Prioritizing global health issues leveraging demographic analysis

Or: What hampers long and prosper lives worldwide?

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Abstract

Surprisingly, prioritizing global health issues scarcely relies on demographic analysis so far. If health programs are aligned with mortality often only basic indicators are considered, such as prevalences and death counts of fatal diseases. Leveraging demographic knowledge we use sensitivity analysis and sorting algorithms to identify the top age–&–cause of death combinations that could best increase life expectancy and decrease lifespan inequality worldwide in upcoming years, based on data of the UN World Population Prospects and the Global Burden of Disease study. Compared to analyzing only death counts of leading causes, our study reveals that HIV/AIDS is indeed more important and that ages of timely intervention often are substantially younger. Consequently, health planning that is based on only basic indicators could perhaps motivate to implement counter-productive actions that are meant well but increase health inequality—an unintended but serious shortcoming that could be overcome with our proposed methodology.

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1 Introduction

56.4 million people eventually died worldwide in 2014 according to the UN World Population Prospects (2017), but they probably did so from different causes of death and at different chronological ages. Massive international efforts are underway to reduce mortality from leading causes of death and to facilitate long and prosper lives for everyone across the globe. To meet these ambitious but also fundamental development goals we need to prioritize health issues first in order to subsequently allocate (domestic and external) health expenditures for implementing meaningful health care reforms. Only timely and effective prevention, diagnosis, treatment, and recovery—fine-tuned for each cause of death—could finally increase further the length and the quality of human lives worldwide.

Global health financing is usually given more attention than prioritizing global health issues when it is about reducing mortality and improving health worldwide. That is probably because the overall goal (to reduce mortality) appears to be rather simple and clear—fighting causes of death from which many people die—while raising, allocating, and managing the financial means through various governments and organizations is not.

Data on global health expenditures exist by source (domestic or external) but are rather scarce by cause of death (Xu et al., 2018; OECD, 2016). Chang et al. (2019) and a corresponding database of the Institute for Health Metrics and Evaluation (IHME) (2019) provide for the first time extensive data estimates on health spending for 195 countries between 1990 and 2018. The majority of these data are about the source of funding and less about their distribution across health issues (with the latter being sparsely available at all and if then only for external funding). External aid represented less than half a percent of total health expenditures worldwide in 2016 but it accounted for more than 25% of all health spending in low income countries. Consequently, the distribution of external aid across so called health focus areas reflects the priorities of the global community assigned to health issues particularly in low income countries: 6% to *Malaria*, 23% to *HIV/AIDS*, 22% to *Newborn and child health*, 12% to *Reproductive and maternal health*, 4% to *Tuberculosis*, 2% to *Non-communicable diseases*, and 9% to *Other infectious diseases*. In contrast, domestic health expenditures account for almost all health spending in high, upper-middle, and lower-middle income countries, 100% through 97% (IHME, 2019). The largest share, more than 60%, is spent on *Non-communicable diseases* from which most people die there (Xu et al., 2018; OECD, 2016).

Prioritizing global health issues in binding programs scarcely relies on demographic analysis so far. If health programs are aligned with mortality often only basic indicators are considered. For example, the third UN Sustainable Development Goal (SDG 3) focuses on global health issues but takes into account only crude measures of mortality intensity—such as death counts, prevalences, and rates of mortality at particular ages and for major causes of death—in order to lay down common health objectives and to monitor progress in its member states until 2030. Overall SDG 3 appears to be specific in terms of setting threshold levels for simple health metrics. However, these threshold levels are largely meaningless unless they come along with proposed actions by demographic means that provide guidance on how to best tackle them. For example, SDG 3 appears to be quite vague in determining the ages that would be most suitable for timely intervention in order to substantially reduce mortality from a particular cause of death—which would be crucial information but that can only be gained from thorough demographic analysis.

Our study scrutinizes and develops further the common practice to prioritize global health issues. It contributes a fully demographic perspective on and a sound methodological solution for prioritizing health issues across ages and fatal diseases on the international stage. It systematically

compares the burden of major causes of death and also identifies the ages that are most suitable for timely intervention for each of them. Objectively ranking causes of death according to their significance for reducing mortality and giving advice on the time point in life when to best tackle them has not, to our knowledge, previously been done to effectively prioritize global health issues.

Re-examining from a demographic perspective the generic goal to reduce mortality and to improve health we suggest to differ between reducing old-age mortality and avoiding premature deaths. Mortality in old age and in premature age is linked to two core metrics in demography: life expectancy and lifespan inequality. Life expectancy, e_x, is a measure of central tendency that gives the average number of remaining years of life at age x in a population. This measurement of mean mortality is complemented with lifespan inequality that takes into account the spread of mortality across age in an entire population. We measure lifespan inequality with $e^\dagger_x$ (e.g. Vaupel and Canudas Romo, 2003; Zhang and Vaupel, 2009; van Raalte et al., 2018) that gives the average number of life years lost due to premature death at age x.

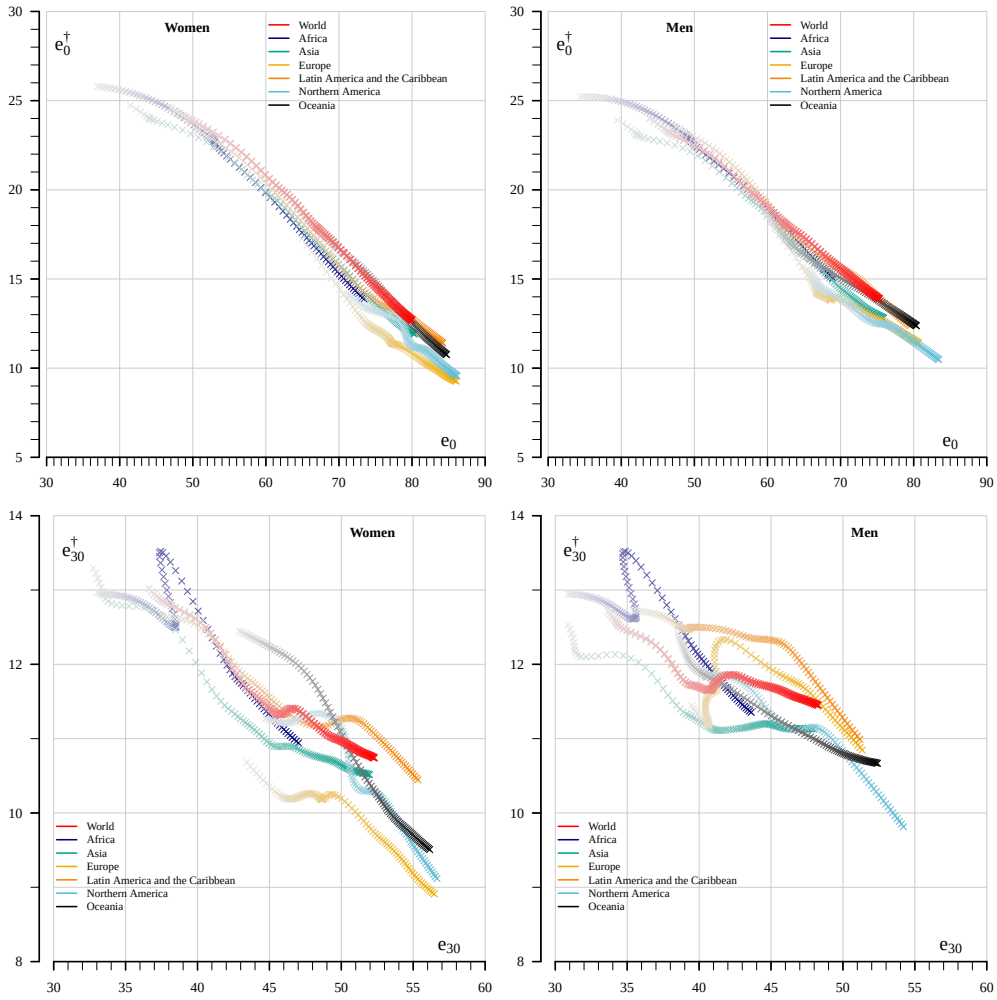

Figure 1: Life expectancy (e_x) on the horizontal axis and lifespan inequality ($e^\dagger_x$) on the vertical axis, for women (left panel) and men (right panel) at age 0 (upper panel) and age 30 (lower panel), globally (red) and in six world regions between 1950 (gray) and 2050 (saturated color). Input data are from the UNWPP (2017).

Applied to our context of reducing mortality we can ask with life expectancy if people enjoy on average longer lives and with lifespan inequality if many (if not all) people enjoy longer lives. The answers to both questions can only be in the affirmative if life expectancy increases and if lifespan inequality decreases with ongoing time. That more and more people enjoyed ever longer lives worldwide between 1950 and 2014 (and are expected to continue to do so until 2050) is shown in Figure 1. Although we can easily spot differences between world regions, we find for newborn girls and boys as well as for 30-year-old women and men that their remaining life expectancy has generally increased (shift to the right on the horizontal axis), while their lifespan inequality has generally decreased (shift downward on the vertical axis).

Leveraging our demographic knowledge about reducing mortality in old age and in premature age we can finally specify that prioritizing global health issues is actually about identifying the age–&–cause of death combinations that hamper most (1) life expectancy to increase and (2) lifespan inequality to decrease. In contrast, common practice often analyzes overall mortality intensity with only simple indicators, sometimes by age and cause of death. As a consequence, common practice is at risk to fall short of the mark when prioritizing global health issues with respect to determining the true significance of causes of death and their corresponding ages for timely intervention. We briefly elucidate the conceptional and methodological advantages of our proposed study design over common practice using the example of *HIV/AIDS* and *Cardiovascular diseases* in this introduction (before we present our complete analysis of *all* age–&–cause of death combinations in the entire world in the subsequent paper).

A key question dealing with prioritizing global health issues concerns: How to justify global health financing so that it could be objectively regarded as being fair? In fact, global health spending could be regarded as being unfair or imbalanced when looking only at death counts attributable to *HIV/AIDS* and *Heart disease*. With the United States being one of the biggest contributors to global health spending, it has spent more than twice as much to fight against *HIV/AIDS*, $3bn, than on *Heart disease*, $1.2bn, in 2015—even though the death counts attributable to *HIV/AIDS*, 7.5k in the United States and 1.2m worldwide, have been respectively one hundred times and ten times smaller than those attributable to *Heart disease* in the same year (NIH, 2015).

Our study sheds light on this alleged discrepancy and reveals a fundamental dilemma. On the one side, it is true that fewer and fewer people die from *HIV/AIDS* but those people who still die from this cause are relatively young and, consequently, lose many life years that they could have enjoyed otherwise. On the other side, it is also true that more and more people die from *Heart disease* in relatively old age and, consequently, limit life expectancy to increase much further. Only if premature deaths (e.g. from *HIV/AIDS*) were avoided more people would have the chance to reach old ages. And only if mortality (e.g. from *Heart disease*) in old age was reduced further people could enjoy ever longer lives. Our study now provides the theoretical concepts and methodological tools to objectively discuss and resolve this dilemma. Instead of prioritizing health issues and justifying health expenditures solely based on simple measures of mortality intensity (such as death counts) we propose to rank the potential impact of each and every age–&–cause of death combination on increasing life expectancy and decreasing lifespan inequality—emphasizing the importance to always take into account both dimensions instead of only one of them.

How do we do this? We use sensitivity analysis and sorting algorithms to identify the top age–&–cause of death combinations that could best increase life expectancy and best decrease lifespan inequality worldwide in years to come. Our study reveals, for example, that *HIV/AIDS* is indeed among the top five leading causes of death when it comes to reducing global lifespan inequality. This is in stark contrast to the much lower ranks assigned to *HIV/AIDS* when analyzing only

global death counts: rank 9 for women and 13 for men. Our study also reveals that ages of timely intervention often are substantially younger when analyzing lifespan inequality compared to life expectancy and even younger when compared to death counts. For *Cardiovascular diseases*, this gap in ages of timely intervention amounts to 18 years when the analysis is based on lifespan inequality and life expectancy and even to 20 years when it is based on lifespan inequality and death counts.

Putting these results together we see that the priority assigned to causes of death and to their corresponding ages for timely intervention can differ substantially between our study and common practice. It is remarkable that the great importance of HIV/AIDS only comes to light when prioritizing global health issues based on lifespan inequality. It is also remarkable that the ages identified for timely intervention are up to 20 years older for *Cardiovascular diseases* when the analysis is based on global lifespan inequality and not on global death counts. Consequently, global health planning that is based on only basic indicators of mortality intensity could perhaps motivate to implement counter-productive actions that are meant well but eventually increase health inequality—leading to unintended but serious errors that could be averted with our proposed methodology based on demographic know-how.

The remainder of the paper is organized as follows. The first part briefly describes the collection and preparation of input data required to finally obtain death rates by single years of age for women and men worldwide between 1950 and 2050, and also by cause of death for the years 1990 through 2014. Secondly, we introduce the methods to quantify for *all* age–&–cause of death combinations the impact they have had and could have on increasing life expectancy and decreasing lifespan inequality, namely decomposition analysis and numerical sensitivity analysis. We then show main levels and trends in global life expectancy and global lifespan inequality since 1950 as well as their high-impact age–&–cause of death combinations in 2005–2014 and in 2014. We thereby focus on complex patterns by gender and metric for newborns and 30-year-old adults. To provide a baseline scenario we also compare our results with those obtained from analyzing death counts as they represent common practice. Finally, we summarize and discuss the main findings in order to draw conclusions for how to best prioritize global health issues based on demographic know-how.

2 Collect and prepare data

We require death rates by single years of age and calendar time, cause of death, world region, and sex to conduct decomposition analysis and sensitivity analysis that both identify high-impact age–&–cause of death combinations for increasing life expectancy and reducing lifespan inequality.

The UNWPP(2017) provide death counts and exposure for women and men, for the world and six world regions: Africa, Asia, Europe, Latin America and the Caribbean, north America, and Oceania, observed from 1950 to 2014 and forecasted from 2015 to 2100. We obtain death counts by five years of age and calendar time as well as exposures by five years of age and single years of time.

The GBD (2018) provides cause-specific death estimates by five years of age and single years of time between 1990 and 2014 for countries worldwide. We consider 22 high level causes of death. Eight communicable diseases: *Tuberculosis*, *HIV/AIDS*, *Diarrhea*, *Neglected tropical diseases & malaria*, *Maternal disorders*, *Neonatal disorders*, *Nutritional deficiencies*, and *Other communicable diseases*. Nine non-communicable diseases: *Neoplasms*, *Cardiovascular diseases*, *Chronic respiratory diseases*, *Cirrhosis*, *Digestive diseases*, *Neurological disorders*, *Mental and substance use disorders*, *Diabetes*, *Musculoskeletal disorders*, and *Other non-communicable diseases*. Four external causes: *Transport injuries*, *Unintentional injuries*, *Self-harm and interpersonal violence*, and *Forces of nature*. Tables 2 and 3 in the appendix link these 22 causes of death with their corresponding ICD 10

codes according to the Global Burden of Disease Collaborative Network (2017).

We first use the `spline` function in R (2019) to smooth data over time and we then use the penalized composite link methodology of Rizzi et al. (2015), implemented in the R-package `ungroup` (2018), to estimate and smooth annual schedules of death counts and exposures across age and time using the 2D function, degree 2, to finally get cause-specific death rates by single years of age, 0 to 110, and calendar year, 1990 to 2014. Tests show that there is a good trade-off of the resulting data with respect to being smooth and matching closely the raw input data.

A brief note on the quality of data used in our study. The cause of death data provided by the GBD (2018) are in fact model estimates that rely on true observations from different sources. However, these estimates are generated with consistent methodology and are, consequently, comparable across countries worldwide. The World Health Organization also provides cause of death data but their coverage across ages and calendar years is severely limited for some countries. For example, causes of death data are missing completely for China, and only incomplete trajectories are available for some other countries. With the GBD (2018) being the only source that provides consistent cause of death data with global coverage to date we decided to make use of their data. A decision that has also been made by the renowned NIH (2015), which also makes use of GBD data to compare causes of death across the globe.

3 Methods to quantify impact of age–&–cause of death combinations on life expectancy and lifespan inequality

Decomposition analysis looks back to the past and quantifies the impact of age–&–cause of death combinations they have had on increasing life expectancy and decreasing lifespan inequality so far. Sensitivity analysis looks ahead to the future and quantifies the impact of age–&–cause of death combinations they could possibly have on increasing life expectancy and decreasing lifespan inequality in years to come. Below we briefly describe the routines implemented in R (2019) to conduct the decomposition analysis and sensitivity analysis.

3.1 Routine of decomposition analysis

We adopt the decomposition method of Horiuchi et al. (2008) that uses numerical integration to quantify the contribution of each age–&–cause of death combination to the change in life expectancy and lifespan inequality in an entire period of time. We apply the following four-step routine for women and men in the world and six world regions for newborns and 30-year-olds:

0. Our core routine of decomposition analysis is based on the Matlab program provided in the supplementary materials of Horiuchi et al. (2008, page 13). We have slightly revised the Matlab program so that we can also account for the a_x, that is, the average proportion lived in an entire age interval x to $x+1$ of people who eventually die in this age interval. This can increase accuracy particularly for world regions with large infant mortality.

1. Determine input parameters such as the start year and the end year of the entire period to be analyzed and the number of intervals N to be used for numerical integration. To analyze the most recent decade we use 2005 as start year and 2014 as end year. And, as recommended in Horiuchi et al. (2008), we use a large number of $N = 100$ time intervals to minimize the residual error in the decomposition analysis.

2. Provide input data—that is, mortality schedules m by age x and cause of death c for the start year 2005, m_{xc}^{2005}, and the final year 2014, m_{xc}^{2014}. In addition, we also provide a_x for the years 2005 and 2014.

3. Run the core routine to decompose the change in life expectancy and lifespan inequality between 2005 and 2014 into contributions by age–&–cause of death:

   (a) Calculate the overall difference, d, in the mortality schedules m_{xc}^{2005} and m_{xc}^{2014} by age x and cause of death c.

   (b) Divide the entire time interval into $N = 100$ sub-intervals, each of the length 1/100.

   (c) Repeat the following steps 3(c)i through 3(c)iv for each age–&–cause of death combination xc and each sub-interval:

      i. Locate the center $(1/100/2, \ldots, 1 - 1/100/2)$, the start point $(0, \ldots, 1 - 1/100)$, and the end point $(1 - 1/100, \ldots, 1)$ of the sub-interval.

      ii. Determine mortality in the center: $m_{xc}^{2005} + d_{xc}^{*} \times 0.005$ for the first sub-interval ... and $m_{xc}^{2005} + d_{xc}^{*} \times 0.995$ for the last sub-interval. Please note that the overall difference d^{*} keeps its original value d of step 3(a) only for xc and is set to 0 for all other age–&–cause of death combinations.

      iii. Determine mortality at the start and end point: $m_{xc}^{2005} + d_{xc}^{*} \times 0.005 \pm d_{xc}^{*}/100/2$ for the first sub-interval ... and $m_{xc}^{2005} + d_{xc}^{*} \times 0.995 \pm d_{xc}^{*}/100/2$ for the last sub-interval. Please note that the overall difference d^{*} keeps its original value d of step 3(a) only for xc and is set to 0 for all other age–&–cause of death combinations.

      iv. Calculate the contribution of the age–&–cause of death combination xc in the sub-interval as the change in life expectancy and lifespan inequality between its start and end point based on the corresponding mortality schedules of step 3(c)iii.

4. Calculate the total contribution of each age–&–cause of death combination to the overall change in life expectancy and lifespan inequality between 2005 and 2014 as the sum of their contributions across all $N = 100$ sub-intervals.

3.2 Routine of numerical sensitivity analysis

We conduct a series of numerical sensitivity analysis to analyze how strongly a proportional change in each age–&–cause of death combination could possibly impact life expectancy to increase and lifespan inequality to decrease. More specifically, we apply the following five-step routine for women and men in the world and six world regions for initial ages 0 and 30 of life expectancy and lifespan inequality:

1. Provide input data—that is, mortality schedules m by age x and cause of death c for the last observed year 2014, m_{xc}^{2014}. In addition, we also provide a_x for the year 2014.

2. Calculate life expectancy and lifespan inequality for the most recent calendar year 2014 based on cause-specific death rates by single years of age and the a_x.

3. Re-calculate life expectancy and lifespan inequality reducing mortality of a single age–&–cause of death combination by 100% and keeping mortality of all other age–&–cause of death combinations at the level observed in 2014. Repeat this procedure for all age–&–cause of death combinations.

4. Calculate the potential impact of each age–&–cause of death combination as the change in life expectancy and lifespan inequality between their original value in 2014 obtained in step 2 and their potential value based on the mortality schedules of step 3.

5. Sort and rank all age–&–cause of death combinations according to their potential impact on increasing life expectancy and decreasing lifespan inequality.

4 Results

We analyze global life expectancy and global lifespan inequality from four perspectives—that is, we (1) describe their overall levels and trends since 1950, (2) explain unusual developments with decomposition analysis, (3) quantify their response to proportional changes in major causes of death in 2014, and (4) identify for each major cause of death the ages of timely intervention they are most sensitive to. Putting all these results together we finally rank age–&–cause of death combinations according to their potential impact on increasing life expectancy and decreasing lifespan inequality in years to come (based on sensitivity analysis for the latest year 2014). In our multi-perspective analysis we focus on patterns by gender and metric for newborns and 30-year-old adults.

4.1 Overall levels and trends in life expectancy and lifespan inequality

Figure 2 depicts global life expectancy and global lifespan inequality for newborn girls and boys and 30-year-old women and men between 1950 and 2050. Sub-figure *Decomposition, 2005–2014* looks into the recent past and displays how the change in global life expectancy and global lifespan inequality between 2005 and 2014 decomposes into contributions of all-cause mortality by single years of age. Sub-figure *Sensitivity, 2014* looks ahead to the future and shows how sensitive global life expectancy and global lifespan inequality in 2014 are with respect to proportional changes in all-cause mortality by single years of age.

Global life expectancy In 2014 newborn girls and boys could expect to live 74 years and 69 years, respectively, and 30-year-old women and men could expect to be alive for another 49 years and 44 years, respectively. In the entire period between 1950 and 2014 global life expectancy has always been higher for females than for males.

The continuous gains in global life expectancy between 1950 and 2014 have been substantially larger for newborns, approximately +26 years of life, than for 30-year-old people, approximately +11 years of life. This much sharper rise in life expectancy at birth indicates that mortality reductions have been particularly strong at young ages below 30.

Decomposition analysis for the period 2005 through 2014 supports this educated guess. That is, we find that reductions in infant mortality contributed most, +0.8 years of life, to the strong growth in life expectancy at birth, +3 years of life, in the last decade. Similarly for newborns and 30-year-olds we find that mortality reductions at medium and old adult ages have also strongly contributed to the growth in global life expectancy for women and men. Regarding a pattern by gender we find that contributions of mortality in young adult ages and in old age have been larger for women than for men (reflecting perhaps progress in maternal disorders in young adult ages and female survival advantage in old age).

Finally, sensitivity analysis reveals that global life expectancy could potentially increase further by +16 years of life for newborns and by +12 years of life for 30-year-olds if we summed over all ages the single potential impacts of reducing all-cause mortality to zero for only one single year of age at a time. Regarding the pattern across age we find that improvements especially in infant and old age mortality could further increase global life expectancy for women and men in years to come.

Global lifespan inequality In the entire period between 1950 and 2014 lifespan inequality has shown overall positive levels and mostly declining trends (interrupted or followed by periods of stagnation and even upward movements). In 2014 newborn girls and boys could expect to lose 15 and 16 years of life due to premature death, respectively. This number has been smaller for 30-year-old

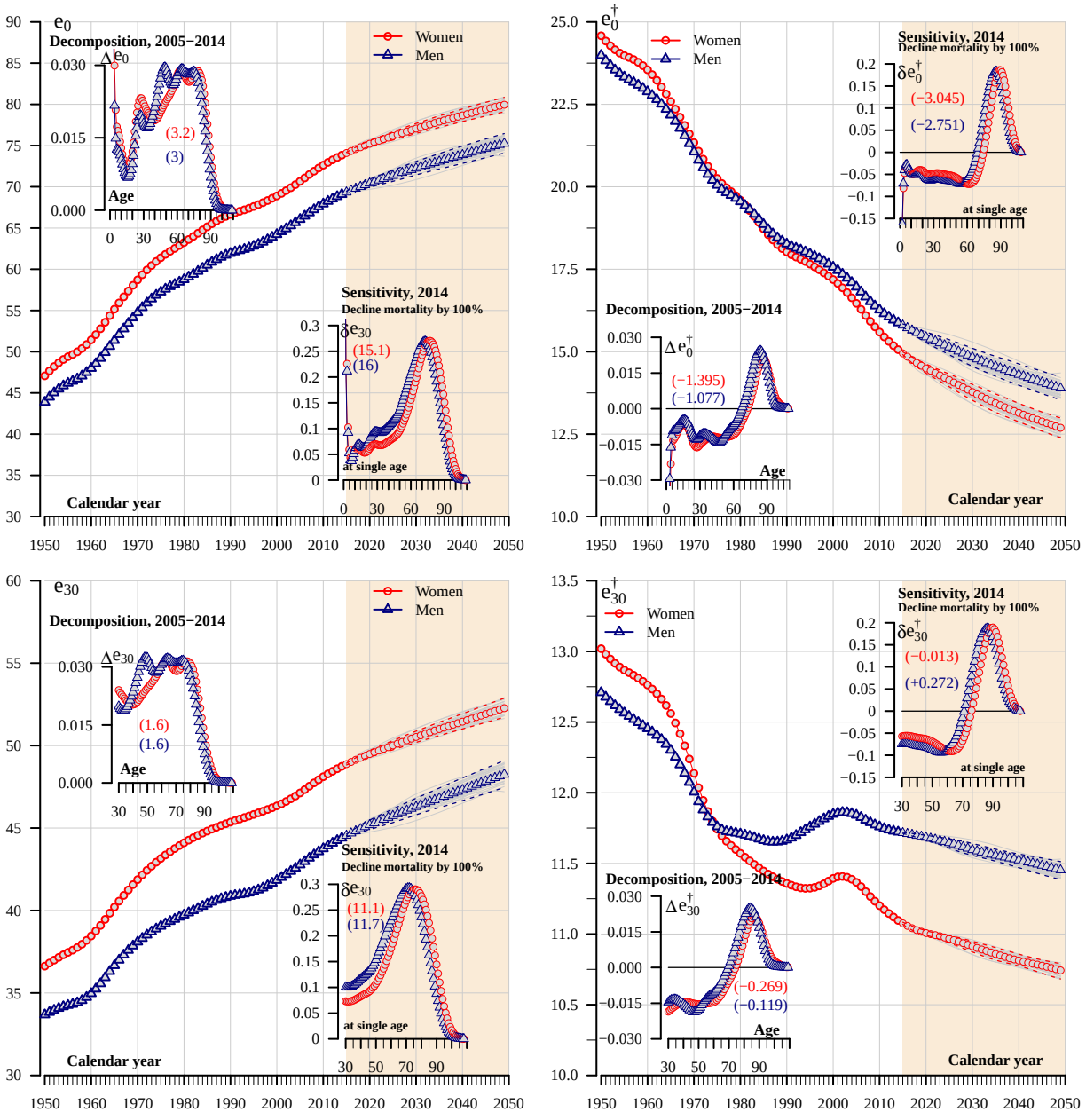

Figure 2: Global life expectancy (left panel) and global lifespan inequality (right panel) at age 0 (upper panel) and age 30 (lower panel) for women (red) and men (blue) between 1950 and 2050. Sub-figures show the decomposition (upper left corner) and the sensitivity (lower right corner) of life expectancy and lifespan inequality with respect to age-specific changes in all-cause mortality. Input data are from the UNWPP (2017).

women and men who could expect to lose 11 and 12 years of life, respectively. Between 1950 and 2014 lifespan inequality has declined by −10 and −8 years for newborn girls and boys, respectively, and by −2 and −1 years for 30-year-old women and men, respectively. The much larger reductions in global lifespan inequality for newborns than for 30-year-olds could indicate that major progress in life years lost might have happened below age 30 in this time. Decomposition analysis for the period 2005 through 2014 confirms that reductions in infant mortality have indeed contributed most, approximately −0.6 years, to the decline in lifespan inequality at age 0, slightly more than one year in the last decade.

While lifespan inequality has continued to decline for newborns in the entire period, 1950 through 2014, we find that it deviates from its overall trend for 30-year-old people. That is, we find a bump in global lifespan inequality at age 30 in the 1990s and 2000s. Decomposition analysis for the period 2005 through 2014 explains this temporary upward trend to a large extent with the fatal consequences of the HIV epidemic that started in the 1980s—and that has led to many premature deaths since then.

That women lose fewer years of life due to premature death than men has not always been the case. In fact we do find a gender crossover in global lifespan inequality, for newborns in the early 1980s and for 30-year-olds in the mid 1970s. Before this gender crossover women have lost in fact more life years due to premature deaths than men.[1]

It is also striking that there has been almost no change in lifespan inequality for 30-year-old men between 1970 and 2014—except for the bump in the 1990s and 2000s—as the number of their life years lost remains to be almost at the same level, 11.7 years. We also find a slowdown in the decline of lifespan inequality for 30-year-old women after the gender crossover in the mid 1970s.

How do such weak trends in lifespan inequality translate into changes of mortality by age? Contrary to life expectancy, age-specific mortality reductions below and above a certain threshold age decrease and increase lifespan inequality, respectively. The overall trend in lifespan inequality is, consequently, a balancing act of young and old age mortality contributions. If mortality reductions at young ages exceeded those above the threshold age the overall trend in lifespan inequality would decline and *vice versa*. According to our decomposition and sensitivity analyses we find this threshold age to be in the mid seventies for women and in the late sixties for men.

Between 2005 and 2014 lifespan inequality has declined by roughly −1 year for newborns and by almost zero years for 30-year-olds. Decomposition analysis reveals that contributions of some older adults far exceed those of many younger adults below threshold age—a development that has finally led lifespan inequality at age 30 not only to slow down decreasing for women but also to almost stagnate at the same level for men in this period of time.

Sensitivity analysis illustrates that life years lost due to premature death could potentially decline by another −3 years for newborns (if we summed over all ages the single potential impacts of reducing all-cause mortality to zero for only one single year of age at a time). This picture changes for 30-year-old people whose lost life years could rather stick to their current level for women and even slightly increase for men. Regarding the pattern over age we find that improvements particularly in infant mortality could further decline lifespan inequality. However, this declining trend could be offset as large mortality improvements advance to increasingly older ages above the threshold age.

[1]Since we have global cause-specific mortality only since 1990 we cannot trace back the exact causes of death that have been responsible for female excess mortality in premature age in the 1970s and 1980s. However, we assume that maternal disorders could be one explanation for this development.

What is next? So far we have analyzed overall levels and trends in global life expectancy and global lifespan inequality for women and men between 1950 and 2014. We have compared contributions of mortality by age (1) to explain deviations from overall trends in the past and (2) to identify potential drivers to further increase life expectancy and decrease lifespan inequality in the future. Knowing that mortality reductions during infancy and in old age could play a key role is already helpful for prioritizing global health issues. However, this crude information is kind of useless unless we can link it to the corresponding causes of death that could have a large impact on increasing life expectancy and decreasing lifespan inequality.

4.2 Potential impact of causes of death on life expectancy and lifespan inequality

We already know that global life expectancy could potentially increase further by roughly +16 years of life for newborns and +12 years of life for 30-year-olds and that global lifespan inequality could decline further by roughly −3 years for newborns and could either stick to its current level or even start to increase for 30-year-olds. We also know how these potential changes in global life expectancy and global lifespan inequality could be distributed over all-cause mortality by age but we do not know yet how they could be distributed over mortality by cause of death.

Figure 3 depicts how the potential changes in global life expectancy and global lifespan inequality could be distributed among causes of death for newborn and 30-year-old women and men. The impact of each cause of death is measured as percentage of the total change in each metric (summed over all causes of death). For example, reducing mortality from *Cardiovascular diseases* could make up almost 25% of the total increase in male life expectancy at birth, +16 years of life. Reducing mortality from *Diarrhea* could make up almost 18% of the total decline in male lifespan inequality at birth, −6 years of life lost. To analyze the true impact of causes of death on *avoiding premature deaths* we narrow down our analysis of global lifespan inequality to ages below the corresponding threshold age. That is why the potential decline in global lifespan inequality changes from −3 years (as stated in Figure 2) to −6 years (as stated in Figure 3).

Comparing the impact of causes of death on potential changes in global life expectancy and global lifespan inequality reveals complex patterns by metric (life expectancy and lifespan inequality), initial age (newborns and 30-year-olds), and gender (women and men). Although there is a lot to discover in Figure 3 we focus on six main findings:

1. *Cardiovascular diseases* and *Neoplasms* have a relatively strong impact on both metrics for newborn and 30-year-old women and men, albeit their impact is weaker on lifespan inequality at birth. More specifically, *Cardiovascular diseases* have a stronger impact (1) on life expectancy and lifespan inequality than *Neoplasms* and (2) on 30-year-olds than on newborns. **Broad impact**

2. The three communicable diseases *Diarrhea*, *Neonatal disorders*, and *Neglected tropical diseases & malaria* impact both metrics but they affect newborns much stronger than 30-year-olds. It is also striking that they play a greater role in avoiding premature deaths than in extending average lifespan. **Newborns & lifespan inequality**

3. The communicable disease *Diabetes* has a substantial impact on both metrics. This impact is stronger (1) for 30-year-olds than for newborns and (2) for women than for men. **Women & 30-year-olds**

4. External causes such as *Self-harm & interpersonal violence*, *Unintentional injuries*, and *Transport injuries* also have a substantial impact on both metrics but they affect men much stronger than women. It is also striking that external causes play a greater role in avoiding premature deaths than in extending average lifespan. **Men & lifespan inequality**

5. The communicable diseases *HIV/AIDS* and *Tuberculosis* have a strong impact on only one metric, lifespan inequality, and this impact is much stronger for 30-year-olds than for newborns. **Lifespan inequality & 30-year-olds**

6. *Neurological disorders* have a strong impact on only one metric, life expectancy, and this impact is much stronger (1) for women than for men and (2) for 30-year-olds than for newborns. **Life expectancy & 30-year-olds**

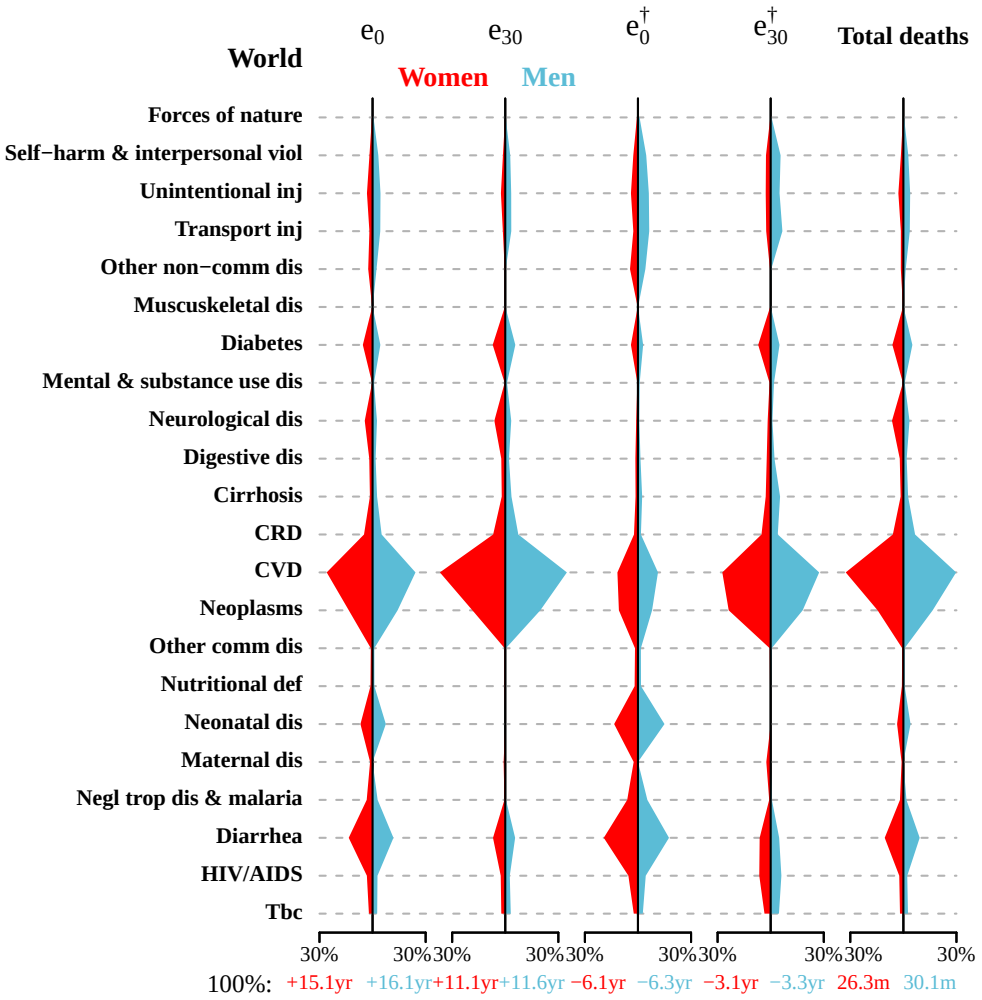

Figure 3: Potential impact in percent of causes of death (rownames on the left) on global life expectancy (columns 1 and 2) and global lifespan inequality (columns 3 and 4) at initial age 0 and 30 for women (red) and men (right). The maximum potential impact (100%) on each of the four metrics can be found in years in the bottom line. Input data are from the UNWPP (2017) and the GBD (2018).

We also provide a baseline scenario in Figure 3 that represents in a sense common practice via the sensitivity of total death counts in 2014 with respect to changes in cause-specific mortality. Overall we can see that the sensitivity pattern of total death counts is similar to those of life expectancy of newborns and 30-year-olds. However, all the important nuances (by metric, initial age, and gender) get lost when using only total death counts for prioritizing global health issues: in particular the true impact of *HIV/AIDS*, *Diarrhea*, and *External causes* on avoiding premature deaths.

What is next? Up to this point we have quantified and compared the sensitivity of global life expectancy and global lifespan inequality in 2014 with respect to proportional changes (1) in all-

cause mortality by single years of age in the last subsection and (2) in cause-specific mortality summed over all ages in this subsection. Although both analyses reveal interesting findings by age and cause of death they still happen to be to a large extent meaningless for prioritizing global health issues due to their isolated view either on age or cause of death. To get the best of both analyses (and a synergy effect on top) the final step forward is to quantify the sensitivity of global life expectancy and global lifespan inequality in 2014 with respect to changes in mortality by age *and* cause of death simultaneously.

4.3 Prioritizing global health issues

For optimally prioritizing global health issues we do not only need to know the causes of death that could best increase global life expectancy and decrease global lifespan inequality but also the top ages by cause of death that could be most suitable for timely intervention. That is why we rank the top five causes of death and their five most effective intervention ages based on sorting all age–&–cause of death combinations according to their potential impact on increasing global life expectancy and decreasing global lifespan inequality in 2014.

Table 1 lists the top five age–&–cause of death combinations that could have the highest impact on increasing life expectancy, decreasing lifespan inequality, and decreasing total deaths of newborn and 30-year-old women and men worldwide. We summarize the main similarities and differences by metric (life expectancy, lifespan inequality, and death counts), initial age (newborns and 30-year-olds), and gender (women and men) in the subsequent sections.

4.3.1 Top 5 causes of death by metric, initial age, and gender

Female life expectancy at birth worldwide The total potential increase in female life expectancy at birth, +15.1 years, is driven by 1. *Cardiovascular diseases*: +3.9 years, 2. *Diarrhea*: +2 years, 3. *Neoplasms*: +2 years, 4. *Neonatal disorders*: +1 years, and 5. *Diabetes*: +0.8 years.

Male life expectancy at birth worldwide The total potential increase in male life expectancy at birth, +16 years, is driven by 1. *Cardiovascular diseases*: +3.9 years, 2. *Neoplasms*: +2.3 years, 3. *Diarrhea*: +1.9 years, 4. *Neonatal disorders*: +1.2 years, and 5. *Chronic respiratory diseases*: +0.8 years.

Female life expectancy at age 30 worldwide The total potential increase in female life expectancy at age 30, +11.1 years, is driven by 1. *Cardiovascular diseases*: +4.1 years, 2. *Neoplasms*: +2.1 years, 3. *Diabetes*: +0.8 years, 4. *Diarrhea*: +0.8 years, and 5. *Chronic respiratory diseases*: +0.8 years.

Male life expectancy at age 30 worldwide The total potential increase in male life expectancy at age 30, +11.7 years, is driven by 1. *Cardiovascular diseases*: +4.1 years, 2. *Neoplasms*: +2.3 years, 3. *Chronic respiratory diseases*: +0.9 years, 4. *Diabetes*: +0.7 years, and 5. *Diarrhea*: +0.7 years.

Female lifespan inequality at birth worldwide The total potential decrease in female lifespan inequality at birth, −6.1 years, is driven by 1. *Diarrhea*: −1.2 years, 2. *Neonatal disorders*: −0.8 years, 3. *Cardiovascular diseases*: −0.7 years, 4. *Neoplasms*: −0.7 years, and 5. *Neglected tropical diseases & malaria*: −0.4 years.

Table 1: Top five causes of death and their corresponding top 5 ages of timely intervention by metric, intial age, and gender

Overall pool of top 5 causes of death	**Life expectancy**				**Lifespan inequality**				**Total deaths**			
	Newborns		**30-year-olds**		**Newborns**		**30-year-olds**		**Newborns**		**30-year-olds**	
	top rank	top ages	top rank	top ages	top rank	top ages	top rank	top ages	top rank	top ages	top rank	top ages
Global women:												
HIV/AIDS	-	-	-	-	-	-	**4**	30–34	-	-	-	-
Diarrhea	**2**	0–3,73	**4**	71–75	**1**	0–3,9	**5**	64–68	**3**	0–2,82–83	-	-
Neonatal dis	**4**	0–3,25	-	-	**2**	0–3,24	-	-	-	-	-	-
Negl trop dis & malaria	-	-	-	-	**5**	0–4	-	-	-	-	-	-
CVD	**1**	76–80	**1**	76–80	**3**	62–66	**1**	63–67	**1**	81–85	**1**	81–85
Neoplasms	**3**	66–70	**2**	66–70	**4**	56–60	**2**	57–61	**2**	71–75	**2**	71–75
Diabetes	**5**	70–74	**3**	70–74	-	-	**3**	61–65	**5**	78–82	**5**	78–82
CRD	-	-	**5**	71–75	-	-	-	-	-	-	**4**	79–83
Neurological dis	-	-	-	-	-	-	-	-	**4**	86–90	**3**	86–90
Global men:												
HIV/AIDS	-	-	-	-	-	-	**4**	34–38	-	-	-	-
Diarrhea	**3**	0–3,9	**5**	71–75	**1**	0–3,9	-	-	**3**	0–2,81–82	**5**	79–83
Neonatal dis	**4**	0–3,25	-	-	**2**	0–3,25	-	-	-	-	-	-
CVD	**1**	72–76	**1**	72–76	**3**	54–58	**1**	55–59	**1**	75–79	**1**	75–79
Neoplasms	**2**	66–70	**2**	66–70	**4**	55–59	**2**	57–61	**2**	68–72	**2**	68–72
Diabetes	-	-	**4**	69–73	-	-	-	-	**5**	74–78	**4**	74–78
CRD	**5**	72–76	**3**	71–75	-	-	-	-	**4**	76–80	**3**	76–80
Transport inj	-	-	-	-	**5**	22–26	**3**	30–34	-	-	-	-
Self-harm & interpers viol	-	-	-	-	-	-	**5**	30–34	-	-	-	-

Male lifespan inequality at birth worldwide The total potential decrease in male lifespan inequality at birth, −6.3 years, is driven by 1. *Diarrhea*: −1.1 years, 2. *Neonatal disorders*: −0.9 years, 3. *Cardiovascular diseases*: −0.7 years, 4. *Neoplasms*: −0.5 years, and 5. *Transport injuries*: −0.4 years.

Female lifespan inequality at age 30 worldwide The total potential decrease in female lifespan inequality at age 30, −3.1 years, is driven by 1. *Cardiovascular diseases*: −0.9 years, 2. *Neoplasms*: −0.7 years, 3. *Diabetes*: −0.2 years, 4. *HIV/AIDS*: −0.2 years, and 5. *Diarrhea*: −0.2 years.

Male lifespan inequality at age 30 worldwide The total potential decrease in male lifespan inequality at age 30, −3.3 years, is driven by 1. *Cardiovascular diseases*: −0.9 years, 2. *Neoplasms*: −0.6 years, 3. *Transport injuries*: −0.2 years, 4. *HIV/AIDS*: −0.2 years, and 5. *Self-harm and interpersonal violence*: −0.2 years.

Female death counts worldwide Female death counts, 26.3m deaths, are mainly driven by leading causes of death: 1. *Cardiovascular diseases*: 8.6m deaths, 2. *Neoplasms*: 3.8m deaths, 3. *Diarrhea*: 2.8m deaths, 4. *Neurological disorders*: 1.7m deaths, and 5. *Diabetes*: 1.6 deaths.

Male death counts worldwide Male death counts, 30.1m deaths, are mainly driven by leading causes of death: 1. *Cardiovascular diseases*: 9m deaths, 2. *Neoplasms*: 5m deaths, 3. *Diarrhea*: 2.8m deaths, 4. *Chronic respiratory diseases*: 2m deaths, and 5. *Diabetes*: 1.5 deaths.

4.3.2 Overall pool of top 5 causes and their ages of timely intervention

Putting the top 5 causes of death by metric, initial age, and gender in one pool we make seven interesting discoveries on a broad scale:

1. The top 5 causes of deaths vary considerably by metric, initial age, and gender.
2. Eight and nine causes of death are among the top 5 according to at least one metric of newborn and 30-year-old women and men, respectively.
3. *Cardiovascular diseases* and *Neoplasms* are the only causes of death that belong to the top 5 according to all metrics of newborn and 30-year-old women and men.
4. The overall pool of top 5 causes includes exclusively for lifespan inequality *HIV/AIDS* and the external causes *Transport injuries* and *Self-harm & interpersonal violence*. And it includes exclusively for life expectancy *Chronic respiratory diseases*.
5. The overall pool of top 5 causes includes exclusively for newborns *Neonatal disorders* and exclusively for 30-year-olds *HIV/AIDS* and *Self-harm & interpersonal violence*.
6. The overall pool of top 5 causes includes exclusively for men the external causes *Transport injuries* and *Self-harm & interpersonal violence* and exclusively for women the communicable disease *Neglected tropical diseases & malaria*.
7. Considering also total death counts the overall pool of top 5 causes includes exclusively *Neurological disorders* for women.

Looking also at the top 5 ages of timely intervention for the top causes of death in this overall pool we find that health care actions are required any time over the entire life course but for different causes of death:

1. Infant and childhood are affected particularly by e.g. *Diarrhea*, *Neonatal disorders*, and *Neglected tropical diseases & malaria*.
2. Young adults are affected particularly by *HIV/AIDS* and the external causes *Transport injuries* and *Self-harm & interpersonal violence*.
3. Medium adults are affected particularly by *Neoplasms*.
4. Old adults are affected particularly by *Cardiovascular diseases*, *Diabetes*, *Chronic respiratory diseases*, and *Diarrhea*.

4.3.3 Patterns by metric, initial age, and gender

1. Findings specific to life expectancy and lifespan inequality:
   (a) Some causes of death belong to top 5 of either life expectancy or lifespan inequality:
      i. Most strikingly, *HIV/AIDS* only comes to light as top 5 cause of death when prioritizing global health issues based on lifespan inequality for 30-year-olds.
      ii. In the same vein do the external causes *Transport injuries* and *Self-harm & interpersonal violence* only turn up when analyzing lifespan inequality for men.
      iii. In contrast, *Chronic respiratory diseases* only belong to top 5 causes of death when analyzing life expectancy.
   (b) Ages of timely intervention are systematically older for life expectancy than for lifespan inequality for some causes of death:
      i. For *Cardiovascular diseases* this gap in ages of timely intervention amounts to approximately 15 years for women and 18 years for men.
      ii. For *Neoplasms* this gap in ages of timely intervention amounts to approximately 10 years for women and 11 years for men.
      iii. For *Diarrhea* this gap in ages of timely intervention amounts to approximately 7 years for women.
      iv. For *Diabetes* this gap in ages of timely intervention amounts to approximately 9 years for women.
2. Findings specific to newborns and 30-year-old adults:
   (a) Some causes of death belong to top 5 of either newborns or 30-year-olds:
      i. *Neonatal disorders* belong to top 5 causes of death only for newborns.
      ii. *HIV/AIDS* belongs to top 5 causes of death only for 30-year-olds.
   (b) Ages of timely intervention can differ between newborns and 30-year-olds for the same cause of death:
      i. *Diarrhea* affects people especially in very young and old ages. The most sensitive ages for lowering the burden from *Diarrhea* are mostly infant and early childhood ages for newborns and older adult ages (beyond 60 years old) for 30-year-olds.

3. Findings specific to women and men:

   (a) Some causes of death belong to top 5 either for women or men:

      i. The external causes *Transport injuries* and *Self-harm & interpersonal violence* are among top 5 exclusively for men.

      ii. The communicable disease *Neglected tropical diseases & malaria* is among top 5 exclusively for women.

   (b) Causes of death belong to top 5 according to more metrics (and initial ages) for one sex than for the other:

      i. *Diabetes* is among top 5 causes of death according to two metrics (and three initial ages) for women and according to only one metric (and one initial age) for men.

      ii. *Chronic respiratory diseases* are prevalent among one metric (and two initial ages) for men compared to one metric (and one initial age) for women.

   (c) Ages of timely intervention can differ between women and men:

      i. For *Cardiovascular diseases* ages of timely intervention are 4 to 8 years older for women than for men. An explanation could perhaps be that this age gap reflects the female survival advantage and becomes apparent when causes of death affect particularly old ages as it is the case for *Cardiovascular diseases*.

      ii. For *Neoplasms* ages of timely intervention are quite similar for women and men.

4.3.4 Compared to common practice

If we implemented common practice instead we could not disentangle the impact of reducing mortality by age and cause of death on life expectancy and lifespan inequality in years to come. In fact common practice would not only miss the little nuances of our analysis above but also major discoveries—with great consequences for prioritizing global health issues first, then planning health care reforms, and finally achieving global health development goals.

1. Based on total death counts top 5 causes of deaths are, if at all, similar (but not the same!) to those based on life expectancy:

   (a) Except for *Diarrhea* we do not find any communicable disease to be among the top 5 causes of death for women and men.

   (b) We also do not find any external causes to be of high relevance.

   (c) We rather find the old-age non-communicable disease *Neurological disorders* to be an addition to the pool of top 5 causes of death for global women.

2. Ages of timely intervention are systematically older for total death counts than for life expectancy than for lifespan inequality:

   (a) For *Cardiovascular diseases*, this gap in ages of timely intervention amounts to 18 years when the analysis is based on lifespan inequality and life expectancy and even to 20 years when it is based on lifespan inequality and death counts.

   (b) For *Neoplasms*, this gap in ages of timely intervention amounts to 11 years when the analysis is based on lifespan inequality and life expectancy and even to 15 years when it is based on lifespan inequality and death counts.

   (c) For *Diarrhea* in old age, this gap in ages of timely intervention amounts to 7 years when the analysis is based on lifespan inequality and life expectancy and even to 25 years when it is based on lifespan inequality and death counts.

(d) For *Diabetes*, this gap in ages of timely intervention amounts to 9 years when the analysis is based on lifespan inequality and life expectancy and even to 17 years when it is based on lifespan inequality and death counts.

5 Summary and Discussion

Adopting a global perspective on prioritizing and financing health issues is inevitable as all parts of the world are closely connected through globalization and are equally affected by causes of death that do not stop at national borders. The global community mobilizes massive efforts to lower the burden of causes from which most people die, to fight against communicable diseases out of humanitarian motives, most notably *HIV/AIDS* in low income countries, and to combat sudden outbreaks of epidemics that might evolve into deadly pandemics.

It is surprising that prioritizing global health issues in the first place—the foundation of global health financing—usually receives only scant attention, as it might perhaps be regarded as trivial. The global community creates and signs binding health programs to fight together for longer lives for everyone worldwide. One example is the third UN Sustainable Development Goal (SDG 3) that focuses on global health. SDG 3 sets health development goals that do cover many important and also urgent health issues worldwide. It defines health objectives that are on the one side very broad ("[...] combat [...] communicable diseases") and on the other side very specific ("[...] reduce under-5 mortality to at least as low as 12 per 1000 live births"). Anyhow, as noble and well-motivated the prioritized health issues of SDG 3 might be, only crude metrics of mortality intensity are taken into account for their creation and no guidance is provided on how to best achieve them by demographic means.

Our study pays special attention to prioritizing global health issues and gives advice about the timing of effective intervention throughout the life course. We provide theoretical concepts and sound methodological tools to objectively discuss and systematically analyze the priority of global health issues from a fully demographic perspective. More specifically, we introduce life expectancy and lifespan inequality as winning combination to resolve the dilemma posed by causes of death that kill few people but in premature age and causes of death that kill many people but in old age. As core task we compare and rank all age–&–cause of death combinations according to their potential impact on increasing global life expectancy and decreasing global lifespan inequality in years to come. We derive our findings from numerical sensitivity analysis and sorting algorithms using data of the UN World Population Prospects (2017) and the Global Burden of Disease study (2018).

Compared to our analysis of potential changes in life expectancy and lifespan inequality we find that common practice (that is represented in a baseline scenario using total death counts) would (1) strongly underestimate the true importance of communicable diseases and external causes and (2) strongly overestimate the true importance of non-communicable diseases. For example, the leading role of *HIV/AIDS* and of the external causes *Transport injuries* and *Self-harm & interpersonal violence* only comes to light in our analysis of reducing lifespan inequality. In addition, common practice would strongly overestimate ages of timely intervention for many leading causing of deaths. We find the largest gap for *Cardiovascular diseases* for which the optimal time points of intervention are up to 20 (!) years apart when the analysis is based on total death counts and lifespan inequality.

Consequently, our findings clearly demonstrate that it is absolutely necessary to consider the impact of mortality reductions—by age and cause of death—on both potential increases in life expectancy and potential decreases in lifespan inequality when it comes to prioritizing global health

issues. Sticking to common practice bears the risk of designing health care investment strategies that could finally increase lifespan inequality—simply because the planned health actions (prevention, diagnosis, treatment, and recovery) would focus too narrowly on mortality in old age and would often be implemented too late in the life course to be also effective in avoiding premature deaths earlier in the life course. Such serious errors could be averted with our proposed methodology that allows to disentangle the impact of reducing mortality on increasing life expectancy and on decreasing lifespan inequality—making the case that it is indispensable to consider both metrics for newborn and adult women and men to correctly prioritize global health issues so that not one of all the details that matter could pass unnoticed.

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A Mapping causes of death between GBD2016 and ICD10

Tables 2 and 3 map causes of death between GBD2016 and the ICD10 according to information provided of the Global Burden of Disease Collaborative Network (2017).

Table 2: GBD causes of death mapped to ICD codes

	Cause of death	GBD code	ICD code
1	Tuberculosis	A.1.1	A10-A14, A15-A19.9, B90-B90.9, K67.3, K93.0, M49.0, N74.1-N74.2, P37.0, U84.3
2	HIV/AIDS	A.1.2	B20-B24.9
3	Diarrhea, lower respiratory, and other common infectious diseases	A.2	A00-A00.9, A01.0-A09.9, A33-A37.9, A39-A39.9, A48.1, A70, A83-A87.9, B01-B02.9, B05-B05.9, B94.1, B97.4-B97.6, F07.1, G00.0-G00.8, G03-G03.8, G04-G05.8, H70-H70.9, J01-J01.9, J04.0, J05-J05.0, J09-J15.8, J16-J16.9, J20-J21.9, J36-J36.0, P23.0-P23.4, P35.8, R19.7, U04-U04.9
4	Neglected tropical diseases and malaria	A.3	A30-A30.9, A68-A68.9, A69.2-A69.9, A75-A75.9, A77-A79.9, A82-A82.9, A90-A96.9, A98-A98.8, B33.0-B33.1, B50-B53.8, B55.0, B56-B57.5, B60-B60.8, B65-B67.9, B69-B72.0, B74.3-B75, B77-B77.9, B83-B83.8, B92, K93.1, P37.1, U06-U06.9
5	Maternal disorders	A.4	N96, N98-N98.9, O00-O07.9, O09-O16.9, O20-O26.9, O28-O36.9, O40-O48.1, O60-O77.9, O80-O92.7, O96-O98.6, O98.8-O99.9
6	Neonatal disorders	A.5	P00-P04.2, P04.5-P05.9, P07-P15.9, P19-P22.9, P24-P29.9, P36-P36.9, P38-P39.9, P50-P61.9, P70, P70.3-P72.9, P74-P78.9, P80-P81.9, P83-P84, P90-P94.9, P96, P96.3-P96.4, P96.8
7	Nutritional deficiencies	A.6	D50.1-D50.8, D51-D52.0, D52.8-D53.9, D64.3, E00-E02, E40-E46.9, E51-E61.9, E63-E64.0, E64.2-E64.9, M12.1
8	Other communicable maternal, neonatal, and nutritional diseases	A.7	A20-A28.9, A32-A32.9, A38-A38.9, A48.2, A48.4-A48.5, A49.1, A50-A58, A60-A60.9, A63-A63.8, A65-A65.0, A69-A69.1, A74, A74.8-A74.9, A80-A81.9, A88-A89.9, B00-B00.9, B03-B04, B06-B06.9, B10-B10.8, B15-B17.9, B19-B19.9, B25-B27.9, B29.4, B33, B33.3-B33.8, B47-B48.8, B63, B91, B94.2, B95-B95.5, G14-G14.6, I00, I02, I02.9, I98.0-I98.1, J02.0, J03.0, K67.0-K67.2, K67.8, K71.2, K71.6, K74.7-K74.8, K75.3, K76.3, K77.0, M03.1, M49.1, M73.0-M73.1, M89.6, P35-P35.3, P35.9, P37, P37.2, P37.5-P37.9, U82-U84, U85-U89, Z16-Z16.3
9	Neoplasms	B.1	C00-C13.9, C15-C25.9, C30-C34.9, C37-C38.8, C40-C41.9, C43-C45.9, C47-C54.9, C56-C57.8, C58-C58.0, C60-C63.8, C64-C67.9, C68.0-C68.8, C69-C75.8, C81-C86.6, C88-C96.9, D00.1-D00.2, D01.0-D01.3, D02.0-D02.3, D03-D06.9, D07.0-D07.2, D07.4-D07.5, D09.0, D09.2-D09.3, D09.8, D10.0-D10.7, D11-D12.9, D13.0-D13.7, D14.0-D14.3, D15-D16.9, D22-D24.9, D26.0, D27-D27.9, D28.0-D28.1, D28.7, D29.0-D29.8, D30.0-D30.8, D31-D36, D36.1-D36.7, D37.1-D37.5, D38.0-D38.5, D39.1-D39.2, D39.8, D40.0-D40.8, D41.0-D41.8, D42-D43.9, D44.0-D44.8, D45-D47.0, D47.2-D47.9, D48.0-D48.6, D49.2-D49.4, D49.6, K31.7, K62.0-K62.1, K63.5, N60-N60.9, N84.0-N84.1, N87-N87.9
10	Cardiovascular diseases	B.2	B33.2, G45-G46.8, I01-I01.9, I02.0, I05-I09.9, I11-I11.9, I20-I25.9, I28-I28.8, I30-I31.1, I31.8-I41.9, I42.1-I42.8, I43-I43.9, I47-I48.9, I51.0-I51.4, I60-I63.9, I65-I66.9, I67.0-I67.3, I67.5-I67.6, I68.0-I68.2, I69.0-I69.3, I70.2-I70.8, I71-I73.9, I77-I83.9, I86-I89.0, I89.9, I98, K75.1

Table 3: GBD causes of death mapped to ICD codes continued

	Cause of death	GBD code	ICD code
11	Chronic respiratory diseases	B.3	D86-D86.2, D86.9, G47.3, J30-J35.9, J37-J47.9, J60-J63.8, J65-J68.9, J70-J70.1, J70.8-J70.9, J82, J84-J84.9, J91-J92.9
12	Cirrhosis and other chronic liver diseases	B.4	B18-B18.9, I85-I85.9, I98.2, K70-K70.9, K71.3-K71.5, K71.7, K72.1-K74.6, K74.9, K75.2, K75.4-K76.2, K76.4-K76.9, K77.8
13	Digestive diseases	B.5	I84-I84.9, K20-K29.9, K31-K31.6, K31.8, K35-K38.9, K40-K42.9, K44-K46.9, K50-K52.9, K55-K62, K62.2-K62.6, K62.8-K62.9, K64-K64.9, K66.8, K67, K68-K68.9, K77, K80-K83.9, K85-K86.9, K90-K90.9, K92.8, K93.8, M09.1
14	Neurological disorders	B.6	F00-F03.9, G10-G13.8, G20-G21.0, G21.2-G24, G24.1-G25.0, G25.2-G25.3, G25.5, G25.8-G26.0, G30-G31.1, G31.8-G31.9, G35-G37.9, G40-G41.9, G61-G61.9, G70-G72, G72.2-G73.7, G90-G90.9, G95-G95.9, M33-M33.9
15	Mental and substance use disorders	B.7	F10-F16.9, F18-F19.9, F24, F50.0-F50.5, G31.2, G72.1, P04.3-P04.4, P96.1, Q86.0, R78.0-R78.5, X45-X45.9, X65-X65.9, Y15-Y15.9
16	Diabetes, urogenital, blood, and endocrine diseases	B.8	D25-D26, D26.1-D26.9, D28.2, D52.1, D55-D58.9, D59.0-D59.3, D59.5-D59.6, D60-D61.9, D63.1, D64.0, D64.4, D66-D67, D68.0-D69.8, D70-D75.8, D76-D78.8, D86.8, D89-D89.3, E03-E07.1, E09-E14.9, E15.0, E16.0-E16.9, E20-E34.8, E36-E36.8, E65-E68, E70-E85.2, E88-E89.9, G21.1, G24.0, G25.1, G25.4, G25.6-G25.7, G72.0, G93.7, G97-G97.9, I12-I13.9, I95.2-I95.3, I97-I97.9, I98.9, J70.2-J70.5, J95-J95.9, K43-K43.9, K62.7, K91-K91.9, K94-K95.8, M87.1, N00-N08.8, N10-N12.9, N14-N16.8, N18-N18.9, N20-N23.0, N25-N28.1, N29-N32.0, N32.3-N32.4, N34-N34.3, N36-N36.9, N39-N39.2, N41-N41.9, N44-N44.0, N45-N45.9, N49-N49.9, N65-N65.1, N72-N72.0, N75-N77.8, N80-N81.9, N83-N83.9, N99-N99.9, P70.0-P70.2, P96.2, P96.5, Q61-Q62.8, R50.2, R73-R73.9
17	Musculoskeletal disorders	B.9	I27.1, I67.7, L93-L93.2, M00-M03.0, M03.2-M03.6, M05-M09.0, M09.2-M09.8, M30-M32.9, M34-M36.8, M40-M43.1, M65-M65.0, M71.0-M71.1, M80-M82.8, M86.3-M86.4, M87-M87.0, M88-M89.0, M89.5, M89.7-M89.9
18	Other non-communicable diseases	B.10	A46-A46.0, A66-A67.9, B86, D86.3, H05.0-H05.1, I89.1-I89.8, L00-L05.9, L08-L08.9, L10-L14.0, L51-L51.9, L88-L89.9, L97-L98.4, M72.5-M72.6, P96.0, Q00-Q07.9, Q10.4-Q18.9, Q20-Q28.9, Q30-Q36, Q37-Q45.9, Q50-Q60.6, Q63-Q86, Q86.1-Q87.8, Q89-Q89.8, Q90-Q93.9, Q95-Q99.8, R95-R95.9
19	Transport injuries	C.1	V00-V86.9, V87.2-V87.3, V88.2-V88.3, V90-V98.8
20	Unintentional injuries	C.2	L55-L55.9, L56.3, L56.8-L56.9, L58-L58.9, W00-W46.2, W49-W62.9, W64-W70.9, W73-W75.9, W77-W81.9, W83-W94.9, W97.9, W99-X06.9, X08-X32.9, X39-X39.9, X46-X47, X47.1-X47.8, X48-X48.9, X50-X54.9, X57-X58.9, Y40-Y84.9, Y88-Y88.3
21	Self-harm and interpersonal violence	C.3	X60-X64.9, X66-Y08.9, Y87.0-Y87.1
22	Forces of nature, conflict and terrorism, and executions and police conflict	C.4	U00-U03, X33-X38.9, Y35-Y38.9, Y89.0-Y89.1