray and black thick lines show the best-fit regression lines in 1990 and 2019, respectively. In each scatterplot, we add dashed lines indicating the iso-LE contours in the (HALE, UHLE)-space as a reference to facilitate interpretation and readability



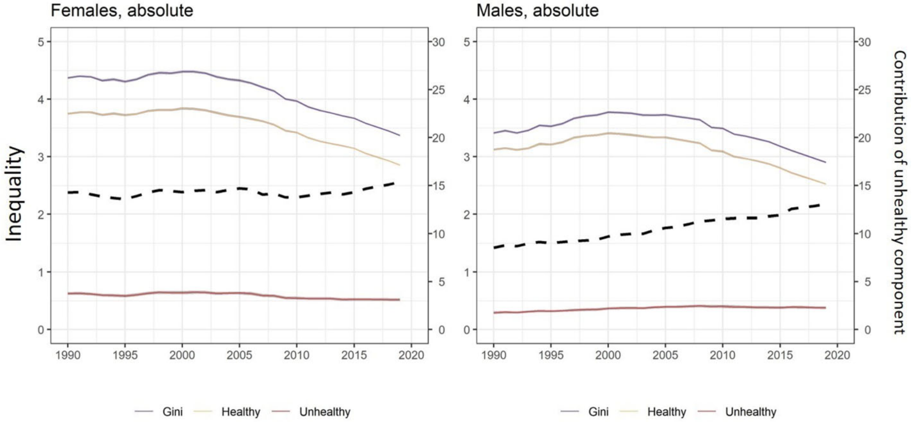
SOURCE: Authors' elaboration based on IHME data.

Longevity composition within countries

Comparing the joint distribution of HALE and UHLE across countries and regions over time, we observe they are positively associated for both sexes, both in 1990 and 2019 (see Figure 4). Therefore, in those countries where HALE is large, UHLE tends to be large as well. In each scatterplot, we add dashed lines indicating the iso-LE contours in the (HALE, UHLE) space as a reference to facilitate interpretation and readability. Despite a few isolated exceptions, the values of HALE and UHLE tend to increase over time, though at different speeds. The United States stands out as a clear outlier, with UHLE increasing at the fastest rate. In general, for those countries that were more longevous in 1990 (i.e., higher LE in that year), further increases in LE were decreasingly attributable to increases in the HALE component (stated otherwise: the arrows starting at higher LE levels tend to be shorter and have steeper slopes than those starting at lower LE levels; see Figure 4).

The slope of the best-fitting regression line tends to increase when moving from 1990 (gray line) to 2019 (black line), both for women and

FIGURE 5 Trends in IHI and its healthy and unhealthy components between 1990 and 2019 as measured by the absolute Gini index (also known as "absolute inter-country difference" (see Appendix D.1). The corresponding 95 percent uncertainty intervals are shown in light gray. The left axis shows the values of IHI and its healthy and unhealthy components, and the right axis the contribution of the unhealthy component to IHI



SOURCE: Authors' elaboration based on IHME data.

men. Likewise, the best-fit regression line for women has a higher slope than that of men, both in 1990 and 2019. This suggests that the contribution of UHLE to LE becomes increasingly prominent over time and is more important among women than among men. The relative position of the clouds of points in the two panels of Figure 4 demonstrates that, at any fixed level of LE (say 60, 70, 80), men spend a longer fraction of their lives in good health than women.

Inequality trends between countries

The female-specific levels of IHI hover around 4.4 until the early 2000s and then start declining monotonically, approaching 3.37 (3.36–3.38) in 2019 (see Figure 5). For males, IHI increases between 1990 and 2000 from 3.41 (3.39–3.43) to 3.77 (3.75–3.79) and then starts declining to reach its minimum of 2.9 (2.89–2.91) in 2019. Figure 5 also shows the trends in the healthy and unhealthy components of IHI (IHI_h and IHI_u; see the Methods section). IHI values are mostly explained by the healthy component of inequality (IHI_h), which is the largest in size. In contrast, the unhealthy component remains relatively flat during the observation period and roughly contributes 0.5 years to IHI during the entire period. Because of these trends, the fraction of IHI that is attributable to the unhealthy component (i.e., IHI_u/IHI) becomes increasingly prominent over time, especially for men (see black dashed lines and secondary (right) axes in both panels of Figure 5). The UIs around the values of IHI, IHI_h and IHI_u

TABLE 1 Decompositions of changes over time of World Life Expectancy: 1990–2019

	World life expectancy (WLE)			
	Healthy ($\Delta_H WLE$)	**Unhealthy ($\Delta_U WLE$)**	**Population ($\Delta_P WLE$)**	**Total WLE change (ΔWLE)**
		Females		
1990–1995	1.004	0.115	−0.250	0.870
1995–2000	1.075	0.191	−0.261	1.005
2000–2005	1.378	0.274	−0.284	1.368
2005–2010	1.656	0.302	−0.280	1.677
2010–2015	1.312	0.313	−0.256	1.369
2015–2019	0.772	0.251	−0.188	0.834
1990–2019	**7.196**	**1.445**	**−1.518**	**7.123**
		Males		
1990–1995	0.909	0.088	−0.174	0.823
1995–2000	1.077	0.187	−0.185	1.079
2000–2005	1.295	0.197	−0.199	1.294
2005–2010	1.505	0.193	−0.194	1.504
2010–2015	1.417	0.300	−0.185	1.532
2015–2019	0.897	0.212	−0.142	0.967
1990–2019	**7.100**	**1.177**	**−1.078**	**7.199**

SOURCE: Authors' elaboration based on IHME data.

are very narrow (see Figure 5), so the changes over time reported above are statistically significant.

Table 1 shows the three-term decomposition results for changes in WLE in five-year periods between 1990 and 2019 (see the Methods section). Both the increases of HALE and UHLE have contributed to increasing WLE between 1990 and 2019, but the contribution of the former (7.196 years for women and 7.1 for men) has been much larger than the contribution of the latter (1.445 years for women and 1.177 for men; see Table 1). In contrast, population growth has systematically contributed to decrease WLE (−1.518 years for women and −1.078 for men), thus indicating that the population has tended to increase more rapidly in those countries with the lowest LE.

Table 2 shows the analogous decomposition results for changes in IHI (see the Methods section). Changes in IHI have been strongly determined by the changes in the HALE distribution, which have contributed to decrease inequality by −1.224 years for women and −0.787 for men, overall (see Table 2). Among women, the generalized increases in HALE have almost always contributed to decrease IHI (except between 1995 and 2000), while for men, HALE trends first contributed to increase IHI (until 2000) and then strongly contributed to decrease its values until the present day. The contribution of UHLE dynamics to changes in IHI has been more modest and has been switching directions over time. Lastly,

TABLE 2 Decompositions of changes over time in international health inequality: 1990–2019

	International health inequality (IHI)			
	Healthy ($\Delta_H IHI$)	**Unhealthy ($\Delta_U IHI$)**	**Population ($\Delta_P IHI$)**	**Total inequality change (ΔIHI)**
		Females		
1990–1995	−0.052	−0.044	0.032	−0.064
1995–2000	0.056	0.062	0.054	0.172
2000–2005	−0.207	−0.010	0.064	−0.152
2005–2010	−0.375	−0.046	0.061	−0.360
2010–2015	−0.337	−0.010	0.048	−0.299
2015–2019	−0.310	−0.022	0.033	−0.299
1990–2019	**−1.224**	**−0.071**	**0.293**	**−1.002**
		Males		
1990–1995	0.084	0.004	0.027	0.115
1995–2000	0.154	0.048	0.044	0.245
2000–2005	−0.117	0.022	0.050	−0.044
2005–2010	−0.289	0.011	0.043	−0.236
2010–2015	−0.328	−0.021	0.037	−0.312
2015–2019	−0.290	−0.021	0.030	−0.280
1990–2019	**−0.787**	**0.043**	**0.231**	**−0.513**

SOURCE: Authors' elaboration based on IHME data.

the force of population growth has been inequality enhancing throughout the observation period (i.e., if the only factor that changed over time were the size of the population, IHI would have increased by 0.293 years for women and 0.231 years for men, overall). Once again, this suggests that population growth has tended to put more weight at the bottom of the LE distribution (i.e., populations have tended to grow faster in low longevity countries)—thus increasing IHI. Overall, the strong equalizing force of the generalized HALE improvements has more than compensated for the inequality-enhancing force of population growth, thus leading to an important reduction in IHI levels by the end of the period (see Table 2).

Discussion

Studies investigating the evolution of LE and its distribution across world countries often assume that gains in longevity are desirable no matter what. Yet, the fact that a nonnegligible and increasing fraction of LE is composed of years spent in less-than-good health casts doubts on the validity of this assumption. While the desirability of the healthy component of LE is undisputed, the potential trade-offs between quantity and "health quality" of years of life pose challenges when interpreting the unhealthy component in our assessments of countries' health performance. This state of affairs could cast doubts on the use of standard approaches when judging the evolution of international health dynamics. Inequality measures make perfect sense when the variable we are analyzing is normatively desirable—as is the case of income when studying economic inequality—but mixing years of life irrespective of the health conditions in which they are lived can muddy the waters when interpreting their values. This paper attempts to distinguish between the two components and investigate how their dynamics have affected LE composition and its distribution around the world between 1990 and 2019.

Summary of main findings

Overall, increases in HALE have been larger in absolute terms, but smaller in relative ones, than increases in UHLE (Figures 1, 2, and 4). While LE has generally increased, the fraction of LE spent in good health has decreased approximately in three out of four countries around the world. The contributions of UHLE to increases in LE (C_U) have been generally greater among low-mortality countries in later stages of the epidemiological transition, where deaths caused by noncommunicable diseases prevail (e.g., in North America, 65 percent and 40.7 percent of the change in LE was attributable to increases in UHLE for women and for men, respectively, while that percentage dropped to 13.7 percent and 11.5 percent for women and men in Africa, a region where "communicable-" and "injury-related" deaths are much more predominant). In addition, increases in UHLE have contributed more to increases in LE at older ages than at younger ages (at the highest ages, half of the increase in LE is attributable to increases in UHLE in some regions), and such contribution has been higher among women than among men (Figures 2 and 4).

Attempts at testing whether the observed changes in HALE and LE lend support to alternative hypotheses around the "compression versus expansion of morbidity" debate using the methods presented in Robine et al. (2020) lead to statistically nonsignificant results because of the uncertainty surrounding the estimation of LE, HALE, and UHLE (details shown in Appendix E). In contrast, the changes over time in IHI are statistically significant. Between 1990 and 2019, they follow an inverted U shape, peaking around the year 2000. IHI values have been mostly attributable to the variability in the corresponding HALE levels. However, the average number of years spent in less-than-good health (UHLE) is becoming an increasingly prominent component that does play a nonnegligible role in determining the levels of IHI. The inequality-enhancing effect of population growth identified in Table 2 is the result of an increasingly large fraction of the world's population living in countries at the lower end of the LE distribution.

It is well known that the epidemiological environment *and* the age structure of populations strongly shape the corresponding mortality profiles. For those countries in the earlier stages of the epidemiological transition, deaths tend to occur at younger ages and are often acute (i.e., they do not involve long morbid periods before death). In contrast, for those countries at later stages of the transition, most deaths occur at more advanced ages and are often the aftermath of noncommunicable diseases involving (potentially long) morbid processes (Figures 2 and 3). Thus, for countries in later stages of the epidemiological transition, further longevity rises seem to be more and more attributable to an increase in the number of years individuals spend in less-than-good health. Yet, results should be interpreted with great caution: the economic and social burden associated with those unhealthy years can vary considerably because it is highly contingent on a complex interplay between factors that change rapidly over space and time (further details below). On the other hand, the fact that IHI has resumed its downward trend after the divergence period between 1990 and 2000 is a cause for celebration that invites cautious optimism. Since the turn of the millennium, individuals' survival prospects not only have increased overall but are also decreasingly dependent on the country where they happen to live.

Explanatory factors

The trends documented in this paper reflect the differential success that societies worldwide have had in pushing the onset of morbidity and the occurrence of mortality to older ages. Efforts to delay health deterioration and death are affected by a variegated set of factors that might push in opposite directions; that is, potentially contributing to the expansion or the compression of morbidity within countries. Among the former, population aging is key: as individuals survive to older ages, it is increasingly likely that they are affected by (multi)morbidity processes (Head et al. 2021). Since delayed mortality selection has shifted health disparities from early to later life, elder populations are composed of an increasingly heterogenous mix of robust and frail individuals (Engelman, Canudas-Romo, and Agree 2010)—and, very often, such inequalities go along socio-economic status (SES) lines. Divergence in health outcomes across SES groups hinders overall progress and is thus a formidable obstacle towards achieving the compression of morbidity. In the last decades, several studies reported increasing mortality-related inequalities between SES groups (e.g., widening gaps in LE by SES (Steingrímsdóttir et al. 2012; Tarkiainen et al. 2012; Brønnum-Hansen and Baadsgaard 2012; Chetty et al. 2016; Case and Deaton 2015): which amplify even further when inspecting its morbidity counterparts (i.e., increasing gaps in HALE across SES groups (Jagger et al. 2008; 2020).

Opposing these forces of divergence, other factors might contribute to generalized delays in the onset of health deterioration, eventually conducing to an overall compression of morbidity within countries. Biomedical research can foster discoveries of new disease treatments. Technological breakthroughs like the development of new therapeutic targets for treating aging-related diseases (Muntane et al. 2018; Farré et al. 2021) have the potential to defer the onset of morbidity even further. Lastly, public health policies aiming at (i) improving the living standards of individuals and the environment where they live and (ii) promoting healthier lifestyles (e.g., healthier diets, exercise) can postpone the deterioration of individuals' health and have ample scope for application in all countries around the globe.

Our findings on IHI trends cohere with those presented in previous studies and extend them further in time. According to Moser et al. (2005), IHI declined from the 1950s up to the 1990s. Between the 1990s and early 2000s, IHI bounced upwards—a period of divergence that has been attributed to the spread of HIV-AIDS in Sub-Saharan Africa and the collapse of the Soviet Union (Goesling and Firebaugh 2004). From the 2000s onwards, our findings suggest that IHI resumed its downward trend until 2019. Comparing the values of IHI between 1990 and 2000 reported in this and other studies (e.g., Goesling and Firebaugh 2004; Moser et al. 2005), we find differences in levels but not in trends (in all cases, this is a period of divergence). The differences in levels can be attributable to several factors, like the use of different inequality indicators, the use of alternative data sources (e.g., GBD vs. United Nations' World Population Prospects (WPP)) with different country coverages (e.g., 204 in GBD vs. 152 in the 2000 version of WPP), the use of overall population versus sex-specific indicators, or the use of alternatives sources to estimate countries' population sizes (a fundamental ingredient in the estimation of IHI).

Several factors contribute to the reduction of IHI, like generalized economic growth (which contributed to improving the living standards of most societies around the globe, particularly those at the bottom of the income distribution (Preston 1975), the expansion of education (which disseminates health-promoting literacy), medical improvements, or the diffusion of technology with spillover effects to the benefit of lower income countries (like the use of cheap methods to reduce child mortality (e.g., oral rehydration therapies)) (McMichael et al. 2004). Alternatively, the collapse of economies and political systems, the outbreak of wars and epidemics, or the health risks associated with large-scale environmental degradation can contribute to LE differences between countries—thus reflecting the interdependence between populations' health and the social, economic, and physical environment where they live (McMichael et al. 2004). Such interdependence leads to the successive waves of convergence–divergence health cycles observed in this paper—as hypothesized by the health transition theory suggested by Frenk et al. (1991) and later adopted by Vallin and Meslé (2004).

Quantity versus quality

The trends reported in this and other studies suggest that, between 1990 and 2019, world countries have been increasingly successful in (i) delaying the occurrence of death, and (ii) attaining increasingly similar survival prospects. However, failure to distinguish between the quantity and quality of the years individuals are expected to live can lead to over-optimistic and biased assessments of the performance of health systems around the globe. If longevity increases were only attributable to increases in survivorship among those living in morbid states, it might be debatable whether we should be speaking about "unambiguous health improvements".

This is the first study investigating how the joint evolution of HALE and UHLE has influenced (1) the composition and evolution of LE within countries and (2) the distribution of LE between countries around the globe. Depending on the outcomes of such decomposition analyses, policies aiming at increasing longevity *and* reducing health inequality should follow a different course of action. For instance, if IHI levels are mostly explained by variations in the healthy component, efforts to curb inequality should be directed towards increasing HALE for those countries at the bottom of the "healthy longevity distribution." In contrast, if IHI levels were mostly driven by variations in the unhealthy component, efforts at curbing such inequality would be most effective when improving the survivorship among those individuals already living in morbid states for the countries at the bottom of the UHLE distribution. While the former scenario would tend to favor disease prevention and socioeconomic environment-improving strategies, the latter would put more emphasis on the treatment of actual disease or disability. Our results suggest that the world's current situation is closer to the former scenario than to the latter (see Figure 5 and Tables 1 and 2), so improvements in HALE for the world's least longevous countries would be the most efficient way of simultaneously increasing WLE *and* reducing health differences between countries.

Limitations

Our study has some limitations. Defining what it means to be in "good" or "less-than-good" health around world countries during the last 30 years is not an easy task, and GBD estimates for many low-income countries rely on imperfect mortality and morbidity data. Despite the use of advanced statistical models to address gaps in data, there is some inescapable uncertainty around HALE, UHLE, and LE estimates (Abbafati et al. 2020; Vos et al. 2015). Because of such uncertainty, our tests on the compression versus expansion of morbidity within countries fail to be statistically significant. Higher quality mortality and morbidity data will be crucial to investigate these issues in further detail in the near future.

In addition, the normative desirability of UHLE is far from being clear. The same average number of years spent in "less-than-good" health could either result from a situation of a high prevalence of a light condition (e.g., moderate impairment in distance vision) or from another one in which a smaller segment population experienced severe conditions (e.g., severe Parkinson's disease)—see the Methods section. The economic and social implications ensuing from those alternative scenarios can differ dramatically. In addition, whether individuals are willing to live in certain morbid conditions or not is often contingent on a host of variegated factors, like the existence of medical treatments, the accessibility to technology and resources, the availability of emotional support, or personal traits' characteristics. In future research, it would be interesting to revisit similar ideas to the ones explored in this paper but focusing exclusively on major chronic diseases with severe consequences for individuals' health (like cancers, ischemic heart diseases, strokes, or neurodegenerative diseases) or different health problems like chronic pain or functional limitations.

Notwithstanding these limitations, the major factors contributing to "less-than-good" health have a strong empirical basis and have enough quality to give a broad-brush overview of the major health differences between world countries. As a robustness check, we have replicated the calculations performed in this paper using the HALE and LE estimates provided by the WHO for the years 2000, 2010, 2015, and 2019. While the values of our key indicators and the corresponding decompositions are not exactly the same, the overall findings of this paper remain unaltered (see Appendix F). Finally, future analyses should go beyond the decompositions documented in this paper and explore what are the causes of death and disability driving them.

Future prospects and final thoughts

For the sake of simplicity, our approach has been limited to the study of IHI and thus disregards the health differences that might exist within countries. While providing very useful information, the three basic indicators used in our analyses (LE, HALE, and UHLE) are country-level averages that hide potentially large health differentials across individuals. Inspecting lifespan inequality across the globe, previous studies have documented that most of the differences in the ages at which individuals die (i.e. mortality differentials) are explained by differences within countries rather than between them—the latter only explaining around 10 percent of the total variation (Smits and Monden 2009; Edwards 2011; Permanyer and Scholl 2019). Extrapolating the previous studies to the mortality and morbidity context we are dealing with in this paper would require estimating what fraction of individuals' lifespans are spent in good and in less-than-good health, an extremely useful piece of information that, unfortunately, can only be estimated under somewhat stringent assumptions for a limited set of countries with high-quality data (e.g., Nordic countries with exhaustive population and health registers; see Jensen et al. 2014). Investigating what portion of lifespan inequality is attributable to the years individuals spend in different health states is a promising area for future research.

Among the different regions considered in this paper, Africa is the only one whose average LE and HALE are well below the world average (Figure 2). This suggests that prospects for further reductions in IHI are highly contingent upon what will happen in that part of the world—which is the one that is predicted to experience the fastest population growth in the coming decades. If longevity and healthy longevity in Africa continue to grow at a faster-than-world average speed (as it has been doing during the last 20 years), we should continue observing further declines in IHI. Likewise, another factor that could contribute to further reductions in IHI during the coming decades is the continuation of the decelerating gains in LE observed among high-income countries (Cardona and Bishai 2018; Leon, Jdanov, and Shkolnikov 2019).

Importantly, the results reported in this and other recent studies suggest that global health inequalities are undergoing profound transformations. First, inequality in LE *between* countries has resumed its downward trend after the temporary blip in the 1990s, while at the same time there is increasing evidence that health inequalities *within* countries have increased during the same period—very often along SES lines. Similar patterns at the global level have also been observed for other key dimensions of well-being, like income (Anand and Segal 2015), education (Jordá and Alonso 2017), or human development (Permanyer and Smits 2020). While still relevant, country of residence is gradually losing prominence as a factor to determine individuals' well-being.

Second, morbidity onset is playing an increasingly important role to explain (1) improved survival prospects among longevity vanguard countries and (2) longevity differences between world countries. Mounting empirical evidence suggests that, as longevity increases further, mortality-related inequalities dwindle with respect to disease- and disability-centered ones (Permanyer et al. 2023), so interventions to improve population health should increasingly focus their attention on the health "disorders that debilitate, rather than kill" (Murray et al. 2015, 38). The same factors leading to an international convergence in basic survival indicators, like LE at birth (mainly through the worldwide reduction of infant and child mortality) have in turn contributed to the emergence of new layers of global inequality in mortality or morbidity among adults at older ages (Permanyer and Scholl 2019; United Nations Development Programme 2019).

In the coming decades, the aforementioned transformations will shape the contours of the research agenda and interventions among scholars and policy-makers concerned with global health inequalities.

Future longevity gains and reductions in IHI are neither deterministic nor guaranteed (McMichael et al. 2004). More and more, such objectives are threatened by pandemics (as evidenced by Covid-19) as well as geopolitical tensions, economic instability, wars, increasing inequalities, natural resource depletion, and environmental degradation (Mackenbach 2020). These factors (alone or in conjunction with each other) can cause reversals in death and morbidity rates and contribute to widening existing health inequalities (Andrasfay and Goldman 2021)—so further progress might be less certain than previously thought.

Notes

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1 In a more recent revision of the compression of morbidity hypothesis, Fries and other colleagues state that "[…] the Compression of Morbidity paradigm does not depend upon whether the human life span is fixed or rising. It depends on relative changes in mortality rates and in morbidity/disability rates" (Fries, Bruce and Chakravarty 2011, 5).

2 A nice summary of state-of-the-art contributions along these different lines is presented in Jagger et al. (2020).

3 Edwards (2011) and Permanyer and Scholl (2019) investigate global trends in length of life inequality. Unlike other traditional group-based indicators (like total fertility rates), length of life is an individual-level indicator that, averaged across individuals in each country, gives the corresponding level of life expectancy. Due to data limitation constraints, the analyses of this paper are restricted to the country level. To conduct individual-level analyses, we would need to know the amount of time each individual has lived in "good" or in "less-than-good" health, an information that is currently unavailable (see the Discussion section).

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